
Frank DiMeo

Energy Recovery Linac

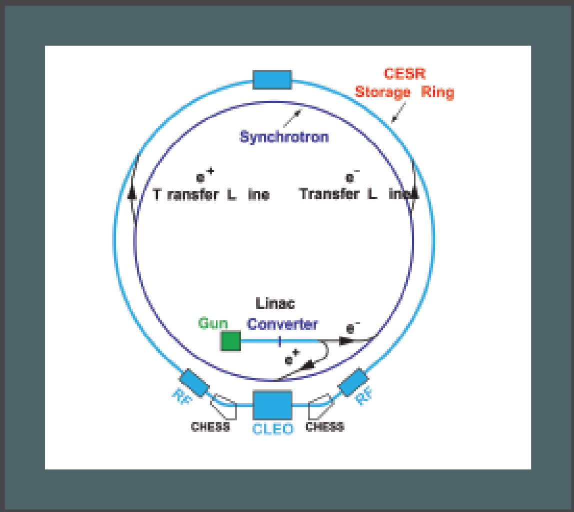
THE FUTURE GETS BRIGHTER

Why an ERL?

X-ray beams from charged particle accelerators have become an essential tool in current investigation of all types of materials, from airplane wings to cell membranes and from pollutants in plant leaves to matter under earth-core pressures. The development of a new type of accelerator envisioned and invented at Cornell will provide more brilliant beams in shorter pulses and will move such investigations to new frontiers.

What Scientists Use Now

Today's x-ray sources are based on electron storage rings, where the electrons get accelerated once, and then they circle billions of times while producing intense x-ray beams (shown at right). Like race cars on a curvy road, these electrons cannot stay on a narrow path as they go around a large number of turns. The electron beams thus obtain an unavoidable width, and the larger electron beam reduces the brightness of the x-ray beam. On straight stretches of their race, however, electrons can be confined to a narrow path. A straight electron accelerator could produce significantly narrower electron beams and therefore brighter x-rays than the best sources in operation.



The nearly 800-meter long accelerator ring, CESR under Cornell's Alumni Fields, produces x-rays for the Cornell High Energy Synchrotron Source (CHESS). In the south (at the bottom of the figure) are seven x-ray producing devices.

A STRAIGHT ELECTRON ACCELERATOR COULD PRODUCE SIGNIFICANTLY NARROWER ELECTRON BEAMS AND THEREFORE BRIGHTER X-RAYS THAN THE BEST SOURCES IN OPERATION.

How an ERL Works

Electromagnetic fields in microwave cavities can accelerate as well as decelerate electrons. In an ERL, electrons are injected into these cavities at the proper time for acceleration, which produces a high energy electron beam. This beam loses only about 0.1 percent of its energy when it is used for x-ray production in undulators. The 99.9 percent of its remaining energy can be recaptured into the electromagnetic fields when the electrons are reinjected into the linear accelerator at the proper time for deceleration. This energy is available for the acceleration of another bunch of electrons. Every bunch of electrons therefore first traverses the linac for acceleration, then a return loop containing undulators leads it from the end of the linac back to its beginning, and finally the bunch traverses the same linac again for deceleration. While a conventional storage ring x-ray source recycles electrons at high energy billions of times, compromising the beam size, the ERL sends each bunch of electrons with its very small size through the undulators only once, but reuses its energy multiple times. Because the energy of the electrons is periodically taken and then put back into the electromagnetic fields in microwave cavities, these cavities must be operated constantly. Conventional cavities made of some conducting material, such as copper, cannot be operated constantly with high fields, because they would become too hot. This is the reason the ERL will employ novel superconducting microwave cavities, which are cooled to -271°C to produce little heat when operated continuously at high fields. Currently the ERL team of LEPP and CHESS is setting up a prototype facility to show that the desired very small beam sizes can be produced and injected into an ERL.

Producing Bright X-ray Beams

Electrons that oscillate emit radiation. This is the same process used to send signals from a cell phone, where electrons oscillate up and down in the antenna. In an x-ray source, intense electron beams are forced to oscillate to the right and left of their mean path in an arrangement of many horse-shoe magnets of alternating orientation called undulators and wigglers (photo above). This motion stimulates emission of intense x-ray beams. Undulators and wigglers let electron beams perform horizontal oscillations while passing through the device. A cell phone emits radiation in all directions from its antenna. This is not the case for undulators and wigglers, through which electrons move with very high speeds. The engine of an approaching car sounds higher pitched than that of a car speeding away. Similarly, high frequency x-ray radiation is mostly observed when an electron beam directly approaches an observer. The electrons in x-ray sources like CHESS travel at 99.9999995 percent of the speed of light, leading to a very strong bundling of the x-ray radiation in the observer's direction and thus to very bright x-ray beams.

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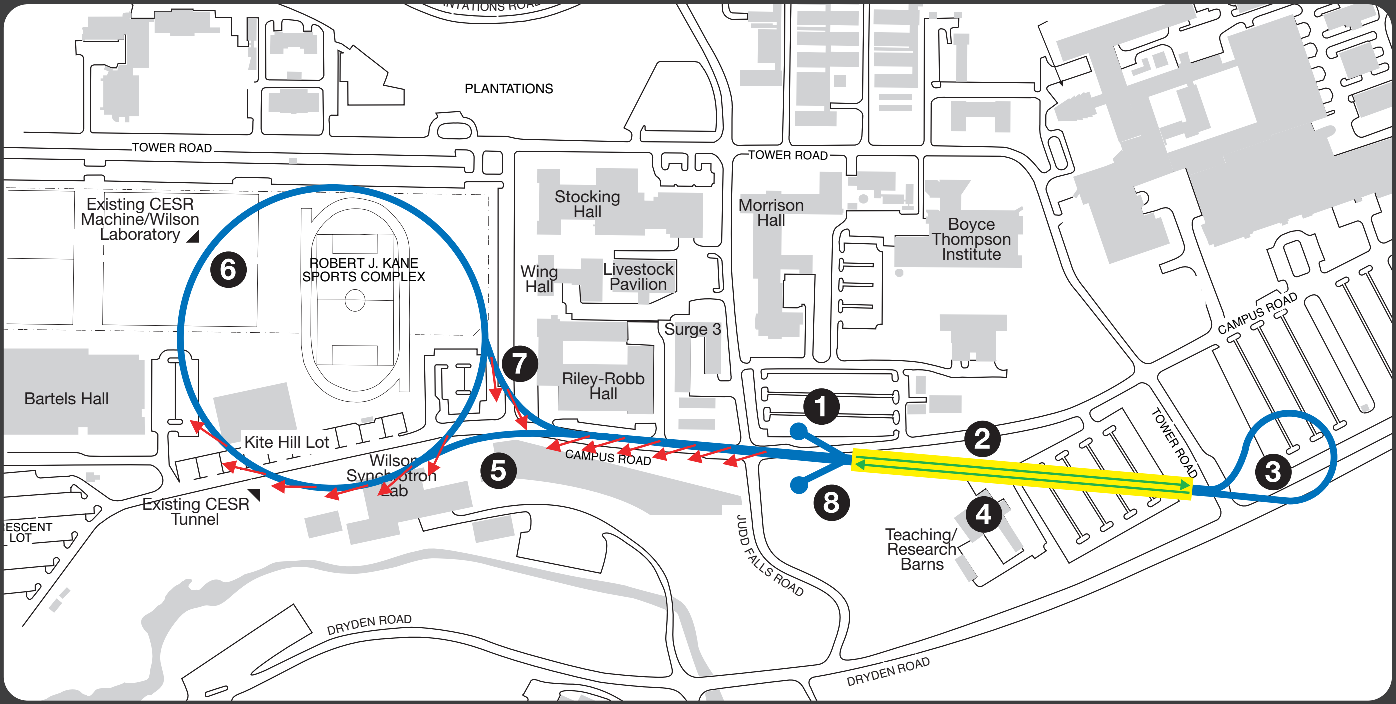
A Cornell ERL

The design of the Cornell ERL will be made cost-efficient by reusing infrastructure from the existing ring accelerator, CESR. The operation of CHESS will be disrupted as little as possible while the ERL is built and commissioned, and the facility will provide space for a sufficient number of x-ray beamlines. While reusing CESR might be thought to impose too many constraints, the flexibility of CESR's magnet arrangement instead holds several advantages for an ERL design. To extend the space for cavities, to make space for possible upgrades, and to minimize the impact on CHESS operation, Cornell has devised the layout illustrated in "How the Cornell ERL Works, a Plan." It shows the CESR tunnel and the design of a possible linear ERL extension.

New user areas will be created in the north section of CESR and in straight sections of the linac tunnel. The linac will be located at a hillside, so no existing building foundations interfere and so x-ray beamlines with easy access can be added between the linac and CESR. Another advantage of this upgrade plan is that most of the CESR tunnel is reused, which creates space for a large number of insertion devices. The tunnel extension has a section of 250 meters with two linacs side by side.



How the Cornell ERL Works, a Plan

The CESR Tunnel and the Layout of a Possible Linear ERL Extension
Electrons from an injector that is optimized for very narrow and short electron pulses (1) would be accelerated to the right in a first linac (2). A return loop (3) would send them into a second linac, which is located in the same straight tunnel (4) and accelerates to the final high energy. An arc (5) injects the electrons into the CESR ring (6), where they travel clockwise until another arc (7) injects them back into the first linac, where they are decelerated to half their energy. The return loop leads the electrons to the second linac section, where they are decelerated back to their low injection energy and finally dumped (8). The south half of the CESR tunnel would contain undulators and would reuse the current facilities of CHESS.

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CURRENTLY THE ERL TEAM OF LEPP AND CHESS IS SETTING UP A PROTOTYPE FACILITY TO SHOW THAT THE DESIRED VERY SMALL BEAM SIZES CAN BE PRODUCED AND INJECTED INTO AN ERL.

THE SUCCESS OF THE PROTOTYPE FACILITY WILL ENHANCE CORNELL'S POSITION WHEN APPLYING FOR FUNDING OF THE FULL ERL X-RAY FACILITY.

Frank DiMeo

Charles Sinclair, project manager for the ERL prototype

LEPP

Researcher Yulin Li with the ERL photo-cathode cleaning and preparation chambers: The system allows the processing of a GaAs wafer to atomically clean and then activate its surface to achieve emission of electron beam with low energy photons.

The Energy Recovery Experiment

With funding from the National Science Foundation, LEPP and CHESS are setting up a prototype facility to verify that the required very narrow and short electron pulses can actually be produced. This task is a major challenge, since bunches with the number of electrons that the ERL must accelerate have never been produced as short and as narrow as needed. To complicate matters, the ERL needs 1.3 billion such pulses per second—much more than any similar electron source has ever produced. Cornell scientists will test that these pulses can be accelerated to an energy at which they could be injected into an ERL x-ray source at Cornell or elsewhere.

The success of the prototype facility will enhance Cornell's position when applying for funding of the full ERL x-ray facility. The project is also important to other institutions with great interest in Cornell's ERL ideas, particularly labs in England and Japan that have already decided to base their next x-ray sources on the energy recovery principle invented at Cornell.

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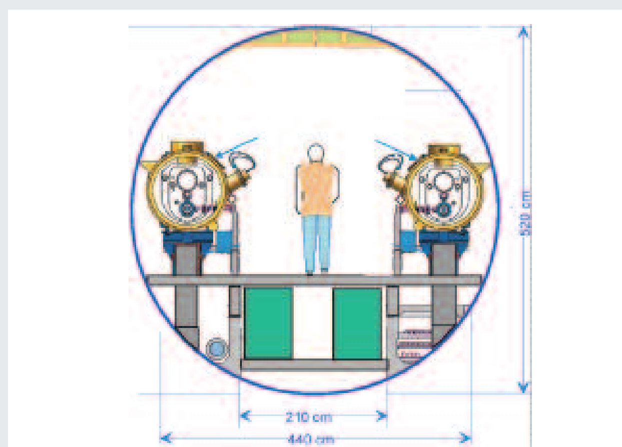
Sketch of a cross section of a tunnel with two linacs: A straight tunnel housing two linacs reduces tunnel cost as well as the required length of cryogenic lines and cables. The tunnel is laid out longer than required for the two linacs so that an extension of the facility by extra undulators or by a free electron laser can upgrade the facility at a later time.



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