High Q Cavities for the Cornell ERL Main Linac

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5 GeV, 100 mA CW beam, 8 pm emittance, 2 ps bunches

~200 W HOM power/cavity
CW operation, $Q(1.8 \text{ K}) = 2 \times 10^{10} \text{ @ 16.2 MV/m}$
ERL documentation:
(1) Science, (2) Generic design

- Science case gathered in international workshops
- Design report
  - 530 pages between conceptual design and engineering design
  - Access at www.classe.cornell.edu/ERL/PDDR
Cornell Cavity Specs

- Cornell ERL, 1.3GHz, 1.8K
- KEK ERL, 1.3GHz, 2K
- XFEL, 1.3GHz, 2K
- ILC BL, 1.3GHz, 2K
- ILC ACD, 1.3GHz, 2K

Cornell ERL
KEK ERL
XFEL
ILC, BCD & ACD
Jlab upgrade

Qo vs. Eacc [MV/m]

1,00E+11
1,00E+10
1,00E+09

0 5 10 15 20 25 30 35 40 45
• HTC-1: Follow vertical assembly procedure as closely as possible

• HTC-2: Include side mounted, **high power** RF input coupler

• HTC-3: Full cryo-module assembly: high power RF input coupler and **beam line** HOM loads
• Cavity exceeded Q specification at 1.8 K by 50%, reaching $3 \times 10^{10}$
• $Q(1.6 \text{ K, } 5 \text{ MV/m}) = 6 \times 10^{10}$
• Exceeded gradient specifications
• RF-based and calorimetric-based Q measurements yielded consistent values
Most of the Parts: 316 Stainless Steel with 5\(\mu\) Copper Coating
Main Linac Input Coupler Testing

Power rating: 5 kW CW
Headroom for 10 kW

Designed by Cornell
Built by CPI
• Quality factor, gradient specifications achieved
• Administrative limits prevented higher field measurements (not limited by quench)
• Lower Q (than HTC-1) due to high radiation levels
Beamline HOM absorbers strongly damp dipole HOMs to under $Q \sim 10^4$.
**Initial Cooldown at 16.2 MV/m**

- \( Q(2.0 \text{ K}) = 2.5 \times 10^{10} \)
- \( Q(1.8 \text{ K}) = 3.5 \times 10^{10} \)
- \( Q(1.6 \text{ K}) = 5.0 \times 10^{10} \)

**10 K thermal cycle at 16.2 MV/m**

- \( Q(2.0 \text{ K}) = 3.5 \times 10^{10} \)
- \( Q(1.8 \text{ K}) = 6.0 \times 10^{10} \)
- \( Q(1.6 \text{ K}) = 10.0 \times 10^{10} \)
Are we (just) lucky?
Total 64 cryomodules, each:

- six packages of 7-cell cavity/Coupler/tuner
- a SC magnets/BPMs package
- five regular HOMs/two taper HOMs

Linac A
344 m with 35 cryomodules

Linac B
285 m with 29 cryomodules

nominal length: 9.8 m
MLC Milestones

• Dec ‘12 – Design completed
• Jan ‘13 – Order 6 remaining input couplers (6 month fab)
• Feb ‘13 – 3 unstiffened cavity built, testing started
• Apr ‘13 – Award vacuum vessel PO (6 month fab) & HGRP (6 month)
• July ‘13 – Production of 3 stiffened cavities started
• Sept. ‘13 – In-house fabrication of string components complete (tuners, HOMs, tapers…)
• Nov. ‘13 – Begin string assembly in clean room
• March ‘14 – Begin cold mass assembly and instrumentation (outside clean room)
• End of ‘14 – MLC ready for testing
Un-stiffened cavities
(#2, #3, #4)

**ERL 7-cell surface preparations**

1. Bulk BCP (140μm)
2. Degassing in TM furnace (650°C*4days)
3. Freq. and flatness Tuning
4. Final BCP (10μm)
5. 120°C bake in TM furnace (120°C*48hrs)
6. HF rinse
7. VT w/ T-map

All cavities were designed, built and tested at Cornell
<table>
<thead>
<tr>
<th>ERL7-1 (HTC)</th>
<th>ERL7-2</th>
<th>ERL7-3</th>
<th>ERL7-4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bulk BCP</strong></td>
<td>140um (witness sample)</td>
<td>135±10 um (cavity equator)</td>
<td>138±5 um (cavity equator)</td>
</tr>
<tr>
<td><strong>Degassing</strong></td>
<td>Jlab, 650C*10hrs</td>
<td>TM-furnace 650C*4days</td>
<td>TM-furnace 650C*4days</td>
</tr>
<tr>
<td><strong>tuning</strong></td>
<td>88%</td>
<td>94%</td>
<td>91%</td>
</tr>
<tr>
<td><strong>Final BCP</strong></td>
<td>10 um</td>
<td>10 um</td>
<td>10 um</td>
</tr>
<tr>
<td><strong>120C bake</strong></td>
<td>On insert</td>
<td>TM-furnace</td>
<td>On insert</td>
</tr>
<tr>
<td><strong>HF rinse</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>VT 1st (1.8K)</strong></td>
<td>17MV/m, 1.6e10 (No T-map, old insert)</td>
<td>17MV/m, 1.53e10 w/T-map</td>
<td>Limited by FE w/T-map</td>
</tr>
<tr>
<td><strong>Re-process</strong></td>
<td>-BCP(10um) -120C bake(in clean room, old set-up) -HF rinse</td>
<td>-Cavity length is too long, re-built &amp; re-test are planed</td>
<td>Re-process to cure FE -BCP(10um) -120C bake(TM-furnace) -HF rinse</td>
</tr>
<tr>
<td><strong>HTC3, 16.2MV/m, 6.0e10 @1.8K</strong></td>
<td>17MV/m, 2.8e10 No T-map (PC down)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Are we (just) lucky?

Well, at least we are happy!
ERL Injector Prototype: Achievements to date:

- 75 mA average current @ 4 MeV
- 0.3 μm emittance @ 77 pC, 8 MeV
Using a Na$_2$KSB photocathode, ran over 8 hours at 65 mA (2000 C) with a 2.6 day 1/e cathode lifetime. Reached as high as 75 mA for a short time.
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