CORNELL ERL RESEARCH AND DEVELOPMENT*

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Abstract

Energy Recovery Linacs (ERLs) are proposed as drivers for hard x-ray sources because of their ability to produce electron bunches with small, flexible cross sections and short lengths at high repetition rates. In particular, Cornell plans to build an ERL lightsource, and the preparatory research for its construction will be discussed. This will include the prototype injector for high current CW ultra-low emittance beams, superconducting CW technology, the transport of low emittance beams, field and alignment tolerance simulations, and the collimation of halos created from Touschek scattering. Several of these topics could become important for other modern lightsource projects, such as SASE FELs, HGHG FELs, and XFELOs.

PDDR

The Cornell ERL Project Definition Design Report (PDDR) [1] was recently completed. This is a detailed technical document describing a full-scale hard x-ray ERL facility, and the example of a Cornell University site (an extension of CESR at the Wilson Synchrotron Laboratory shown in Fig. 1) shows how existing storage rings can be extended to be ERL facilities. It is supported by a number of external documents, including a proposal for electron-beamline construction, two proposals for a large cryogenic plant, a design for a new x-ray science building, an economic impact study, and a tunnel design, evaluated by an underground tunnel-engineering advisory panel. An environmental impact study is still in progress.

The PDDR covers research performed over the course of many years. The following sections in this paper merely highlight some of the recent research and development at Cornell that will aid in enabling the realization of hard x-ray ERL lightsources.

INJECTOR PROTOTYPE

CLASSE currently operates a prototype ERL injector based on a DC photoemission gun and a SRF CW cryomodule, both built at Cornell. This machine is intended to aid in solving critical technology issues in order to build a functioning ERL injector capable of delivering 100 mA current with 0.3 mm-mrad normalized emittance bunches at 15 MeV to the main linac of an ERL.

The injector has reached 25 mA maximum current at 5 MeV (CW), which is the highest current ever achieved using a GaAs cathode. This was made possible by improvements in a number of subsystems. These include the incorporation of a fast current feedback based on μTCA electronics that acts on a Pockels cell in the laser transport path. Without this feedback, current fluctuations can cause transient effects in the gun and RF systems which lead to beam loss, limiting operation to 10 mA. Presently the limiting factor in high current operation (at 5 MeV) is RF input coupler heating. The maximum energy achieved was 13 MeV, and was limited by cryogenic capacity.

Bunches with the full ERL design charge of 77 pC were created using the 50 MHz laser, and normalized emittances of 2 to 3 μm were measured (at 5 MeV) from a GaAs cathode [2]. We have noticed that the heating process to clean the GaAs wafer roughens the surface, and suspect that this leads to emittance growth and causes field emission at high gun voltages [3]. We are studying ways to do this cleaning at reduced temperatures while still reaching high quantum efficiencies.

While GaAs has the lowest thermal emittance of any known cathode, high quantum efficiency of greater than 10% at 520 nm, and a reasonable response time of less than 1 ps, its lifetime is poor at high current (25 mA) operation, primarily due to back-streaming ions. CsK_2Sb cathodes, however, are known to be less sensitive to vacuum issues [4], and in our first lifetime experiment with this material it ran for 8 hours at 20 mA. Even though the expected thermal emittance for this material is larger than GaAs, its good lifetime will be useful for future commissioning [5].

The DC gun was designed for 750 kV (and intended to operate at 500–600 kV), but its processing has been limited to approximately 440 kV due to insulator failure, and currently is operated to 350 kV. We have therefore designed a segmented insulator with intermediate guard rings, shown in Fig. 2, which is currently being manufactured. These rings are intended to catch field-emitted electrons before they reach the insulator material, and the design is similar

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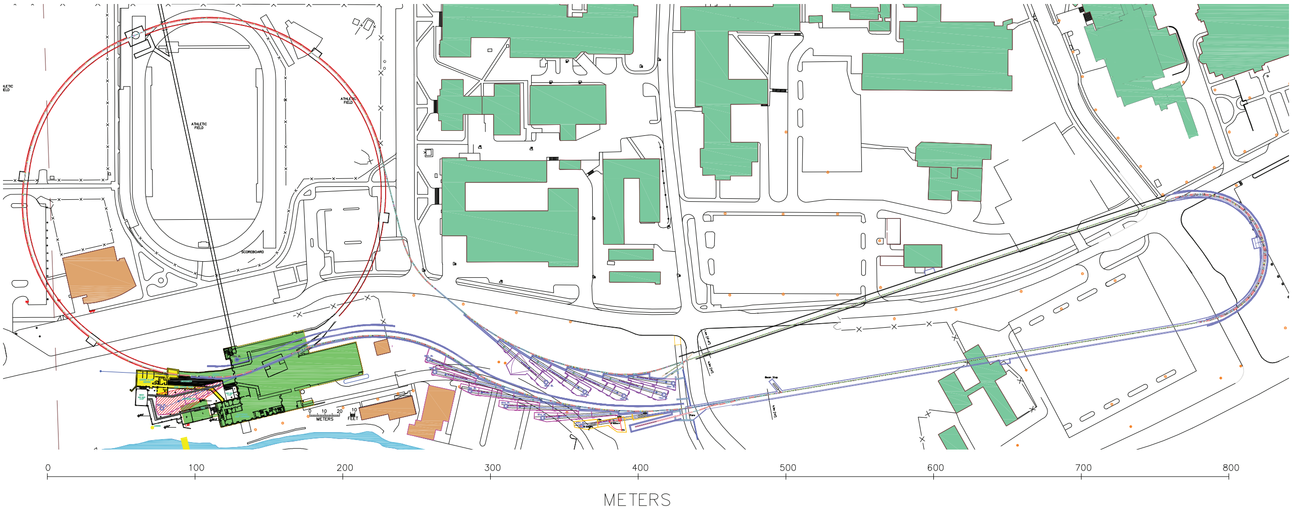


Figure 1: The Cornell ERL on the campus map.

that discussed in [6]. The gun's HVDC power supply was recently rebuilt by the manufacturer to solve issues with ripple and noise.

In related progress, the beam stop (designed for 600 kW) was tested up to 125 kW, and the emittance measurement system (based on two scanning magnets and two slits) was improved to be able to obtain a phase space plot in less than 10 s.

SRF

Recent progress on SRF research is given in [7]. Here we briefly note that the 7-cell SRF cavity design has been finalized (see [8]), and a prototype is currently being built.

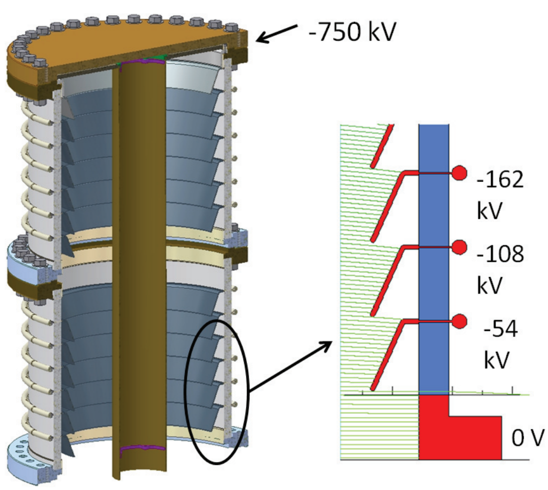


Figure 2: Design for a segmented insulator with intermediate guard rings, which catch field-emitted electrons before they reach the insulator material. The green lines indicate electron trajectories.

A prototype cryomodule for the main linacs in the ERL will be built by 2014.

FELS IN ERLS

All ERLs are driven by CW linacs, and ERL beams can potentially be used to drive FELs. Recent calculations for seeded and SASE FEL schemes using extracted bunches from the Cornell ERL, as well as XFEL-Os using extracted or recirculative beams, are discussed in [9].

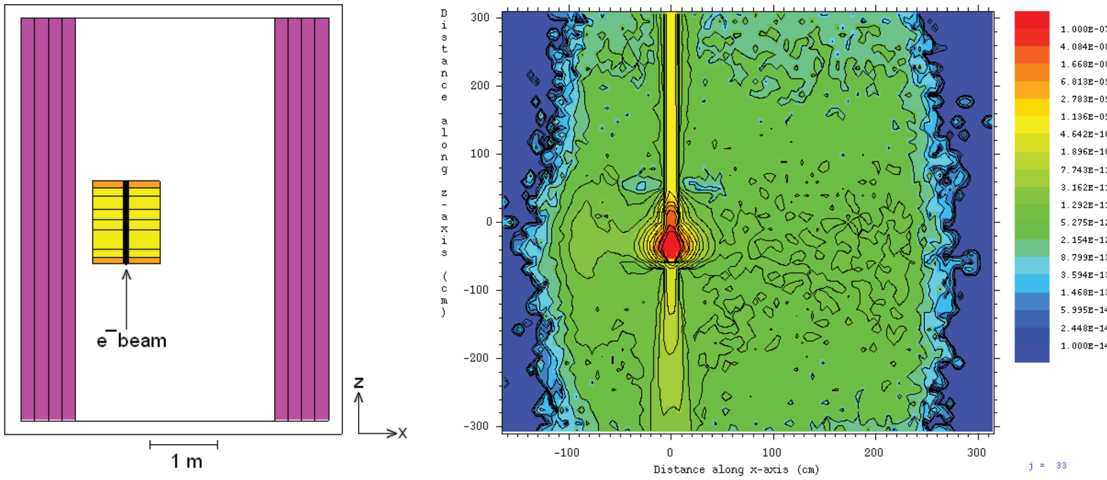
HALO COLLIMATION

Touschek scattering and rest-gas scattering are unavoidable mechanisms that can lead to the creation of a beam halo, which can potentially be lost to the vacuum chamber walls. To shift these losses to preferential locations, five collimators are strategically placed throughout the ERL [10]. The 5 GeV electrons intercepted by these collimators generate an electron-photon cascade, and the resulting energetic photons and neutrons can create a radiation hazard. These collimators are therefore designed to reduce this radiation field as much as possible.

Relatively smaller losses can damage the permanent magnets in the undulators, so protectors are placed in front of all insertion devices. To calculate the resulting radiation field, we use the Monte Carlo code MCNPX [11], taking as an input a simulated distribution of Touschek particles incident on a protector face. A typical distribution of these particles is shown in Fig. 4. An example calculation of the photon dose from such a protector is shown in Fig. 3. We have implemented ways to mitigate the Touschek scattering and loss rate by optics optimizations.

ERROR SIMULATIONS

The ERL model includes an orbit-correction scheme based on singular value decomposition (SVD), and the



(a) MCNPX geometry

(b) Calculated photon dose rate

Figure 3: Top down view of the MCNPX geometry of an ERL insertion-device protector, with its center at $(x, y, z) = (0, 0, 0)$, is shown in Fig. 3a. Yellow is iron, orange is lead, and purple is heavy concrete. A ceiling of heavy concrete and a floor of regular concrete are not shown. Figure 3b shows the calculated photon-dose-rate countours from a distribution of Touschek particles intercepting this protector, in units of (rem/hour)/(electron/s).

scheme itself was optimized using SVD techniques described in, for example, [12]. With such a scheme in place, it is possible to introduce errors into the model, simulate corrections, and examine the resudial impact on important beam-quality parameters such as the emittance. Error simulations, along with a detailed error tolerance table, are shown in [13]. Future work will use these more realistic models to calculate Touschek scattering rates.

REFERENCES

[1] Hoffstaetter, G. H., S. Gruner, & M. Tigner, *eds.*, Cornell ERL Project Definition Design Report (2011) `erl.chess.cornell.edu/PDDR`

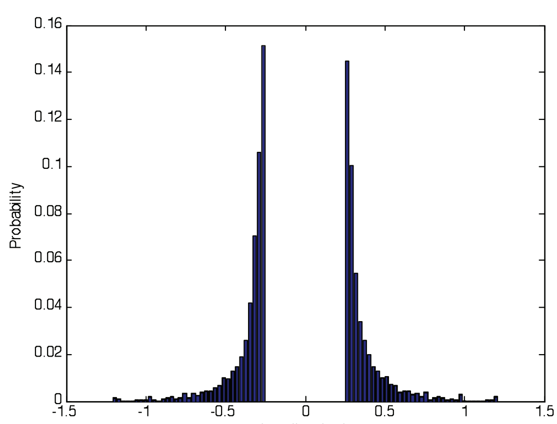


Figure 4: Typical probability distribution of Touschek particles, as a function of position incident on the face of a protector or collimator with a 5 mm aperture.

[2] Loehl, F. *et al.*, “ High Current, High Brightness Electron Sources,” Proc. IPAC10 MOZRA01 (2010)

[3] Karkare, S. & I. Bazarov, “Effect of nanoscale surface roughness on transverse energy spread from GaAs photocathodes,” Appl. Phys. Lett. **98**, 094104 (2011)

[4] Cultrera, L. *et al.*, “Growth and characterization of bialkalai photocathodes for Cornell ERL injector,” Proc. PAC11, WEP244 (2011)

[5] Dowell, D. H. *et al.*, “Cathode R&D for future light sources,” Nuc. Instrum. Methods Phys. Res. A, **622** (2010)

[6] Nagai, R. *et al.*, “High-voltage testing of a 500-kV dc photocathode electron gun,” Rev. Sci. Instrum. **81**, 033304 (2010)

[7] Liepe, M. *et al.*, “Progress on Superconducting RF for the Cornell Energy-Recovery-Linac,” Proc. PAC11, FROBS3 (2011)

[8] Valles, N. R. A. & M. Liepe, “Designing Multiple Cavity Classes for the Main Linac of Cornell’s ERL,” Proc. PAC11, TUP064 (2011)

[9] Meseck, A. *et al.*, “FELs as X-ray Sources in ERL Facilities,” Proc. PAC11, THP144 (2011)

[10] Ehrlichman, M.P. & G.H. Hoffstaetter,“Collimating Touschek particles in an Energy Recovery Linear accelerator,” Proc. PAC09, Vancouver/CA (2009)

[11] X-5 Monte Carlo Team, “MCNP: A general Monte Carlo N-particle transport code, Volume 1: Overview & Theory,” Report LA-UR-03-1987, Los Alamos National Lab (Revised 2005)

[12] Chao, Y.-C. & V. Mertens, LHC Project Report 470 (2001)

[13] Mayes, C. E., “Cornell ERL Tolerance Simulations,” Proc. PAC11, WEP067 (2011)