Polarized Electron Sources for the ILC and CLIC

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Students: A. Jayaprakash, J. McCarter, K. Surles-Law
Some perspective: Gun R&D Projects at JLab

Growing into a “Center for Injectors and Sources”…

- New and improved CEBAF photoinjector, including gun at ~ 200kV and SRF ¼ cryounit with internal graded-beta capture. (Note: Max gun voltage set by chopper power limitation) Very Expensive
- Design and build gun for ILC: pulsed, high charge/microbunch, 100uA ave. current, polarized $
- Design gun for CLIC: pulsed with high rep rate microstructure, very high peak current and current density, polarized No $, only notoriety
- Continue high current studies (> 1mA at high polarization) with new LL-gun at test cave. EIC application (mostly eRHIC)
- Contribute to FEL Gun development. Shared Challenges, e.g., reliable HV operation, load lock design, etc. Shared Resources
- Positron source: 2mA ave current, 10MeV, high rep rate, small bunch charge Thermionic Gun?
- RF-gun? Polarized and CW – the big challenges
ILC e-Source Photoinjector

Damping Ring

Energy Compression
Spin Rotation

2 x 5 MW (1 + 1 spare)

SC tune-up dump (311 kW)

SC e⁻ LINAC (5.0 GeV)

8 x 10 MW

NC tune-up dump (11.3 kW)

L-band (β = 0.75)
TW Bunching and Pre-Acceleration

Faraday Cup and Mott Polarimeter (13.5 kW)

3.2 nC

76 MeV - 5.0 GeV

5 nC

140 keV - 76 MeV

DC Gun (2x)

Energy Collimation (Vertical Chicane)

433.3 MHz SHB

216.7 MHz SHB

Drive Laser (above Ground)
The GDE Plan and Schedule

Global Design Effort

2005  2006  2007  2008  2009  2010

Baseline configuration
Reference Design
LHC Physics
Engineering Design
IlC R&D Program
Expression of Interest to Host
International Mgmt
ILC e- Beam Time Structure

5 Hz Repetition Rate

1 ms, 2820 micro-bunches

2 ns

337 ns
3 MHz
## ILC e-Beam Source Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
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<tbody>
<tr>
<td>Number Electrons per microbunch</td>
<td>$N_e$</td>
<td>$3 \times 10^{10}$</td>
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<tr>
<td>Number of microbunches</td>
<td>$n_b$</td>
<td>3000</td>
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<td>Width of microbunch</td>
<td>$t_b$</td>
<td>$\sim 1$ ns</td>
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<td>Time between microbunches</td>
<td>$\Delta t_b$</td>
<td>337 ns</td>
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<tr>
<td>Microbunch rep rate</td>
<td>$f_b$</td>
<td>3 MHz</td>
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<tr>
<td>Width of macropulse</td>
<td>$T_B$</td>
<td>1 ms</td>
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<tr>
<td>Macropulse repetition rate</td>
<td>$F_B$</td>
<td>5 Hz</td>
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<tr>
<td>Charge per micropulse</td>
<td>$C_b$</td>
<td>4.8 nC</td>
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<tr>
<td>Charge per macropulse</td>
<td>$C_B$</td>
<td>14420 nC</td>
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<tr>
<td>Average current from gun ($C_B \times F_B$)</td>
<td>$I_{ave}$</td>
<td>72 uA</td>
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<td>Average current macropulse ($C_B / T_B$)</td>
<td>$I_B$</td>
<td>14.4 mA</td>
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<td>Duty Factor within macropulse (1ns/337ns)</td>
<td>$DF$</td>
<td>$3 \times 10^{-3}$</td>
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<tr>
<td>Peak current of micropulse ($I_B / DF$)</td>
<td>$I_{peak}$</td>
<td>4.8 A</td>
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</tbody>
</table>
The CLIC Injector complex in 2007

- **Laser**
  - Unpolarized e-
- **RF gun**
  - 3 TeV
  - Base line configuration
- **Primary beam Linac for e-**
  - 1.5 GHz, 2 GeV
  - ~ 150 m
- **Pre-injector Linac for e**
  - 1.5 GHz, 200 MeV
  - ~ 15 m
- **Pre-injector Linac for e**
  - 1.5 GHz, 200 MeV
  - ~ 15 m
- **RF gun**
  - Polarized e-
- **Laser**
  - DC gun

---

**e** Main Linac
- 12 GHz, 100 MV/m, 21 km
- 360 m
- 2.424 GeV
- 3 GHz
- ~ 10 m
- 162 MV
- 10 m

**e** Main Linac
- 12 GHz, 100 MV/m, 21 km
- 360 m
- 2.424 GeV
- 3 GHz
- ~ 10 m
- 162 MV
- 10 m

**e** DR
- 2.424 GeV
- 360 m
- 3 GHz
- 162 MV
- 10 m

**e** DR
- 2.424 GeV
- 360 m
- 3 GHz
- 162 MV
- 10 m

**PDR**
- 2.424 GeV
- 360 m
- 3 GHz
- 162 MV
- 10 m

**Injection Linac**
- 1.5 GHz
- ~ 150 m
- 9 GeV

**Booster Linac**
- 3 GHz
- ~ 360 m
- 12 GHz, 100 MV/m
- 21 km

**e**+ DR
- 2.424 GeV
- 360 m
- 3 GHz
- 162 MV
- 10 m

**e**- DR
- 2.424 GeV
- 360 m
- 3 GHz
- 162 MV
- 10 m

**Pre-injector Linac for e**
- 1.5 GHz
- ~ 15 m
- 200 MeV

**Pre-injector Linac for e**
- 1.5 GHz
- ~ 15 m
- 200 MeV

**e**- DR
- 2.424 GeV
- 360 m
- 3 GHz
- 162 MV
- 10 m

**e**+ DR
- 2.424 GeV
- 360 m
- 3 GHz
- 162 MV
- 10 m

**PDR**
- 2.424 GeV
- 360 m
- 3 GHz
- 162 MV
- 10 m

---

3 TeV

**Base line configuration**

- ~ 100 m
- ~ 30 m
- ~ 30 m
- ~ 100 m
- ~ 30 m
- 2.3 GV
- 2.3 GV
- 12 GHz
- 12 GHz
- 9 GeV
- 48 km
- 12 GHz
- 12 GHz
- 12 GHz
- 12 GHz
- 12 GHz
The CLIC Injector complex in 2007

Thermionic gun
Unpolarized e⁻

12 GHz, 100 MV/m, 21 km

Laser
Pre-injector Linac for e⁻

200 MeV
1.5 GHz
~ 15 m

e⁻/e⁺ Target
1.5 GHz
~ 5 m

Ppsitron Drive beam Linac
2 GeV
1.5 GHz
~ 200 m

Pre-injector Linac for e⁺
200 MeV
1.5 GHz
~ 15 m

RTML RTML
30 m

Polarized e⁺

DC gun

Polarized e⁻

12 GHz

9 GeV

48 km

3 GHz
3 GHz

e⁺ DR
2.424 GeV
365 m

e⁺ PDR
2.424 GeV

~ 230 m

~ 30 m

3 GHz
88 MV

~ 5 m

3 GHz
88 MV

~ 5 m

3 GHz
88 MV

~ 5 m

e⁻ DR
2.424 GeV
365 m

e⁻ PDR
2.424 GeV

1.5 GHz

~ 220 m

~ 100 m

RTML RTML
12 GHz, 100 MV/m, 21 km

3 TeV
Base line configuration
(September 2007)
**CLIC overall layout**

**3 TeV**

- *e* injector: 2.4 GeV
- *e* DR: 365 m
- *e* DR: 365 m
- *e*^+ injector, 2.4 GeV
- *e*^+ DR: 365 m

- Drive beam accelerator: 2.37 GeV, 1.0 GHz
- Combiner rings: Circumferences delay loop 80.3 m
  - CR1: 160.6 m
  - CR2: 481.8 m
- Decelerator, 24 sectors of 868 m
- Booster linac, 9 GeV, 2 GHz
- Drive beam generation complex
- Main beam generation complex
Tentative long-term CLIC scenario
Shortest, Success Oriented, Technically Limited Schedule

Technology evaluation and Physics assessment based on LHC results for a possible decision on Linear Collider funding with staged construction starting with the lowest energy required by Physics

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<td>Construction detector</td>
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</table>

CDR | TDR | Project approval | First Beam
CLIC e-Beam Time Structure

50 Hz Repetition Rate

207 ns, 311 micro-bunches

~ 100 ps

667 ps, 1497 MHz
# CLIC e-Beam Source Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Electrons per microbunch</td>
<td>$N_e$</td>
<td>$6 \times 10^9$</td>
</tr>
<tr>
<td>Number of microbunches</td>
<td>$n_b$</td>
<td>312</td>
</tr>
<tr>
<td>Width of microbunch</td>
<td>$t_b$</td>
<td>$\sim 100$ ps</td>
</tr>
<tr>
<td>Time between microbunches</td>
<td>$\Delta t_b$</td>
<td>0.5002 ns</td>
</tr>
<tr>
<td>Microbunch rep rate</td>
<td>$f_b$</td>
<td>1999 MHz</td>
</tr>
<tr>
<td>Width of macropulse</td>
<td>$T_B$</td>
<td>156 ns</td>
</tr>
<tr>
<td>Macropulse repetition rate</td>
<td>$F_B$</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Charge per micropulse</td>
<td>$C_b$</td>
<td>0.96 nC</td>
</tr>
<tr>
<td>Charge per macropulse</td>
<td>$C_B$</td>
<td>300 nC</td>
</tr>
<tr>
<td>Average current from gun ($C_B \times F_B$)</td>
<td>$I_{ave}$</td>
<td>15 uA</td>
</tr>
<tr>
<td>Average current in macropulse ($C_B / T_B$)</td>
<td>$I_B$</td>
<td>1.9 A</td>
</tr>
<tr>
<td>Duty Factor w/in macropulse (100ps/667ps)</td>
<td>DF</td>
<td>0.2</td>
</tr>
<tr>
<td>Peak current of micropulse ($I_B / DF$)</td>
<td>$I_{peak}$</td>
<td>9.6 A</td>
</tr>
</tbody>
</table>
## Source Parameter Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CEBAF</th>
<th>JLab/FEL</th>
<th>JLab 100mA FEL</th>
<th>SLC</th>
<th>CLIC</th>
<th>ILC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number electrons/microbunch</td>
<td>8.3 x 10⁵</td>
<td>8.3 x 10⁸</td>
<td>8.3 x 10⁸</td>
<td>1 x 10¹¹</td>
<td>6 x 10⁹</td>
<td>3 x 10¹⁰</td>
</tr>
<tr>
<td>Number of microbunches</td>
<td>CW</td>
<td>CW</td>
<td>CW</td>
<td>2</td>
<td>312</td>
<td>3000</td>
</tr>
<tr>
<td>Width of microbunch</td>
<td>35 ps</td>
<td>35 ps</td>
<td>35 ps</td>
<td>2 ns</td>
<td>~ 100 ps</td>
<td>~ 1 ns</td>
</tr>
<tr>
<td>Time between microbunches</td>
<td>0.667 ns</td>
<td>13 ns</td>
<td>1.3 ns</td>
<td>61.6 ns</td>
<td>0.5002 ns</td>
<td>337 ns</td>
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<tr>
<td>Microbunch rep rate</td>
<td>1497 MHz</td>
<td>75 MHz</td>
<td>750 MHz</td>
<td>16 MHz</td>
<td>1999 MHz</td>
<td>3 MHz</td>
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<tr>
<td>Width of macropulse</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>64 ns</td>
<td>156 ns</td>
<td>1 ms</td>
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<tr>
<td>Macropulse repetition rate</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>120 Hz</td>
<td>50 Hz</td>
<td>5 Hz</td>
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<tr>
<td>Charge per micropulse</td>
<td>0.13 pC</td>
<td>0.133 nC</td>
<td>0.133 nC</td>
<td>16 nC</td>
<td>0.96 nC</td>
<td>4.8 nC</td>
</tr>
<tr>
<td>Charge per macropulse</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>32 nC</td>
<td>300 nC</td>
<td>14420 nC</td>
</tr>
<tr>
<td>Average current from gun</td>
<td>200μA</td>
<td>10 mA</td>
<td>100 mA</td>
<td>2 uA</td>
<td>15 uA</td>
<td>72 uA</td>
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<td>Average current in macropulse</td>
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<td>-</td>
<td>0.064 A</td>
<td>1.9 A</td>
<td>0.0144 A</td>
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<tr>
<td>Duty Factor: beam ON/beam OFF (during macropulse for pulsed machines)</td>
<td>5x10⁻²</td>
<td>2.6x10⁻³</td>
<td>2.6x10⁻²</td>
<td>2.8x10⁻⁷</td>
<td>0.2</td>
<td>3x10⁻³</td>
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<td>Peak current of micropulse</td>
<td>3.8 mA</td>
<td>3.8 A</td>
<td>3.8 A</td>
<td>8 A</td>
<td>9.6 A</td>
<td>4.8 A</td>
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<tr>
<td>Current density (for spot size below)</td>
<td>1.9 A/cm²</td>
<td>19 A/cm²</td>
<td>19 A/cm²</td>
<td>10 A/cm²</td>
<td>12.1 A/cm²</td>
<td>6 A/cm²</td>
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<tr>
<td>Laser Spot Size</td>
<td>0.05 cm</td>
<td>0.5 cm</td>
<td>0.5 cm</td>
<td>1 cm</td>
<td>1 cm</td>
<td>1 cm</td>
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</table>

- **Existing facilities**
- **Proposed facilities**

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**Bulk GaAs**
ILC Polarized e-Source Considerations

Shared Challenges (compared to CEBAF experience)
• Photocathode material – polarization > 80%
• High QE, Ultrahigh vacuum requirement
• Machine-friendly gun design to minimize downtime: reliable load lock
• High voltage and high field gradient: no high voltage breakdown, no field emission + a desire to extend operating voltage beyond 100kV.
• Cathode/anode design: manage ALL of the extracted beam

Unique Challenges (compared to CEBAF experience)
• High bunch charge and high peak current: space charge and surface charge limit
• Injector design with sub-harmonic bunching
• Drive laser, high energy pulses
Recent Developments at CEBAF

- CEBAF load-locked gun
  - Improved vacuum and accelerator-friendly ops
- Commercial strained-superlattice photocathode
  - Consistent 85% polarization, ~ 1% QE
  - Demonstration of sustained 1mA operation
- High Voltage R&D (just beginning: K. Surles-Law)
  - Reduce field emission
  - Push value of “routine” operation beyond 100kV
  - Reduce complexity and cost of HV insulator
- Cathode/Anode Design (just beginning: A. Jayaprakash)
  - Optimize geometry to support loss-free beam delivery across entire photocathode surface
CEBAF 100kV polarized electron source

- Two-Gun Photoinjector - One gun providing beam, one “hot” spare
- vent/bake guns – 4 days to replace photocathode (can’t run beam from one gun while other is baking)
- Activate photocathode inside gun – no HV breakdown after 7 full activations (re-bake gun after 7th full activation)
- 13 mm photocathode, but use only center portion, 5 mm dia.
- Extract ~ 2000 Coulombs per year
- Beam current ~ 100uA, laser 0.5mm dia., lifetime: ~ 100C, 1x10^5 C/cm^2
Preparing for Demanding New Experiments

Vent/Bake Guns: need improvement

- Difficult to meet demands of approved high current/high polarization experiments like PRex (100uA) and Qweak (180uA and 1-year duration).
- Our vent/bake guns can provide only ~ 1 week operation at 180uA
- 12 hours to heat/reactivate, four days downtime to replace photocathode

Design Goal for New Gun: One Month Uninterrupted Operation at 250uA, One Shift to Replace Photocathode
New CEBAF load-locked gun

Preparation/activation chamber

Loading chamber

“suitcase”

HV chamber

Vent/bake gun
Key Features:
• Smaller surface area
• Electropolished and vacuum fired to limit outgassing
• NEG-coated
• Never vented
• Multiple pucks (8 hours to heat/activate new sample)
• Suitcase for installing new photocathodes (one day to replace all pucks)
• Mask to limit active area, no more anodizing

All new guns based on this basic design
LL Gun and Test Beamline

10 mA, 47C
7.5 mA, 54C
5 mA, 95C

Y-scale: multiple variables

Time (hours)
1mA at High Polarization*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Laser Rep Rate</td>
<td>499 MHz</td>
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<tr>
<td>Laser Pulselength</td>
<td>30 ps</td>
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<td>Wavelength</td>
<td>780 nm</td>
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<td>Laser Spot Size</td>
<td>450 mm</td>
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<tr>
<td>Current</td>
<td>1 mA</td>
</tr>
<tr>
<td>Duration</td>
<td>8.25 hr</td>
</tr>
<tr>
<td>Charge</td>
<td>30.3 C</td>
</tr>
<tr>
<td>Lifetime</td>
<td>210 C</td>
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<tr>
<td>Charge Lifetime</td>
<td>160 kC/cm²</td>
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</tbody>
</table>

* Note: did not actually measure polarization

Note High Initial QE

“Lifetime Measurements of High Polarization Strained Superlattice Gallium Arsenide at Beam Current > 1 mA Using a New 100 kV Load Lock Photogun”, J. Grames et al., Particle Accelerator Conference, Albuquerque, NM, June 25-29, 2007
New LL Gun at CEBAF, Summer 2007

So far, lifetime no better than vent/bake gun. Why?
Possible reasons for short lifetime

• Need to “season” the gun
• We have a leak (gun and/or beamline)
• Beamline vacuum not as good at CEBAF (activate dif-pump NEGs and/or re-bake)
• Field emission from cathode electrode (hi-pot gun to 125kV)
• Gun ion pump exhibits field emission: need to hi-pot
• Wrong magnet (solenoid) settings: beamloss at the bend chamber, Wien filter, etc
• Activate the gun NEG pumps again….
Increase Gun Voltage: Why?

Historically, Labs have had difficulty operating DC high voltage guns above field gradient ~ 5 MV/m and bias voltage ~ 100kV (at least polarized guns).
That said, it would be beneficial to build an ILC gun with higher field gradient and bias voltage to...

- Address current density limitation due to Child’s Law
- Reduce space-charge-induced emittance growth, maintain smaller transverse beam profile and short bunchlength
- Reduce problems associated with surface charge limit (i.e., QE reduction at high laser power)
- Prolong Operating Lifetime?
Space Charge Limit

Peak current at ILC photocathode ~ 6 A
Assume laser spot size 1cm
Current density $j = 7.6 \text{ A/cm}^2$

Space Charge Limit (Child’s Law)

$$j_0 = \left(2.33 \times 10^{-6}\right)V_0^{3/2} / d^2$$

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<tr>
<th>$V$ (kV)</th>
<th>$j_0$ (A/cm$^2$)</th>
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<td>140</td>
<td>14</td>
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<tr>
<td>200</td>
<td>23</td>
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<tr>
<td>350</td>
<td>53</td>
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</table>

for 3 cm cathode/anode gap

At lower gun voltages, large laser spot is required. Must also consider charge limit at anode...

Slide info courtesy Jym Clendenin, SLAC
Surface Charge Limit

QE reduction at high laser power

Heavily doped surface: viable solution?

5.5 A/cm² measured @ SLAC for 780 nm, 75 ns pulse
9.7 A/cm² @ Nagoya for 780 nm, 30 ps

ILC current density comparable to these values…something to worry about

Slide info courtesy Takashi Maruyama, SLAC
Improve Lifetime with Higher Bias Voltage?

Hypothesis: Double the gun voltage, halve the # of “bad” ions, improve lifetime by 2
Must Eliminate Field Emission

Investigate the SRF-cavity technique “high pressure rinsing”

Recent tests at JLab with shaped electrodes

Work of M. Chetsova, K. Surles-Law

FE from Handpolished 304 SS Cathode Electrode with ~6 mm gap

- Hand Polished
- Hand Polished HPR
- Electropolished HPR

Ken preparing new electrodes, including single crystal Niobium…
Cathode/Anode Design

• We learned at CEBAF that it is extremely important to manage ALL of the extracted beam
  – Anodized edge: beam from outside 5 mm active area can hit beampipe walls, degrade vacuum, reduce operating lifetime

• ILC requires large laser beam to reduce current density and overcome space and surface charge limit

• Suggest detailed modeling of cathode/anode optic and first few meters of beamline
  – Perhaps using multivariate optimization?
Goals of Cathode/Anode Design

• Create cathode/anode optic with small aberration across large photocathode active area, with very little beam loss. What to optimize?
  – Size of cathode electrode diameter, size of photocathode active area
  – Size of laser beam: lowest possible current density but with adequate emittance
  – Cathode/anode shape for adequate focusing
  – Cathode voltage/gradient: higher voltage to reduce space charge and provide possibility of extracting higher peak current with more narrow laser pulsewidth, to reduce SHB requirements
Inverted Gun Geometry

- Medical x-ray technology
- Ceramic not exposed to FE
- Compact

Present design

New design?
Conclusions: ILC Deliverables

- R&D program to push gun voltage > 120kV to reduce ill effects related to space and surface charge limitations. Empirically determine the reasonable maximum bias voltage for trouble-free operation. Develop an inverted ceramic insulator design.

- Model gun (particularly cathode/anode optic) for 100% transmission of beam. No loss. Set laser beam diameter and pulsewidth to overcome problems associated with space and surface charge limit.

- Engineering design. Incorporate features from bullets above, plus state-of-the art vacuum (small volume, low outgassing rate, NEG pumps and coating), plus reliable load-lock design for quick photocathode replacement (modification of CEBAF load lock design)

- Build and Commission gun
Conclusions: CLIC Deliverables

- Same as ILC Deliverables except we won’t build a CLIC gun: paper-study only.
- CLIC gun = ILC gun?
- At the moment, CLIC photoinjector very vague…
- Clearly, ILC gun modeling comes first…
- Then apply the same modeling tools using CLIC beam parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CLIC</th>
<th>ILC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number electrons/microbunch</td>
<td>$6 \times 10^9$</td>
<td>$3 \times 10^{10}$</td>
</tr>
<tr>
<td>Number of microbunches</td>
<td>312</td>
<td>3000</td>
</tr>
<tr>
<td>Width of microbunch</td>
<td>$\sim 100$ ps</td>
<td>$\sim 1$ ns</td>
</tr>
<tr>
<td>Time between microbunches</td>
<td>0.5002 ns</td>
<td>337 ns</td>
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<tr>
<td>Microbunch rep rate</td>
<td>1999 MHz</td>
<td>3 MHz</td>
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<tr>
<td>Width of macropulse</td>
<td>156 ns</td>
<td>1 ms</td>
</tr>
<tr>
<td>Macropulse repetition rate</td>
<td>50 Hz</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Charge per micropulse</td>
<td>0.96 nC</td>
<td>4.8 nC</td>
</tr>
<tr>
<td>Charge per macropulse</td>
<td>300 nC</td>
<td>14420 nC</td>
</tr>
<tr>
<td>Average current from gun</td>
<td>15 uA</td>
<td>72 uA</td>
</tr>
<tr>
<td>Average current in macropulse</td>
<td>1.9 A</td>
<td>0.0144 A</td>
</tr>
<tr>
<td>Duty Factor: beam ON/beam OFF (during macropulse for pulsed machines)</td>
<td>0.2</td>
<td>$3 \times 10^{-3}$</td>
</tr>
<tr>
<td>Peak current of micropulse</td>
<td>9.6 A</td>
<td>4.8 A</td>
</tr>
<tr>
<td>Current density (for spot size below)</td>
<td>12.1 A/cm²</td>
<td>6 A/cm²</td>
</tr>
<tr>
<td>Laser Spot Size</td>
<td>1 cm</td>
<td>1 cm</td>
</tr>
</tbody>
</table>
Warm RF Gun for ILC? for CEBAF?

- PWT gun: open geometry for adequate UHV
- Low Q, but 1 MeV energy possible
- Pulsed-RF so cooling not so problematic
- Something similar for CEBAF? Need 200 to 500kV beam
- Use CEBAF load lock
- Be the first to demonstrate GaAs QE and lifetime in RF gun
- “Cheap” way to get into RF gun business.

SBIR proposal from David Yu, Duly Research and Fermi Lab, for ILC gun
What limits photogun lifetime?

Imperfect vacuum and Ion Backbombardment

Laser IN

anode

cathode

photocathode

e beam OUT

Note, other factors can limit lifetime: Field emission, photocathode material, laser wavelength, laser radial position at photocathode, beam optics, gun voltage, gap size,….. (i.e., many ways to get a bad result)
Improving Gun Vacuum

Ultimate Pressure = Outgassing Rate x Surface Area

Pump Speed

How to explain this discrepancy?
- Outgassing rate higher than assumed "standard" value; $1 \times 10^{-12} \text{Torr} \cdot \text{L/s} \cdot \text{cm}^2$?
- NEG pump speed smaller than SAES says?

Measured pressure always much greater than predicted
<table>
<thead>
<tr>
<th>Chamber</th>
<th>t(h)</th>
<th>T(°C)</th>
<th>EP</th>
<th>Surface roughness</th>
<th>t(h)</th>
<th>T(°C)</th>
<th>Outgassing Rate (Torr·L/s·cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old 304</td>
<td></td>
<td></td>
<td>no</td>
<td>3.7 μm</td>
<td>400</td>
<td>250</td>
<td>9.7x10⁻¹³</td>
</tr>
<tr>
<td>New 304</td>
<td></td>
<td></td>
<td>no</td>
<td>3.7 μm</td>
<td>180</td>
<td>250</td>
<td>1.9x10⁻¹²</td>
</tr>
<tr>
<td>EP 304</td>
<td>4</td>
<td>900</td>
<td>yes</td>
<td>2.1 μm</td>
<td>30 then 90</td>
<td>150 250</td>
<td>8.9x10⁻¹³</td>
</tr>
</tbody>
</table>

**Benefit of EP and Vacuum Firing**

- Electropolishing and vacuum firing provides low rate with fewer bakes
- Extremely low values (e.g., $10^{-14}$ to $10^{-15}$) reported in literature elude us
- Conclusion: We have the “industry-standard” outgassing rate $\sim 1 \times 10^{-12}$ Torr·L/s·cm²
Recent High Temperature Bake of JLab FEL Gun

316 LN Stainless Steel, Baked at 400°C for 10 days
Vacuum inside, hot air outside, Strip heaters instead of hot air guns
Outgassing rate: $1.49 \times 10^{-13}$ Torr L/s cm²

FEL Gun Outgassing Measurement

slope = 2.59E-11 Torr/sec
Volume: 92.65 liters
Surface: 16100 cm²
Outgassing rate 1.49e-13 TorrL/sec/cm²

Lessons for CEBAF/ILC?
• We should have vacuum fired our end flanges
• Welding introduces hydrogen
• 250°C for 30 hours not adequate
• Full NEG activation better than passive activation via bake
• NEG pump speed very good, at least at high pressure
• Conclusion: Can’t explain reduced pump speed at low pressure – a real effect? More likely an indication of gauge limitations
NEG Coating

NEG coating turns a gas source into pump
\(~0.02\,\text{L/s}\cdot\text{cm}^2\) : Modest pump speed can be improved

SAES claims > 5 L/s\cdot\text{cm}^2
for a chamber with 4000 cm\(^2\), that would be a big pump!
Compare NEW and OLD load locked guns

Vacuum gauges indicated same pressure in both guns, suggesting our gauges don’t work below $1.5 \times 10^{-11}$ Torr

"Further Measurements of Photocathode Operational Lifetime at Beam Current $> 1$mA using an Improved 100 kV DC High Voltage GaAs Photogun," J. Grames, et al., Proceedings Polarized Electron Source Workshop, SPIN06, Tokyo, Japan
Future R&D Toward Improved Vacuum

• Ion pump studies (do ion pumps limit our vacuum?)
• 400C heat treatment: does outgassing remain low following venting?
• A better vacuum gauge? SBIR with ElVac
• Do NEGs really quit pumping at low pressure?
• If so, we need different pumps: Ti-sublimators, cryo-pumps…
Photocathode Material

**Bulk GaAs**
- High QE ~ 20%
- Pol ~ 35%

**Strained GaAs: GaAs on GaAsP**
- 100 nm
- “conventional” material
- QE ~ 0.15%
- Pol ~ 75%
  @ 850 nm

**Superlattice GaAs: Layers of GaAs on GaAsP**
- 100 nm
- No strain relaxation
- QE ~ 1%
- Pol ~ 85%
  @ 780 nm

**Commercial Products**
Significant FOM Improvement

HAPPEX-II 2004 run Compton Polarimetry

\[ \frac{P_{\text{sup.}}^2 I}{P_{\text{str.}}^2 I} = 1.38 \]

But we could not operate with long lifetime....
Commercial Superlattice Photocathodes

- Success required ~ 1 year of effort
- Cannot be hydrogen cleaned
- Arsenic capped (worked with vendor SVT)
- No solvents during preparation!

M. Baylac et al., “Effects of atomic hydrogen and deuterium exposure on high polarization GaAs photocathodes” PRST-AB 8, 123501 (2005)

Anodized edge: a critical step. Eliminates electrons that hit beampipe walls
Fiber-Based Drive Laser

Gain-switched seed

ErYb-doped fiber amplifier

Frequency-doubler

1560nm

780nm
Fiber-Based Drive Laser

- ~ 30 ps autocorrelator trace
- CEBAF’s last laser!
- Gain-switching better than modelocking; no phase lock problems, no feedback
- Very high power
- Telecom industry spurs growth, ensures availability
- Useful because of superlattice photocathode (requires 780nm)
Improve Lifetime with Larger Laser Spot?

(Best Solution – Improve Vacuum, but not easy)

Bigger laser spot, same # electrons, same # ions

Ionized residual gas strikes photocathode

Ion damage distributed over larger area
Lifetime with Large/Small Laser Spots

Tough to measure large Coulomb lifetimes with only 100-200 C runs!

Factor of 5 to 10 improvement with larger laser spot size

Expectation: $\left(\frac{1500}{350}\right)^2 \approx 18$

"Further Measurements of Photocathode Operational Lifetime at Beam Current > 1mA using an Improved 100 kV DC High Voltage GaAs Photogun," J. Grames, et al., Proceedings Polarized Electron Source Workshop, SPIN06, Tokyo, Japan