

# “The Cyclotron Kids” 2 MeV Proton Cyclotron

Heidi Baumgartner, MIT Class of 2014  
Cyclotrons ’13, Vancouver,  
September 18, 2013

# It began at summer camp...

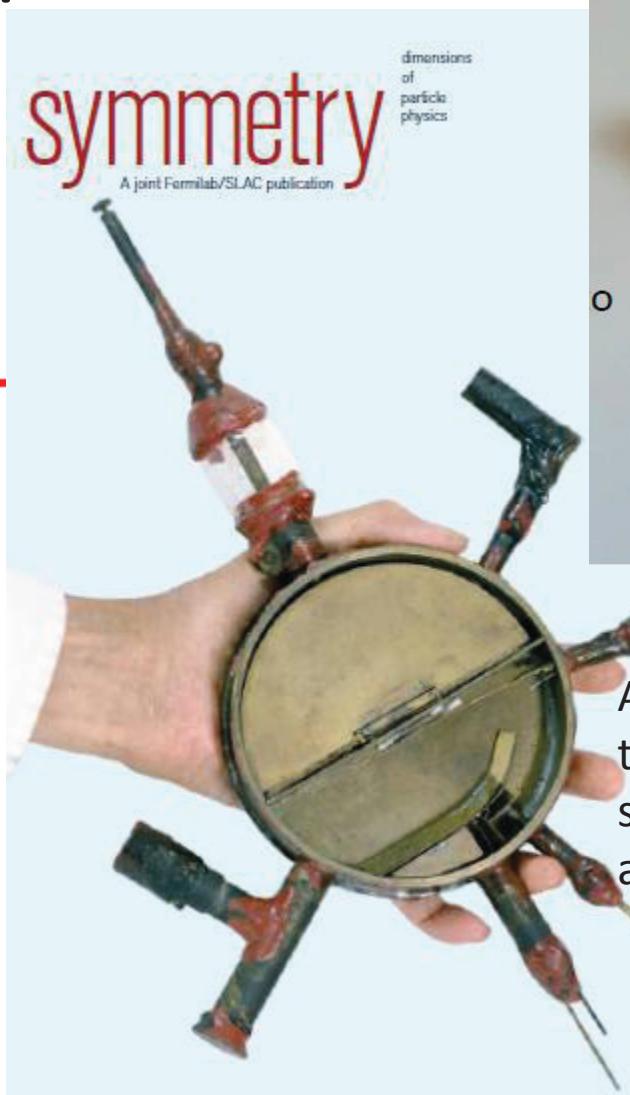
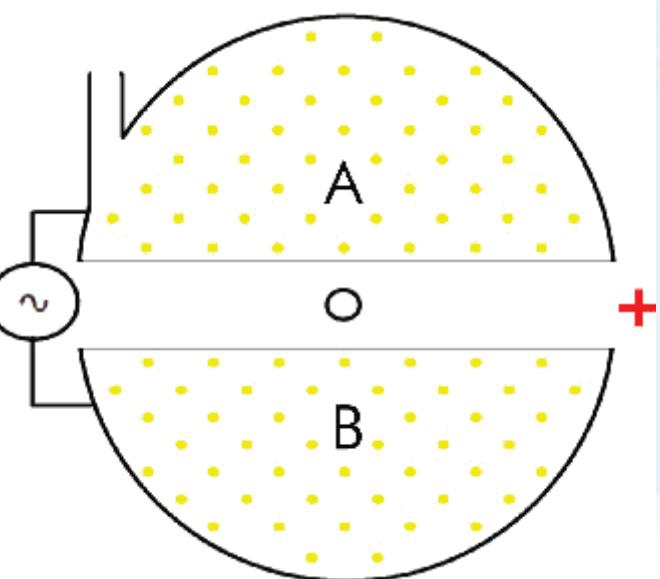


Kopernik Observatory, Binghamton NY

Heidi Baumgartner, Peter Heuer and  
German Diagama met in their  
freshman year of high school



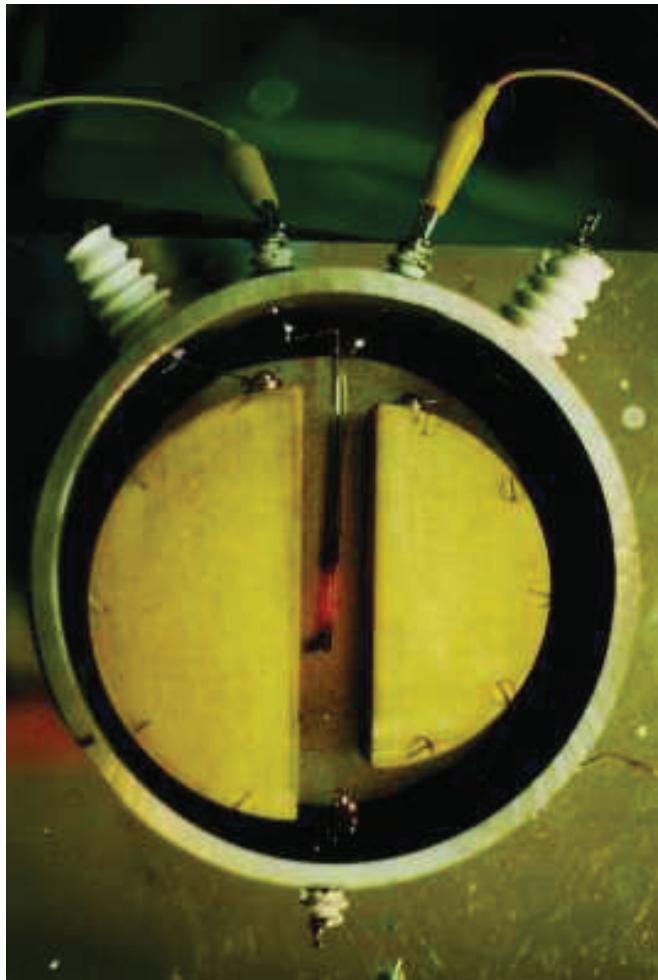
Some Googling convinced us it  
couldn't *possibly* be that hard.  
Right?



After all, the design that won  
the Nobel Prize in 1939 was  
small enough to fit into a hand,  
and was made with sealing wax.

august 07

# Previous amateur accelerators: Fred Neill



Top-down view of his cyclotron chamber



His homemade vacuum system had a thermocouple gauge in a jar



# Previous amateur accelerators: Tim Koeth



## Issues and Events

### Building a Cyclotron on a Shoestring

Starting when he was an undergrad, Tim Koeth built a 12-inch cyclotron.

Now he is in grad school and his creation is used in a senior-level lab class.

"I was immediately obsessed," says Timothy Koeth, who as a sophomore in 1998 at the University of Illinois at Urbana-Champaign began to build a cyclotron—a device that uses a magnetic field to accelerate ions. "I had no operator, no RF [radio frequency] equipment, no vacuum system, no machine parts, no computer programming—just basic graduate." To have one constructed from scratch, Koeth says, "is like building a particle accelerator physics lab from the ground up." But he had some skills: "I had learned how to turn on the computer, how to do certain experiments, such as measuring the charge-to-mass ratio of different ions or the mass of a neutron." It took him three years to build his first cyclotron, says Koeth, who is now a graduate student at the University of Illinois at Urbana-Champaign. "That has such creative potential for an amateur player. Even though I might not be an experimentalist, I don't know the inner workings of a cyclotron. To actually construct one...Tim is very a remarkable individual."

#### Teaching tool

Koeth is now in Rutgers' PhD program in nuclear astrophysics and particle physics at Fermilab. When he started graduate school, he had to find a new home for the cyclotron—which by then had been passed from his parents' garage to a warehouse on campus. "I sold the idea of using the cyclotron in the senior lab," says Koeth. "It may be the only fully functioning 1-MeV cyclotron in the country." In teaching at the US, or the world?

The first students to work on the cyclotron in the lab setting modified the machine to produce a proton beam. Others have worked on improving the ion source and, most recently, on a robotic measuring device to map the magnetic field in two dimensions. "It's a really useful and accessible education," says Koeth. "We think we might have to further adjust

cyclotrons from the start, as writing a user's manual. At Henselbach's insistence, they are also exploring rigging the cyclotron to be remotely operable by high-school students.

The cyclotron is made from more than 1000 pieces of sheet metal, and features the classic—photocopying the design of the first cyclotron ever built by Ernest Lawrence.

So far, Koeth says, the cyclotron has inspired easier or multiple experiments or an independent study project for many. Christopher says, the students "are really excited about it."

Christopher is in the physics department at the University of Illinois at Urbana-Champaign, where he is working on a thesis on the properties of the nucleus.

"It's a great opportunity for him to learn," says Christopher. "He's a great student," says Henselbach, who has worked on the

researched a Geiger counter and was measuring everything." He found a hot spot in his former school. It turned out to be radium on a macepharyngeal applicator—a device for treating oral tumors. It had never been known why the device was in the school, but, just within about a half hour, Koeth had convinced a teacher to let him take it home. "When I got it home, I learned that their house had become contaminated, and had exposed to 275 millirem—or nearly a year's worth of radiation." It was a piece of memory, says Koeth. "I was

surprised it had survived decades ago."

Christopher says Koeth is a pioneer in the field of cyclotrons. "He's a real innovator," says Christopher. "He's a real innovator."

The two friends met when Koeth responded to Henselbach's online ad for a Geiger counter, which Koeth had purchased, right down to the red light on top of the machine, which he bought from US military surplus stores on eBay, says Christopher.

Christopher says Koeth had need in Science World, a publication for teens, about an eighth grader who discovered a radioactive source in a toy. "They were shocked."

"That was me!" says Koeth. "I had

The pair spent perhaps \$10 000 on their creation. Koeth estimates that had they bought new parts and "paid red money to the machine shop," it would have cost about \$250 000.

#### Plans and projects

Henselbach says Koeth and Christopher have already started making plans for the next cyclotron at Fermilab. Says Koeth, "It's a curiosity. It has no magnetic field, no superconducting coils. The idea is to demonstrate our ability."

Christopher says Koeth is a "real innovator" and "a true technician. I had an impression that I wanted to go back to graduate school full time." He started back in 2003. When he finishes, he says, he'll move to Los Alamos National Laboratory, in New Mexico, to work on nuclear physics, perhaps at a national lab like Los Alamos. But El prefer it not be weapons related."

Tony Feder

# Physics Today: “Building a Cyclotron on a Shoestring”—about Tim Koeth’s machine at Rutgers



The cyclotron built by Timothy Koeth is shown here in the lab setting modified to produce a proton beam. The dark brown cylinders are the coils that generate the 12-inch magnetic field central to the cyclotron. The small circular window allows one to look into the vacuum chamber. The outer shell contains a stack of pure protons from hydrogen gas (blue tank) or protons and deuterons from deuterium (green tank).



G. Peter Nemes, the director of Los Alamos National Laboratory; addressed attendees at a fall-wide meeting.

## LANL Resumes Work, Morale Stays Low

### In response to a safety violation and an supposed security breach this summer, Los Alamos National Laboratory has been closed since early August, eight others.

On 25 September memo to lab staff, LANL Director G. Peter Nemes wrote, "It is time to begin cautiously resuming business in a safe, secure, manner focused in a positive direction."

The period of the last several months marks a new beginning for this institution.

"But many lab scientists, technicians and support staff are still under safety and security leases, are skeptical about how new the beginning really is," Nemes wrote. The eye injury, he said, was the result of a series of misadventures in a tunnel, says Rhonda Schuch, longtime LANL weapons scientist.

Nemes halted work across the lab in July, after two obvious storage devices containing classified data

partially went missing and a student's eye was damaged by a laser (see PHYSICS TODAY, September 2004, page 10).

Los Alamos' administrative reports earlier this year that the lab had never existed, the real one, it seemed, was one of inventory, not of materials, security, or classified information. By the end of the year, LANL expects to have an investigation, but lab officials would neither confirm nor deny the existence of the storage devices.

Earlier this year, David Cremers, a laser physicist, was preparing to appeal his firing in connection with the eye injury and an alleged affair, when he and lab staff were called to the hot air legal funds for other scientists.

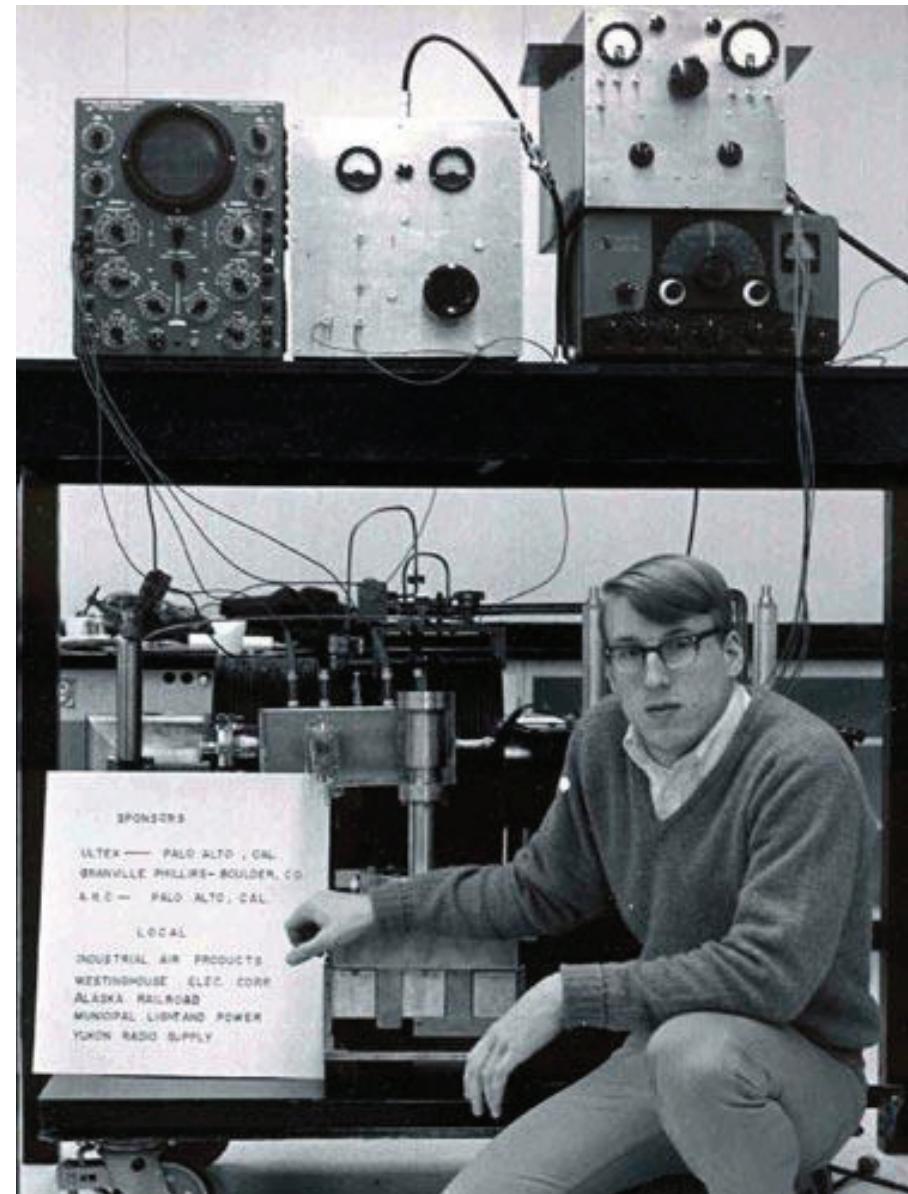
As of early October, administrative tasks, such as cleaning up and preparing for the fall semester, had been suspended. A lab spokesman said most activities would be back to normal by December, and everything should be running by year's end. The work stoppage must taxpayers keep in mind when they vote on the upcoming ballot.

# Previous amateur accelerators: Al Swank

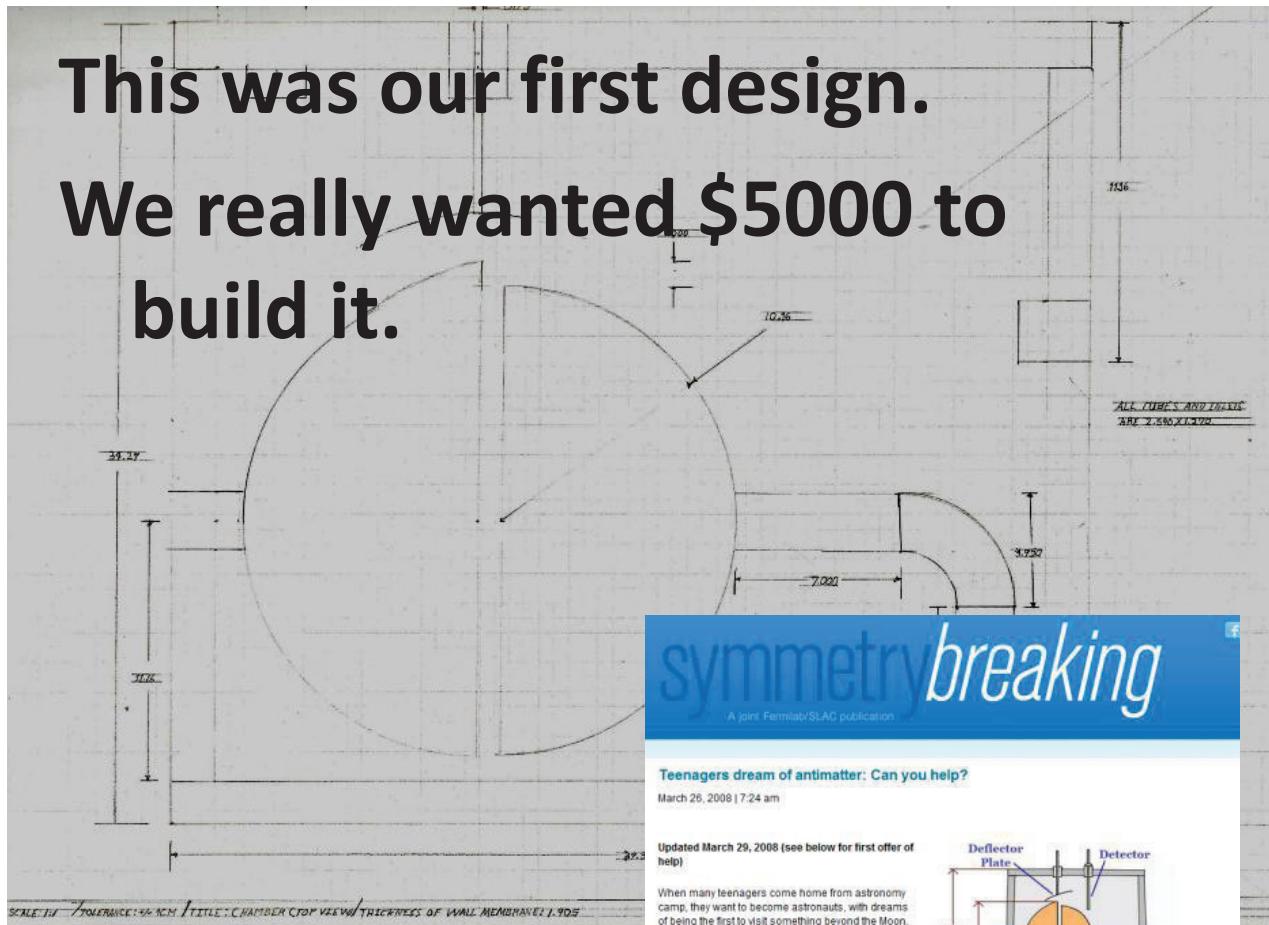
A high school cyclotron project launched him on his career in engineering.

WIRED, Dec. 2005: “The Cyclotron Comes to the ‘Hood’:

*“Local lawmakers rushed to introduce emergency legislation banning the use of cyclotrons in home businesses”*



# First funding attempts



Published a post in the blog “symmetry breaking.”

Got a donated vacuum pump

Sent out letters asking for sponsorship to enter a science fair

# It worked! Jefferson Lab sponsored us

Some lines from the original email we received from Andrew Hutton, Head of the Accelerator Division of JLab:

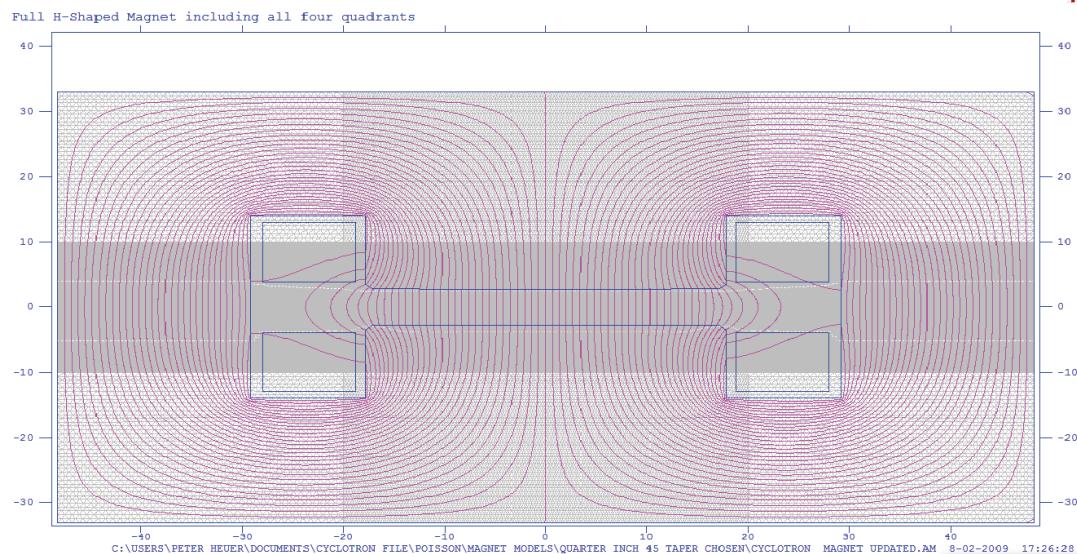
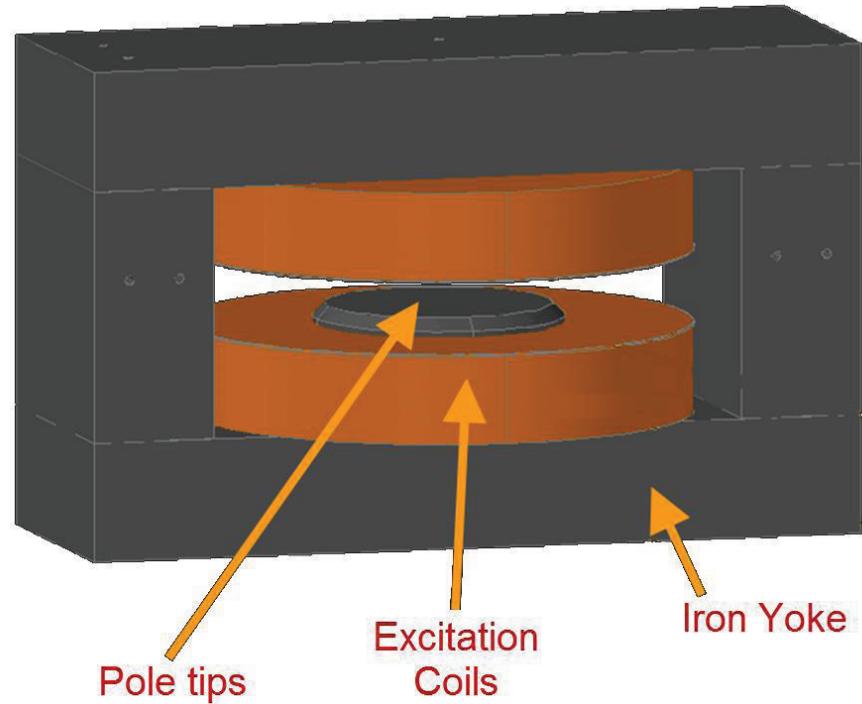
*“We have talked it over here at the lab and we have decided to help you realize your goal by being your sponsors.”*

*“I must say that I really appreciated the enthusiasm you have shown in developing the project and your nerve in approaching the President of the America Institute of Physics for money!”*

*“Safety and security are paramount here, as in the rest of the country, so we are not comfortable with the idea that you build the cyclotron in your basement - I can't imagine how many zoning laws that might violate! ”*

*“We are looking forward to making your dream a reality.”*

# Electromagnet design

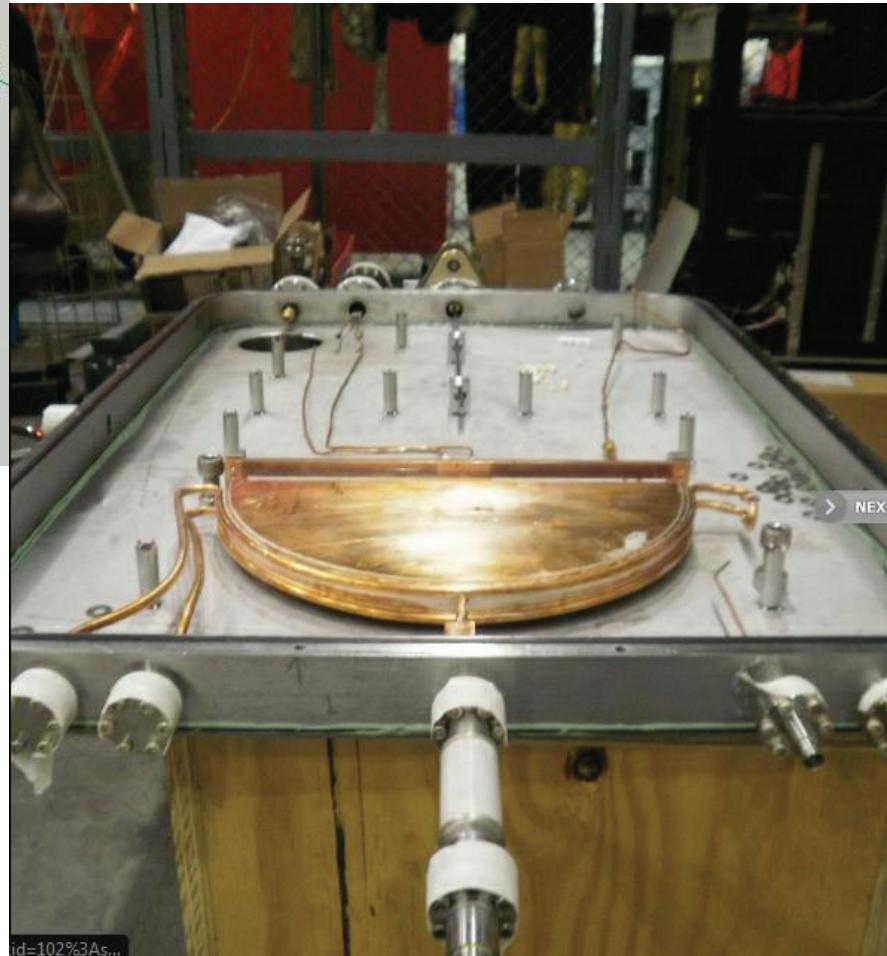
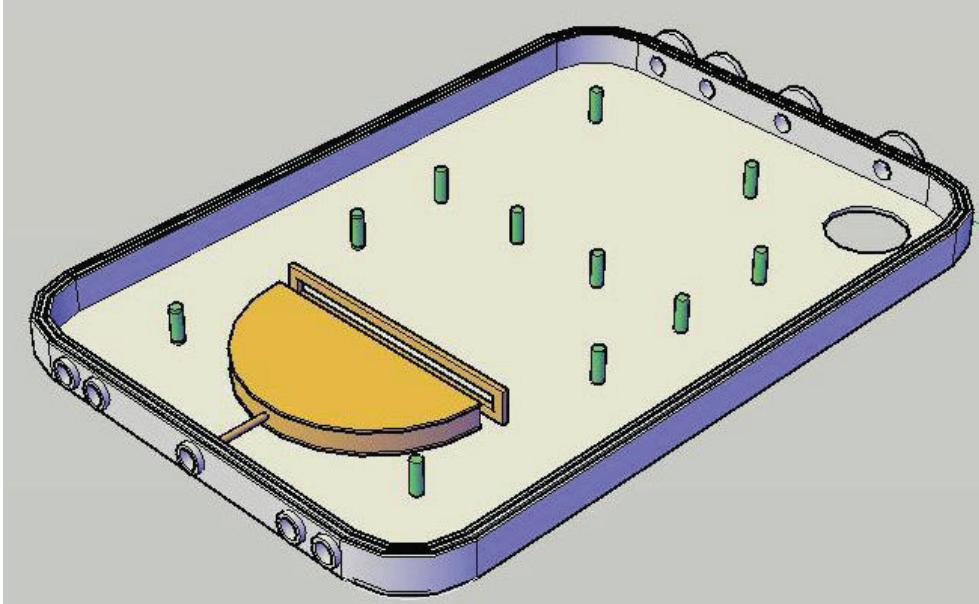


1.6 Tesla  
100A, 120V (12 kW)  
4 Tons  
Slight taper for weak focusing  
Simulations with POISSON

# Electromagnet construction

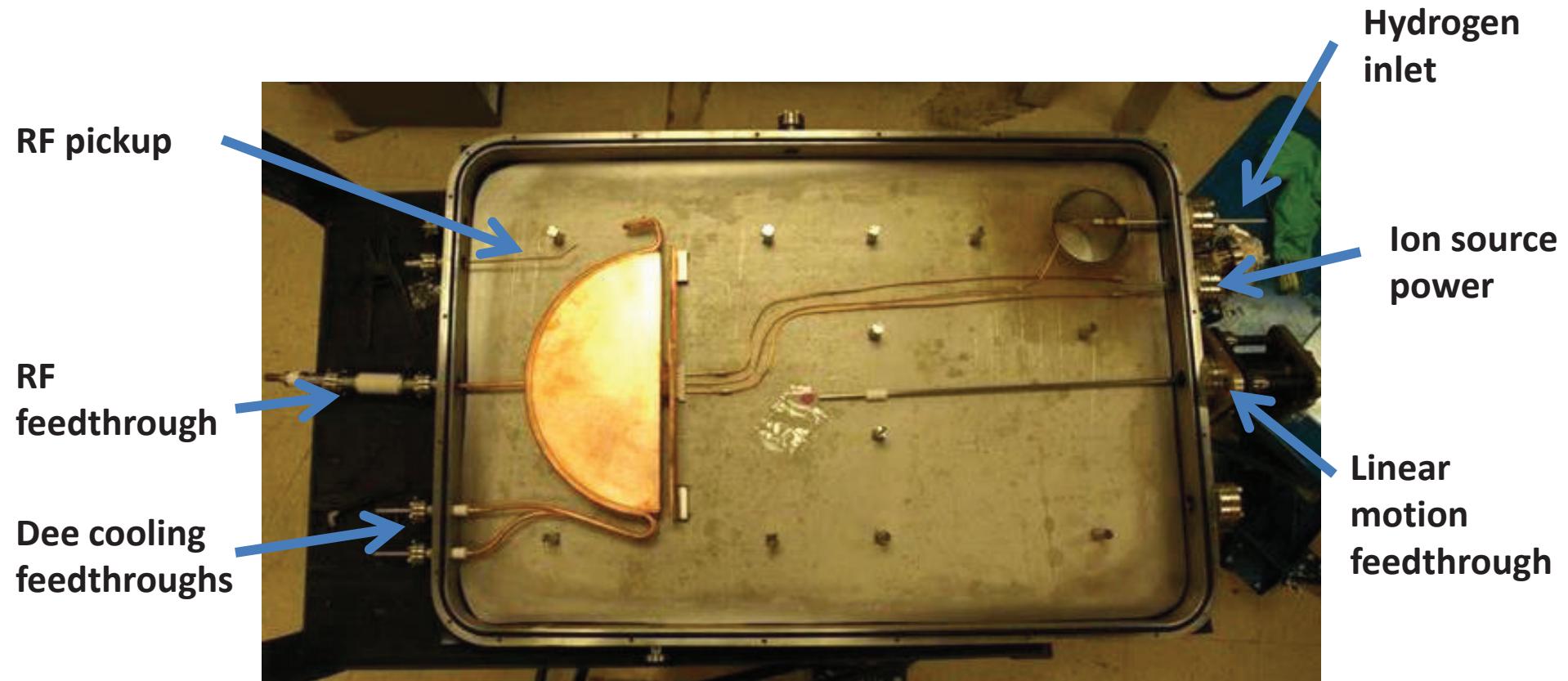


# Vacuum Chamber



- Approximately 2'x3'; large area for good vacuum conductance
- Two inches (10cm) high due to magnet constraints
- Large plates bowed in: needed internal supports
- One dee, one grounded “dummy dee”

# Vacuum Chamber

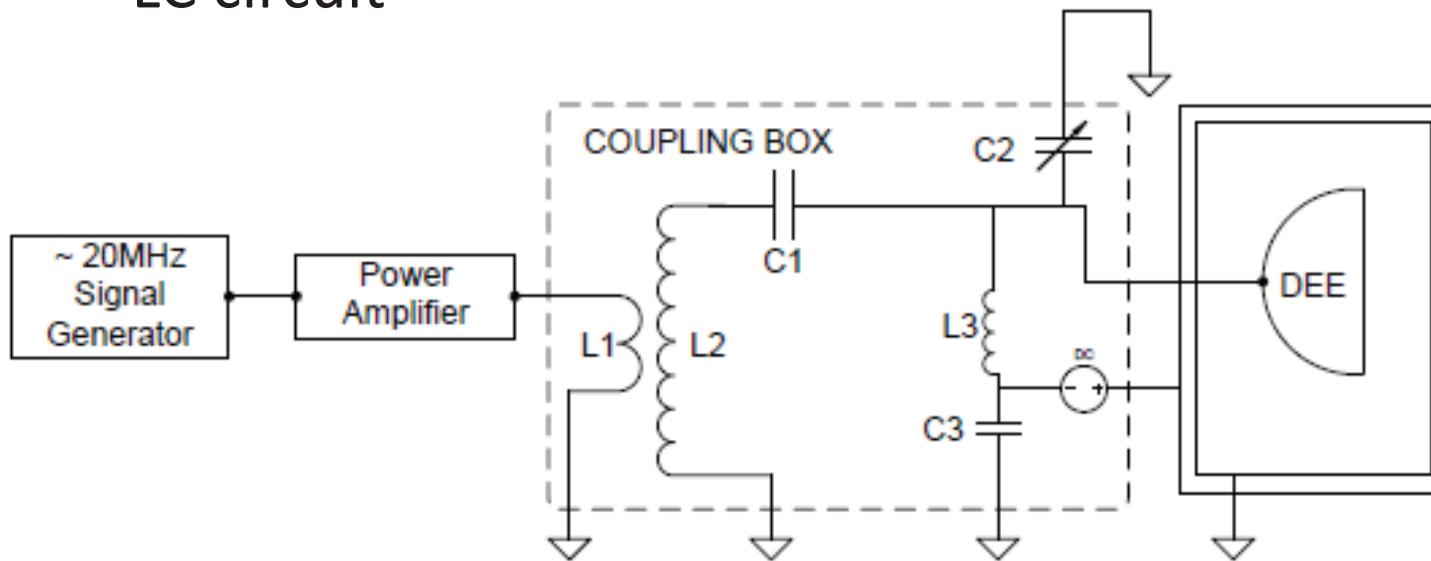


# RF System

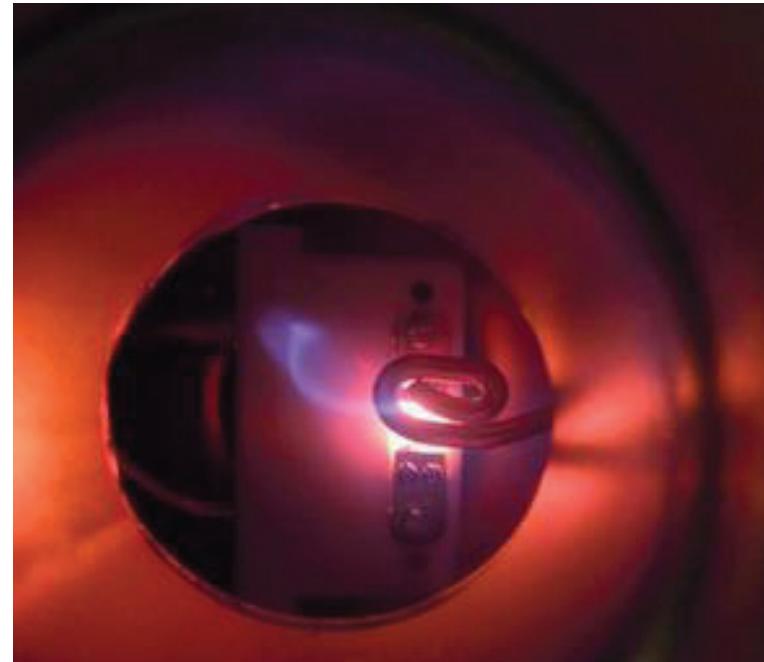
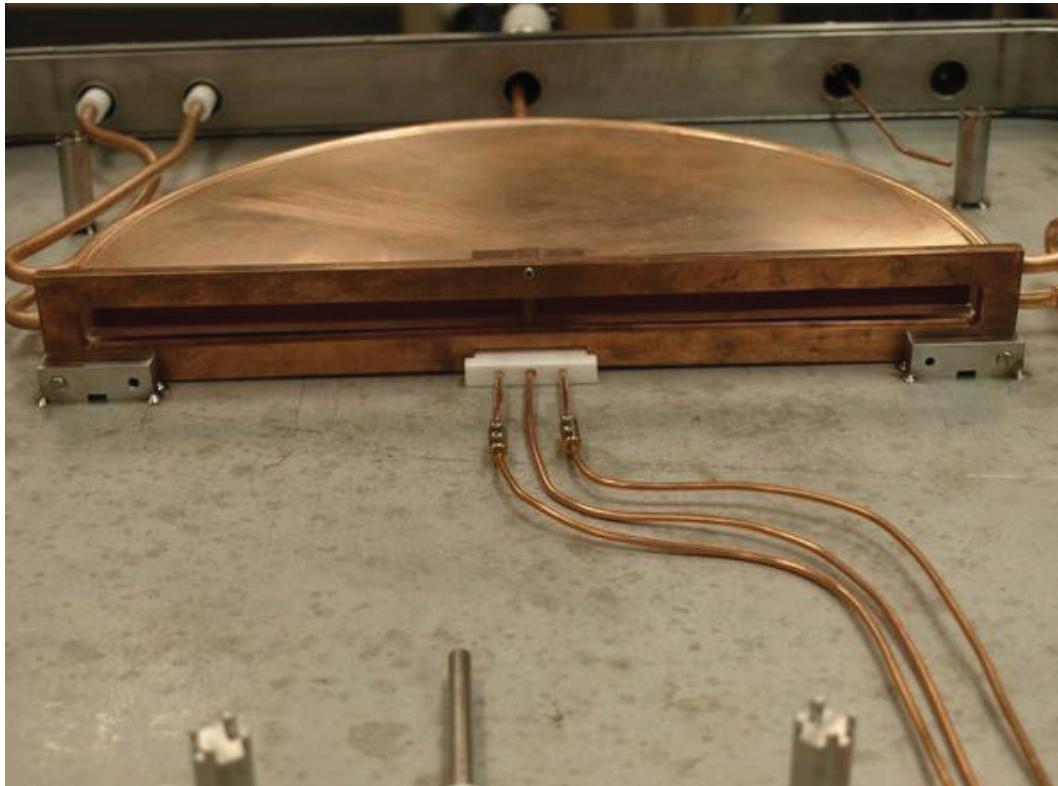
3kW Plasma Therm tube-based power amplifier at 24MHz

Matching network couples power to the dee

Resonant circuit made with the capacitance dee and an inductor, power inductively coupled into this LC circuit



# Ion Source



We tested an oxide-coated nickel filament

“Chimney” Ion source design  
Current in and out, and hydrogen  
discharge into the middle of the  
cyclotron.

# Chamber problems



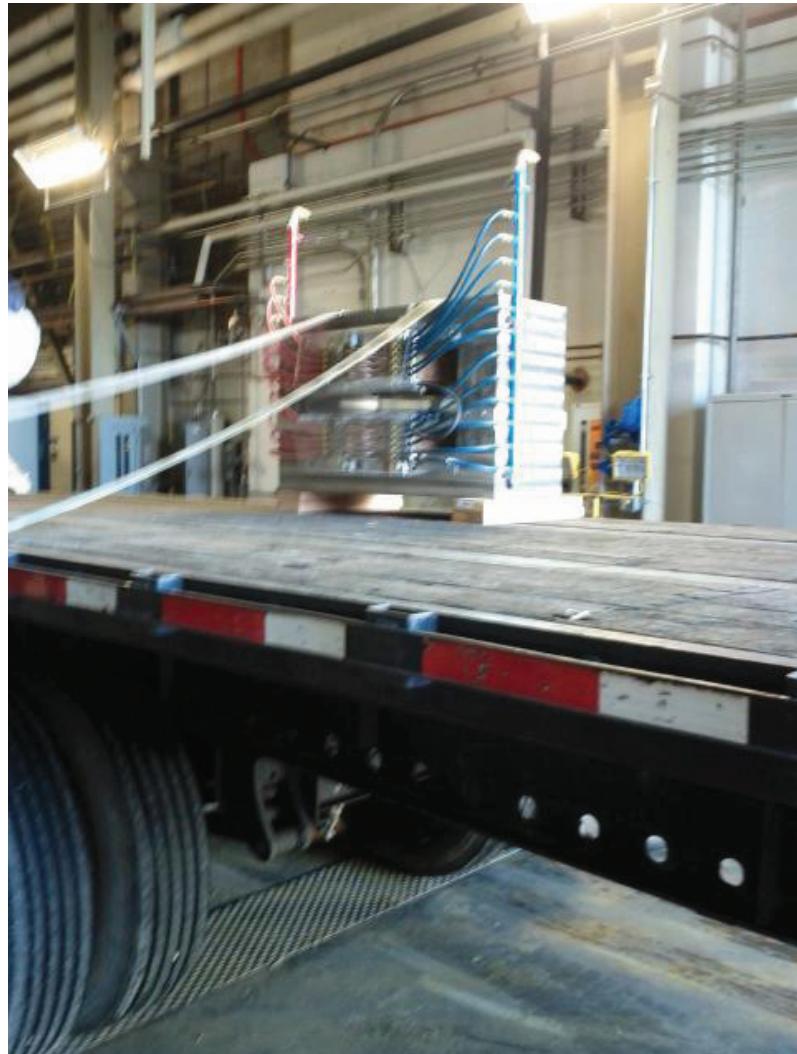
Problems arose from the welding of a thin plate to the frame.

An attempt was made to fix frame warping using flame treatment.

Eventually the bottom plate was ground off, and a viton sheet was used to seal the plate against the frame.



# The state of our cyclotron



- Most pieces complete
- Moved to Old Dominion University
- Waiting for the necessary equipment or infrastructure (e.g. distilled water lines)
- And for additional motivated students to continue work on it

# We are all “Cyclotron Kids”

If the allure of high energy particles, RF, strong magnetic fields, or vacuum systems has captured your imagination...

It's up to you to inspire the next ambitious students!

Join the forum and help inspire others:

*<http://cyclotrons.net>*

*Passcode: cyc-code-123456*