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A Bright Future: Wilson Lab Competes to Build Ambitious Bright X-Ray Source

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- Center Box Story
- Science Story

In a tunnel deep below Alumni Fields, electrons accelerated to nearly the speed of light have revolutionized scientific discovery by allowing researchers to form images on the atomic scale using powerful X-ray radiation. Cornell physicists are currently planning an ambitious expansion to this facility, which will provide a more powerful X-ray source which promises to push the limits of atomic imaging.

The expanded device, known as the Energy Recovery LINAC (ERL), will use an unprecedented number of superconducting cavities to provide a continuous, bright stream of X-rays which scientists will harness to image tiny molecular objects previously impossible to see.

A Tenth of a Billionth of a Meter

With the advent of nanotechnology and molecular biology, scientists have been obsessed with producing accurate images with resolution high enough to see individual atoms. With visible light this is impossible: as the light waves are bigger than the atoms themselves. To solve this problem, physicists needed to look elsewhere on the electromagnetic spectrum to tiny, high energy X-rays, which are smaller than single atoms.

But building an X-ray microscope with enough focus and power requires a lot more ingenuity than simply making a laser pointer. Fortunately, it turns out the radiation rocketing off of the particle accelerator at Cornell’s Wilson Lab provides just the right kind of radiation for atomic imaging.

Richard Cerione, Goldwin Smith Professor of Pharmacology and Molecular Chemistry, researches how large molecules like proteins assist in bringing information from the exterior of cells to the biological effectors within.

Large biological molecules, such as protein complexes, carry messages across cell membranes and cytoplasm by a series of twisting, folding chemical reactions. Traditionally, biologists could use a variety of tricks to figure out when these reactions occurred, in what sequence, and where, but they could never actually see what the surface of these molecules looked like or how they actually interacted.

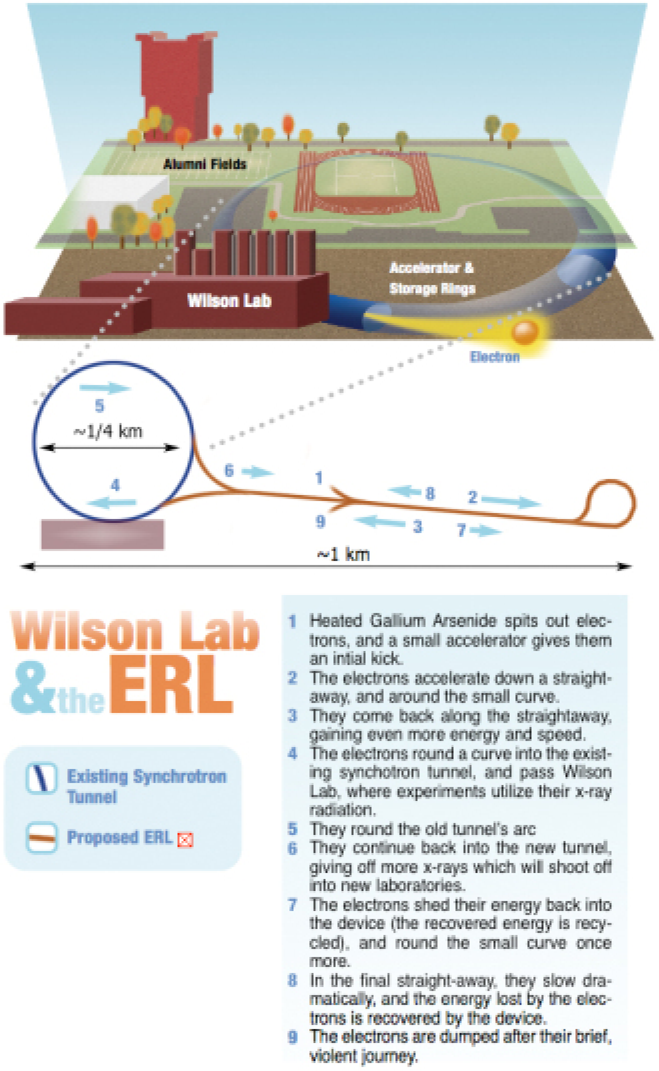
“We have lots of information on function,” said Cerione, “but we need structure.” X-ray crystallography managed to change that.

Already, X-ray imaging of proteins has accelerated the pace of research in molecular biology, but major setbacks prevent biologists from imaging just any protein complex. The images are mathematically constructed from complicated X-ray diffraction patterns, and therefore require multiple, identical proteins to be solidified into large regular patterns — crystals. In general, the larger the crystals become, the more successful the imaging.

Crystals form easily for really small polarized molecules like ice. But for big, complicated proteins and systems of molecules, forming these crystals represents a huge challenge, and has prevented biologists from imaging complicated sets of molecules associated with major diseases and cellular mysteries.

The proposed ERL, with its even more powerful and focused beam, allows scientists to use smaller crystals, and perhaps completely non-periodic molecules. With such techniques, scientists have “orders of magnitude more information than we’re currently getting,” said Cerione.

The powerful imaging capabilities of Wilson Lab have also extended well beyond molecular biology. Nanotechnology relies on manipulating materials on the single-atom scale, and the imaging capabilities have been just as tremendous for the world of silicon as they have for that of carbon.



1 Heated Gallium Arsenide spits out electrons, and a small accelerator gives them an intial kick.
2 The electrons accelerate down a straightaway, and around the small curve.
3 They come back along the straightaway, gaining even more energy and speed.
4 The electrons round a curve into the existing synchotron tunnel, and pass Wilson Lab, where experiments utilize their x-ray radiation.
5 They round the old tunnel's arc
6 They continue back into the new tunnel, giving off more x-rays which will shoot off into new laboratories.
7 The electrons shed their energy back into the device (the recovered energy is recycled), and round the small curve once more.
8 In the final straight-away, they slow dramatically, and the energy lost by the electrons is recovered by the device.
9 The electrons are dumped after their brief, violent journey.

[1]**CLICK TO ENLARGE**

The Energy Recovery LINAC

With the proposed Energy Recovery LINAC, Cornell physicists plan to up the ante in X-ray imaging by providing a more powerful, focused beam with more continuous pulses than any current X-ray source in the world.

To make a higher quality beam, the electrons in the accelerator need to orbit in smaller clusters than currently possible at Cornell. The current ring uses the particles many times over, as they repeatedly pass through the lab providing X-rays. Over time, the clump of particles spreads into a less ideal form, providing lower quality imaging, with a broad, poorly focused beam.

Linear accelerators or LINACs, like the ERL, can produce these smaller, quality beams at higher energies, but cannot run continuously, since the electron bunch is used just once, and the tremendous amount of energy used to accelerate them must be provided with each snapshot. That's where the "energy recovery" in ERL comes in.

Using superconducting cavities developed here at Cornell, electrons about to be dumped by the device will be gradually decelerated, with the recovered energy slipping back into an electromagnetic field, and used to simultaneously accelerate the next batch of electrons. Superconductors are used for their zero-resistance properties, which will prevent the device from overheating or becoming inefficient, and allow continuous operation. This new technique will recover over 99 percent of energy, making continuous acceleration of particles feasible. The result is a powerful, high quality, continuous X-ray source unlike anything currently available.

Sol Gruner performs research in self-assembling nano materials as well as proteins and is the director of the Cornell High Energy Synchrotron Source (CHESS), the organization in charge of the X-ray imaging facility. “There’s no real experience in the world today on how to operate very long superconducting linear accelerators.”

For this reason the National Science Foundation (NSF) has funded Cornell in their efforts to prototype the device. Already, scientists have built a 5-meter long device which will create the electrons and provide their initial acceleration.

“We’ve proven we can fabricate all of these state-of-the-art devices,” said Zachary Conway, a research associate working on the ERL project. “We’re preparing to take the data which will characterize the high power, high quality beam.”

Using these results, the Cornell team will submit a proposal within six months to the NSF to fund development of the complete device. Currently a team from U-Wisconsin is also competing for this funding to build a bright x-ray source, using a different style device known as a Free Electron Laser.

If awarded funds by the NSF, the ERL would take approximately 5 years for construction, with a projected cost between $400 million and $500 million.

From Particle Physics to X-Rays

Large particle accelerators were built in the decades following World War II during the atomic era, when scientists were obsessed with the hidden ingredients of the atomic nucleus. The accelerated particles would be smashed into each other and physicists would study the properties of what was created in the crash. Cornell’s device accelerates electrons and positrons (their anti-matter cousins) in opposite directions, until they’re moving so fast they traverse the massive ring roughly 400,000 times a second.

The current Cornell accelerator is an eight-tenths of a kilometer long ring, dug out below Alumni Fields by the same equipment used to make the New York subway system. Clouds of electrons orbit at speeds approaching that of light in a tiny vacuum tube. As the electrons orbit, they’d like to fly off tangent to the ring, like a tetherball snapping from its string. To keep them in their orbit, powerful electromagnets pull the particles back into the circle. In addition to staff scientists and professors, dozens of graduate and undergraduate students conduct research at the lab.

When originally built, Cornell’s accelerator ring was the largest in the world, opening the door for new experiments in particle physics. Today, larger accelerators like CERN’s 17-mile long LHC dwarf Cornell’s ring in both size and power, but experiments continue to thrive at Wilson Lab, thanks to a valuable byproduct of the accelerating electrons.

As the electrons are pulled, focused, and jostled by the magnets, they are knocked into slightly different orbits, losing momentum, and spitting out high-energy x-ray light waves. In the late ’70s physicists realized they could use the bright x-ray radiation coming out of the device for imaging purposes.

WILSON LAB SLIDESHOW:

Click here [2] to view a slide show tour of the Wilson Lab Synchrotron, including the accelerator ring, ERL prototype devices, X-ray crystallography labs, and the "Right Hand Rule."

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Links:
[1] http://cornellsun.com/content/images/wilson-lab-erl
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