For the Local Organization Committee

BJ Bortz, Cornell
Devin Bougie, Cornell
Georg Hoffstaetter, Cornell (chair)
Karl Smolenski, Cornell
Monica Wesley, Cornell
and
Lora Hine for Wilson lab tours
Eric Chojnacki for SRF tours
Jeanne Butler for designs and posters
Mark Roman for computer setup
ERL Workshop Housekeeping

- Continental breakfast at 8:30 each morning, coffee break mid-morning, and snack break in the afternoon.

- No food or drink in the Kiplinger Theater. Food and drink is allowed in other rooms.

- Lunch on your own - map and list of restaurants within a block in registration folder.


- Picnic Thursday – buses to the park and back to hotels.

- Group photo in lobby at 12:30 today.

- If you need any assistance see an organizer with blue ERL tag on their name badge.
Tour Information

• Sign up for tours of Wilson Lab (ERL injector) and Newman Lab (SRF Lab) on Monday / Wednesday.

• Both tours are within walking distance – walking is highly recommended to see campus,

• as is walking from and to the hotel.

• Buses will be available at 5:15pm to the tours as well as back to the hotels.

• After the tours - buses will be at Wilson / Newman for the return trip to the hotels.

• Sign up at the registration desk.
Information for Presenters

• Continuous poster session during the breaks all week - along the glass wall of the lobby.

• Please load and test your presentation in advance on the computer for your session to avoid delays. Morning presentations by 9:00, Afternoon presentations before Lunch.

• There are desktop folders for each day of the workshop for storage of presentations.

• All presentations will be archived and available online soon after they have been presented.
Cornell ERL Program

Georg Hoffstaetter
Cornell Physics Dept. / CLASSE
Cornell’s ERL team

Cornell Electron Storage Ring Tunnel
CW linac R&D
DC-gun R&D
SRF injector R&D
Undulator R&D
Energy recovery needs continuously fields in the RF structure
- Normal conducting high field cavities can get too hot.
- Superconducting cavities used to have too low fields.
Preparation for an x-ray ERL at Cornell

Science case development and community building

Component prototyping

Facility design

Accelerator design

DC electron-gun prototyping

SRF cw injector linac prototyping

Laser developments

ERL layout and design

ERL linac development

Beam dynamics

X-ray production

Merger and ERL-injector beam dynamics

Workforce development

Management structure preparation

Georg H. Hoffstaetter

International Energy Recovery Linacs Workshop ERL09.

08 June 2009
Space charge emittance compensation
Final emittance $< 2 \times$ photocathode emittance

$80 \mu C$

$\varepsilon_{n\perp, \text{final}} \approx 1.4 \times \varepsilon_{n\perp, \text{cath}}$

$z = 0.000 \text{ m}$

$p_z = 0.000 \text{ MeV/c}$

$\sigma_z = 0.364 \text{ mm} \quad \varepsilon_z = 0.077 \text{ mm-mrad}$

$\sigma_z = 0.000 \text{ mm} \quad \varepsilon_z = 0.000 \text{ mm-kV}$

Georg H. Hoffstaetter
International Energy Recovery Linacs Workshop ERL09
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Ivan Bazarov (Cornell University)
Maximum achievable beam brightness for photo injectors
(Kiplinger Theater: Wed, 9:25 - 9:55)
## The injector: goals for the ERL

<table>
<thead>
<tr>
<th>Modes:</th>
<th>(A) Flux</th>
<th>(B) Coherence</th>
<th>(C) Short-Pulse</th>
<th>(D) High charge</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Energy</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2.5</td>
<td>GeV</td>
</tr>
<tr>
<td>Current</td>
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<td>25</td>
<td>100</td>
<td>0.1</td>
<td>mA</td>
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<td>Bunch charge</td>
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<td>Repetition rate</td>
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<td>1300</td>
<td>1300</td>
<td>0.1</td>
<td>MHz</td>
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<td>Norm. emittance</td>
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<td>0.08</td>
<td>1</td>
<td>5.0</td>
<td>mm mmr</td>
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<tr>
<td>Geom. emittance</td>
<td>31</td>
<td>8.2</td>
<td>103</td>
<td>1022</td>
<td>pm</td>
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<tr>
<td>Rms bunch length</td>
<td>2000</td>
<td>2000</td>
<td>100</td>
<td>50</td>
<td>fs</td>
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<tr>
<td>Relative energy spread</td>
<td>0.2</td>
<td>0.2</td>
<td>1</td>
<td>3</td>
<td>10^{-3}</td>
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<tr>
<td>Beam power</td>
<td>500</td>
<td>125</td>
<td>500</td>
<td>0.25</td>
<td>MW</td>
</tr>
<tr>
<td>Beam loss</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>micro A</td>
</tr>
</tbody>
</table>
Exceedingly large average spectral brightness is one large advantage for ERLs, but by far not the only one.
Science case development and community building

- **ERL Machine Workshop**
  11-12 Aug, 2000, Cornell University

- **X-ray Science Workshop for an ERL**
  2-3 December 2000, Cornell University

- **SRI Workshop 1: ERL Sources of Synch. Rad.**
  August 22-24, 2001 - Madison, Wisconsin

- **X-ray Science with Coherent Radiation Workshop**
  **Satellite Meeting of SRI 2003** - August 22-23, 2003
  Lawrence Berkeley National Laboratory, Berkeley, CA

- **12th International Workshop on RF Superconductivity**
  Cornell University, July 10-15, 2005

  **ERL05**  Jefferson Lab, Virginia, March 19-23, 2005

- **X-ray Science Workshops for an ERL**
  June 2006 – RPC Center, Cornell University

  **ERL07**  Daresbury Laboratory, UK, May 21-25 2007

  **ERL09**  (to occur @ Cornell, June 8-12, 2009)

As well as private technical reviews by outside committees:

- ERL/Ring workshop  7/05
- ERL Retreat 11/11/06
- KEK/CLASSE ERL workshop 3/12/07
- Director’s ERL review 7/07
- ERL instrumentation workshop 6/2/08
- etc.

- **APS workshops**
- **KEK workshops**
- **Coherence 2007**
- **PAC 05 / 07 / 09**

- **2007 X-ray Gordon**
- **SRF 2007**
- **EPAC 08, LINAC 08**
- **CHESS User meeting**

Cornell ERL pubs
Science case development and community building

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Don Bilderback (Cornell University)

X-ray applications in ERLs
(Kiplinger Theater: Wed, 15:45 - 16:10)
Preparation for an x-ray ERL at Cornell

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Management structure preparation

Georg H. Hoffstaetter

International Energy Recovery Linacs Workshop ERL09.

08 June 2009
Facility design

1) Find a location
   a) Should be on campus
   b) Reuse as much infrastructure as possible
   c) Provide a sufficient number of beamlines to develop forefront experiments.
   d) Provide a sufficient angle between x-ray beamlines to have
      i) First x-ray optics element close enough after the undulator (30m)
      ii) Distance between x-ray lines sufficient for hutches (5m)
   e) Provide space for upgrades and future accelerator R&D
2) Accommodate Accelerator physics limits
   a) Chose energy and current for hard x-ray science
   b) Dipole strength limits
   c) Power limits on the wall, and power density limits
   d) Emittance growth limits
   e) Check compatibility with other accelerator physics effects
3) Accommodate limits of tunnel construction, architecture, and facilities, i.e. cooling, cryogenics, …
ERL Layout at Cornell

1: injector
2: acceleration to 2.8GeV
3: turn around with 2.8GeV
4: acceleration to 5GeV
5: to x-ray beamlines
6: return through CESR
7: further x-ray beamlines
8: dump at 10MeV
9: deceleration to 2.2GeV
3: turn around with 2.2GeV
Campus planning
Existing infrastructure

Wilson Lab
Architecture firm involved

Wilson Lab

X-ray user area
Cryogenic firms involved
Involved Engineering Firms

- Wilson Lab
- X-ray user area
- Cooling and cryogenics
- Accelerator company
- Architects
- Cryogenic companies
- Tunneling consultants
Shielding and x-ray optics

1\textsuperscript{st} optics at 35m after center of undulator, outside shielding wall. 80m long x-ray beamlines.
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Accelerator Design and Prototyping

- **Cornell ERL DC Gun**
  by Bruce Dunham  
  (Kiplinger Theater: 10:45 - 11:05)

- **DC Gun Discussion: Ceramic Insulators and HV Breakdown**
  by Bruce Dunham  
  (Kiplinger Theater: 13:50 - 14:10)

- **Electrode Shapes for Small Emittance**
  by Ivan Bazarov  
  (Kiplinger Theater: 15:10 - 15:30)

- **Laser Systems Discussion**
  by Dimitre Ouzounov  
  (Kiplinger Theater: 16:40 - 17:00)

- **Restrictions from CSR Forces for Different ERL Running Modes**
  by Chris Mayes  
  (Film Forum: 10:00 - 10:15)

- **Minimal Requirements for a Hard X-ray ERL Design**
  by Chris Mayes  
  (Film Forum: 10:15 - 10:30)

- **Analysis of Multi-Turn ERLs for X-ray Sources**
  by Georg Hoffstaetter  
  (Film Forum: 12:15 - 12:30)

- **Beam Loss in ERLs due to Scattering Effects / Collimation**
  by Michael Ehrlichman  
  (Film Forum: 14:15 - 14:30)

- **Upgrading BMAD for Combined Beam and X-ray Optics Design**
  by Dave Sagan  
  (Film Forum: 10:15 - 10:30)

- **Cornell ERL Injector Linac Testing Status**
  by Sergey Belomestnykh  
  (322 Theater Classroom: 10:45 - 11:05)

- **Cornell ERL High Power Delivery and Low Level Control Systems**
  by Matthias Liepe  
  (322 Theater Classroom: 15:10 - 15:30)

- **Addressing SRF Input Coupler Design Challenges**
  by Vadim Veshcherevich  
  (322 Theater Classroom: 10:45 - 11:05)
Challenges for x-ray ERLs

• Limit emittance growth during beam transport and acceleration
  – Optics for simultaneous beams, optics errors
  – Limit emittance growth from incoherent synchrotron radiation (ISR)
  – and Coherent Synchrotron Radiation for short bunches
  – emittance growth from coupler kicks / cavity misalignments
  – Limited emittance growth from ion focusing
  – Fast and slow orbit stabilization, during startup and operation
  – Beam loss from intra beam scattering (IBS) and rest gas scattering
  – Timing for short pulse options
Challenges for x-ray ERLs

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  - Fast and slow orbit stabilization, during startup and operation
  - Beam loss from intra beam scattering (IBS) and rest gas scattering
  - Timing for short pulse options
Challenges for x-ray ERLs

• Limit energy spread after deceleration by a factor of 500
  – Limit energy spread from incoherent / coherent synchrotron radiation (ISR / CSR), wakes, IBS and RGS, field errors for time of flight corrections.

• Beam loss concerns
  – Beam loss from IBS / Touschek, RGS, ion accumulation, halo

• Superconducting RF challenges
  – Phase and amplitude control for very narrow frequency window ($10^{-8}$)
  – Avoid heating / Higher order mode absorption
  – Limit cooling power
Challenges for x-ray ERLs

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• Beam loss concerns
  – Beam loss from IBS / Touschek, RGS, ion accumulation, halo

• Superconducting RF challenges
  – Phase and amplitude control for very narrow frequency window (10^-10)
  – Avoid heating / Higher order mode absorption
  – Limit cooling power

Hasan Padamsee (Cornell University)
SRF challenges in ERLs
(Kiplinger Theater: Mo, 16:30 - 17:15)
Preparation for an x-ray ERL at Cornell

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Component Prototyping and Preconstruction R&D

a) Continued Gun R&D  
b) ERL cryomodule construction  
c) Hi-brightness beam physics  
d) ERL Undulators  
e) Other X-ray beamline R&D
Advantages of ERL beams
(c) Small emittances for round beams
Cornell Injector prototype: Verification of beam production

- Dump
- Diagnostics
- SC injector
- Gun
- HOM absorb.
- CW coupler
- Dressed cavity
- Gun
Cornell Injector prototype: Verification of beam production

Bruce Dunham (Cornell University) Challenges in Guns and Injectors (Kiplinger Theater: Mo, 13:30 - 14:15)
Cornell Injector prototype: 3D
Don’t forget: Tour Wilson Lab

Parameters:
100 mA avg current (5 MeV)
33 mA avg current (15 MeV)
77 pC / bunch at 1.3 GHz
< 1 mm emittance
< 1-2 ps bunch length

Demonstrate:
Cathode longevity
Low emittance
RF controls
Parameter sensitivity
reliability
Cavity Production in the SCR group

Don’t forget: Tour Newman Lab

- Pressed Nb cups for cavities
- E-beam welding of cavities
- Tuning of cavities
- BCP cavity etch
- Cavity with and w/o He vessel
- Final matching of He vessel

All done at CLASSE – No company could do this today!
Prototype SC linear accelerator
Designed and constructed by the SRF group

Transport from Newman Lab to Wilson Lab
Emittance Measurement System

 Beam properties at the cathode

Fixed slits phase space measurements
- Corrector coils for beam scanning
- 10 micron precision slits
- 1 kW beam power handling

Are transported through the accelerator, measured in a fixed slit phase space measuring system, and compared with simulations.

Good agreement with theory gives confidence that the very small simulated emittances can be achieved.
Asymmetric beam distributions

Asymmetric phase space distribution leads to reduced brightness

This brightness reduction has been traced back to asymmetric photon distributions on the cathode.

Are transported through the accelerator, measured in a fixed slit phase space measuring system, and compared with simulations.

Gun milestones:
- Highest current: 25mA
- Highest voltage: 430kV
- Highest bunch charge: 80pC
- Emittance at 250keV: 1.5μm

Exceedingly large average spectral brightness is one large advantage for ERLs, but by far not the only one.
Electron beams from ERLs can have much higher brightness, especially in the core of the beam.

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Electron beams from ERLs can have much higher brightness, especially in the core of the beam. Exceedingly large average spectral brightness is one large advantage for ERLs, but by far not the only one.

Ivan Bazarov (Cornell University)  
Maximum achievable beam brightness for photo injectors  
(Kiplinger Theater: Wed, 9:25 - 9:55)
Achieved parameters:
1. 25mA cw electron beam from test DC gun
2. 4mA bunched electron beam through injector cryomodule
3. 430kV during conditioning, 250kV DC gun operation
4. 1.5 micron emittance, milestone of prototype injector
5. Measured emittance corresponding to simulation with 250kV and non-uniform laser distribution
6. 1.8K and 2K operation of injector linac
7. 50kW conditioning of each coupler pair
8. High voltage conditioning of each cavity

Still open questions, e.g. reduced Q in cavities

**Significant progress seems imminent:**
A) A strong magnetic obstruction has been eliminated.
B) Better ceramic ready for installation.
Localization and elimination of magnetic error

Distortions of a regular grid of beamlets

Before cryomodule

After cryomodule
Change of grid distortion after steering at two locations

Steering at coupler 2

Steering at coupler 3

Comparison of two scales localizes the error field.

This would require magnetic field errors of
Between cavity 2 and 3:
rotated quadrupole at 22.5 degree of 4.6 Gcm/cm
rotated sextupole at 30 degree of 20Gcm/cm²
Nonlinear Field Error in the 2-3 region

Center of 3\textsuperscript{rd} HOM absorber

Coupler 2

Coupler 3

Coupler 4
Nonlinear Field Error in the 2-3 region

Center of 3rd HOM absorber

Coupler 2

Coupler 3

Coupler 4

Georg H. Hoffstaetter           International Energy Recovery Linacs Workshop ERL09.       08 June 2009
Rest distortion is compatible with 50mG background field.
Gun prototype: verify beam production
Further preconstruction work:
Main x-ray ERL cryomodule

- Continued Gun R&D
- ERL cryomodule
- Hi-brightness beam physics
- ERL Undulators
- Other X-ray beamline R&D
Main x-ray ERL cryomodule

a) Continued Gun R&D
d) ERL Undulators
e) Other X-ray beamline R&D
b) ERL cryomodule
c) Hi-brightness beam physics

Matthias Liepe (Cornell University) SRF system optimization process (Kiplinger Theater: Th, 9:25 - 9:55)
Collaborations

- Collaboration w. JLab on ERL prototype design
- Use of JLab IR FEL for beam experiments to verify
  + beam instability calculations
  + low level rf control circuitry with ERL capability
- Collaborative agreement with KEK for ERL developments
- Collaboration with Daresbury / UK in the ERLP project
- Host of the international ERL accelerator workshop 2009 for all ERL applications.
- Current Chair of the world wide SRF technology development (TTC)
- Current Chair of the LCSGA (LC steering group Americas), member with MoU
- Current Chair of the LHC Machine Advisory Committee
- Current Chair of the RHIC Machine Advisory Committee
- Membership in NFMCC (Neutrino factory and muon collider col.)
- Service in many accelerator advisory, review, and APS committees
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Georg H. Hoffstaetter

International Energy Recovery Linacs Workshop ERL09. 08 June 2009
Education and workforce development

Undergraduate and graduate students working on ERL injector with physics faculty (Cornell, Wilson lab, L0 area)
Laboratory management and workforce development

- Laboratory structure has built and operated world leading accelerators for decades under Maury Tigner’s lead.
- Sol Gruner (ERL PI) has lead a major light source (CHESS) for a decade.
- There is the expertise and strength to expand modestly to build and operate an x-ray ERL.

This growing project needs the best people in the field:
Post PhD scientists are sought for
- experimental beam dynamics.
- experimental SRF systems.
And collaborations are encouraged.
A laboratory structure that has operated world leading accelerators for decades has the expertise and strength to expand and operate an x-ray ERL light.

This growing project needs the best people in the field:

**Post PhD scientists** is sought for:

- experimental beam dynamics.
- experimental SRF systems.

Florian Loehl (Cornell University)

Kiplinger Theater: Mo, 15:00 - 15:25
At Cornell, we have gone through the full design circle of science-case and community building, facility design, accelerator layout, and prototyping.

Prototypes of a DC gun and an SRF cw injector linac have been built and progress is being made in commissioning these.

Preconstruction prototyping will continue with: advanced gun designs, a main linac cryomodule, undulators and x-ray beamline components.

Cornell has the history, the facilities, and the expertise to build and manage a large x-ray ERL.

We are engaged in workforce development by education and hiring and encourage collaboration.