First Results for the Cornell ERL Injector

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• An ERL at Cornell
• The ERL Injector Prototype Project
  - Overview
  - DC Photoemission Gun/Laser
  - Superconducting RF
  - Beam Diagnostics
• Results and Prospects

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ERL at Cornell

1. Injector
2. Linac 1
3. 2.5 GeV turnaround
4. Linac 2
5. X-ray beam-lines
6. 5 GeV turnaround
7. X-ray beam-lines
8. Beam dump

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• **Phase I**: Build, test injector, LINAC modules; resolve machine issues. Engineering studies for Phase II (in process; $30M NSF & NY State)

• **Phase II**: Build a high energy (5 GeV) ERL x-ray facility at Cornell as an upgrade to CESR. (5 year construction, no funding yet)
Parameters:
100 mA avg current (5 MeV)
33 mA avg current (15 MeV)
77 pC / bunch at 1.3 GHz
< 2 μm emittance
< 2-3 ps bunch length

Demonstrate:
Cathode longevity
Low emittance
RF controls
Parameter sensitivity
reliability
The Photoemission DC Electron Gun
Basic design has been used in GaAs polarized electron sources for decades (@ 100 kV).
GaAs is still our cathode of choice . . .

- good quantum efficiency (QE)
- low thermal emittance (cold)
- fast time response (@520 nm)

But . . .

- need extreme UHV (< 1x10^{-11} Torr)
- limited lifetime
- minimum thermal emittance near bandgap (where the QE is lowest)
- thermal emittance degrades at higher QE

. . . We are willing to try other cathodes
Insulator Design

- Large size to keep field gradients low
- Field emitted electrons can build up on the insulator and punch thru
- External SF$_6$
- High mechanical stresses due to SF$_6$ pressure and bakeouts
- Difficult to find suppliers
- Braze difficulties due to large size

Maximum voltage so far 440kV. Operating at 250-300 kV now until a spare is obtained

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750 kV HV power supply

Custom floating ammeter to measure field emission current during processing

Gun and HVPS inside a high pressure SF₆ vessel

750 kV, 100 mA supply
Kaiser Systems, Beverly, MA

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For a 10% QE cathode, one needs ~2 Watts to reach 100 mA
We use an ‘optical pulse-stretcher’ to get 20-40 ps flat-top pulses from a 2 ps laser (DPA – divided pulse amplifier)

Gauss to flat top transformation using a commercial aspheric lens (Newport Corp)

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Beamline for characterizing the phase space from the gun
Emittance data at 250kV, 80 pC

\[ \varepsilon = 1.8 \, \mu m \]

- Data
- Parmela3D
- GPT
- 3.4A → SOL1 → 3.8A
The RF and Superconducting RF Systems
• High RF power transfer to beam for acceleration of high current beam ⇒ input coupler challenge: 1 MeV per cavity * 0.1 A = 100 kW
• High beam loading needs to be compensated very accurately for injectors ⇒ RF control challenge.
• Emittance preservation ⇔ reduce beam-cavity interaction effects, small transverse kick fields, high RF field stability.
• Strong damping of HOMs (monopole, dipole and quadrupole) is essential for emittance preservation and to reduce monopole HOM power.
• CW cavity operation at higher fields ⇒ cryogenic power ⇒ cryostat design challenge.
ERL injector cryomodule

- five 2-cell cavities
- symmetric beam line
- 2 opposing 50 kW input couplers per cavity
- six beam line HOM loads for aggressive HOM damping

Manufactured by CPI, Beverly, MA
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Manufactured by Cornell, Accel
### Injector cavity parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>cavity frequency</td>
<td>1300 MHz</td>
</tr>
<tr>
<td>cells per cavity</td>
<td>2</td>
</tr>
<tr>
<td>R/Q per cavity</td>
<td>222 Ω</td>
</tr>
<tr>
<td>acc. voltage per cavity</td>
<td>1 to 3 MV</td>
</tr>
<tr>
<td>acc. gradient</td>
<td>4.6 to 13.8 MV/m</td>
</tr>
<tr>
<td>$Q_0$</td>
<td>$&gt; 1 \cdot 10^{10}$</td>
</tr>
<tr>
<td>$Q_{\text{ext}}$</td>
<td>$&gt; 4.6 \cdot 10^4$ to $4.1 \cdot 10^5$</td>
</tr>
<tr>
<td>active cavity length</td>
<td>0.218 m</td>
</tr>
<tr>
<td>total cavity length</td>
<td>0.536 m</td>
</tr>
</tbody>
</table>

**Vertical test data**

<table>
<thead>
<tr>
<th>Eacc [MV/m]</th>
<th>0</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_0$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10^9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10^10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Cryomodule installed at the ERL injector

Klystron gallery

Cavity string before installation into cryomodule

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## Cavity Performance

<table>
<thead>
<tr>
<th>Cavity</th>
<th>CW</th>
<th>Limit</th>
<th>Pulsed</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.8 MV</td>
<td>Cryogenics</td>
<td>4.35 MV</td>
<td>IC</td>
</tr>
<tr>
<td>2</td>
<td>2.9 MV</td>
<td>IC</td>
<td>3.75 MV</td>
<td>IC</td>
</tr>
<tr>
<td>3</td>
<td>3.5 MV</td>
<td>Cryogenics</td>
<td>3.66 MV</td>
<td>IC</td>
</tr>
<tr>
<td>4</td>
<td>3.4 MV</td>
<td>Cryogenics</td>
<td>4.15 MV</td>
<td>Quench</td>
</tr>
<tr>
<td>5</td>
<td>3.5 MV</td>
<td>none</td>
<td>5.20 MV</td>
<td>IC</td>
</tr>
<tr>
<td>All 5</td>
<td>2.4 MV/12 MV total</td>
<td>Cryogenics</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**IC** - input coupler vacuum

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Beam Diagnostics and Beam Dump
A-line: Full phase space characterization
  emittance measurement slits (EMS), bpm's, flying wire, deflection cavity, energy spread, viewers

B-line: Merger studies (low average power)
  emittance measurement slits, bpm's, viewers

C-line: phase and energy spread/stability, bunch length
  THz interferometer, flying wire, bpm's, viewers

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Beam Dump

Up to 500 kW average power in the beam for the Phase 1 injector, probably need 1.5 MW for the final ERL design.

Before reaching the dump, the 1 mm dia, 500 kW beam is expanded and rastered to reduce the instantaneous power load. Aluminum is used to minimize neutron production.
Results

- All construction (except for dump and final shielding) is complete
- RF and SRF commissioning nearly complete
- Diagnostics commissioning is underway
- Beam through all beamlines, 5 MeV, 50 uA max
- All components ready for 100 mA
- Phase space measurements to begin soon

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This work is supported by NSF PHY-0131508

Industrial Partners:
- Communication and Power Industries (CPI) - DC Gun and RF couplers
- e2V - 100 kW klystrons
- Accel - HOM loads
- Kaiser Systems - 750 kV power supply
- Metalex - 500 kW beam dump
- Myer Tool - Cryomodule
- Pritel - Laser oscillator

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The next ERL workshop is in Ithaca, NY
Coupler design highlights

Design features:

- Design derived from the TTF-III coupler
- The cold part was completely redesigned using a 62 mm, 60 Ohm coaxial line for stronger coupling, better power handling and avoiding multipacting
- Antenna tip was enlarged and shaped for stronger coupling
- "Cold" window was enlarged to the size of "warm" window
- Outer conductor bellows design was improved for better cooling (added heat intercepts)
- Air cooling of the warm inner conductor bellows was added

Manufactured by CPI, Beverly, MA
### HOM load design

<table>
<thead>
<tr>
<th>Total # loads</th>
<th>3 @ 78mm + 3 @ 106mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power per load</td>
<td>26 W (200 W max)</td>
</tr>
<tr>
<td>HOM frequency range</td>
<td>1.4 – 100 GHz</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>80 K</td>
</tr>
<tr>
<td>Coolant</td>
<td>He Gas</td>
</tr>
<tr>
<td>RF absorbing tiles</td>
<td>TT2, Co2Z, Ceralloy</td>
</tr>
</tbody>
</table>

2 proto-types fabricated at Cornell
6 production loads fab’ed by ACCEL

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• Beam position resolution: 10 μm (spec)
• Energy spread resolution: 10^{-4}
• Transverse beam profile resolution: 30 μm (viewscreens)
  10 μm (slits)
  30 μm (flying wire)
• Angular spread resolution: 10 μrad
• Pulse length (deflecting cavity&slits): 100 fs
• RF phase angle: 0.5°

Ability to take phase space snapshots of the beam, both transverse planes, and longitudinal phase space

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