USPAS Course on Photocathode Physics

John Smedley, BNL and Matt Poelker, TJNAF

Lecture 4
Lecture 4:
• DC versus RF guns
• Examples of RF guns
• Examples of DC guns
• Today’s state of the art and challenges
DC versus RF Gun

It’s mostly about bunch charge and duty factor...

• High Bunch Charge Applications (nano-Coulomb, nC)....
  
  RF Gun

• Continuous Wave (CW) Applications, i.e., if you want to accelerate electrons every RF cycle....
  
  DC Gun
DC versus RF Gun

It’s mostly about bunch charge and duty factor...

• RF guns accelerate electrons to high energy (MeV) over very short distance (few cm). This is very appealing for at least two reasons:
  ➢ MeV beams are “stiff”, providing immunity to space charge forces, highly desirable for high bunch charge applications
  ➢ RF guns make for relatively simple injectors: short pulses right out of the gun, no bunching cavities (?), no booster cavities, a very compact injector
• Great, so everyone should use an RF gun.....
DC versus RF Gun

It’s mostly about bunch charge and duty factor...

- Vacuum inside a warm (i.e., normal conducting) RF gun is not very good
  - So forget about using GaAs
- And warm RF guns get very hot when operating CW. Lots and lots of cooling required, presenting a complicated mechanical design. Most warm RF guns are pulsed, low duty factor devices
- SRF guns should provide excellent vacuum, maybe an opportunity for GaAs?
- Low frequency RF guns promise better vacuum....(?) but not explicitly CW....
- Note: Field emission can “kill” a photocathode in an instant (which is also true for DC gun)
Benchmarking PARMELA Simulation Results Against Beam-Based Measurements at CEBAF/Jefferson Lab – work of Ashwini Jayaprakash, JLab

Measurements at CEBAF/JLab

Electron Bunchlength vs Gun Voltage

- Electron Bunchlength (ps) vs Ave. Gun Current (µA)
- Similar Trends

PARMELA Simulation Results

Bunchlength Vs Gun Voltage

- Electron Bunchlength (ps) vs Ave. Gun Current (µA)

Transmission vs Gun Voltage

- Transmission (%) vs Ave. Gun Current (µA)

Transmission Vs Gun Voltage

- Transmission (%) vs Ave. Gun Current (µA)

Message: Beam quality, including transmission, improves at higher gun voltage
A simple injector

- DC thermionic gun followed by a buncher cavity which ballistically compresses electrons
- Thermal energy excites the electrons to overcome the cathode work function

Sketch courtesy of Dr. D. Dowell, SLAC.
Thermionic cathode inside RF cavity

• This is the most common type of electron source in third generation light sources like APS at Argonne and SSRL at SLAC.
• When a thermionic cathode is placed in a radio frequency cavity, the oscillating electric field extracts a long (ns), low charge pulse at the operating radio frequency, which later is usually compressed in an “alpha” magnet. Such devices are known as thermionic radio-frequency guns.
• Thermal energy excites the electrons to overcome the cathode work function
Thermionic Normal Conducting Radio Frequency electron gun

Radio Frequency input port

Electron beam exit
Photoinjector

- RF Klystron
- Drive Laser
- Master Oscillator
- Solenoid
- Bucking Coil
- Photocathode (Cs₂Te, CsK₂Sb, Cu etc.)

Electron bunches

Slide compliments of P. O’Shea, UMd
Normal Conducting RF Photoinjector

Highest peak gradient - $>150$ MV/m
Pulsed RF to minimize heating
  CW operation very challenging
Good vacuum is challenging,
  typically $>10^{-10}$ Torr
Good for high peak current, low average current applications
  High peak brightness X-ray FELs (LCLS, FLASH)
Chemical poisoning is the typical source of cathode degradation

D. H. Dowell *et al.*, FEL2007
LCLS Warm RF PhotoGun

Metal photocathodes, pulsed-RF

https://slacportal.slac.stanford.edu/sites/ard_public/bpd/acd/Pages/acmod.aspx
The LCLS RF photoinjector is the state-of-the-art technology with a Cu cathode. It generates electron beam with 0.7 μm emittance. The beam is comprised of 250pC bunches, each 2.5 ps rms, at a repetition rate of 120Hz. The cathode peak field is ~100 MV/m
GaAs inside warm RF gun

Photocathode survived just a few RF cycles. Killed by “dark current”, i.e., field emission from RF cavity and the photocathode itself.

Figure 1: The scheme of RF gun prototype. 1 - activation chamber, 2 - photocathode assembly, 3 - manipulator, 4 - accelerating cavity, 5 - waveguide, 6 - focusing lens, 7 - transverse corrector, 8 - working chamber, 9 - vacuum window for laser beam, 10 - ceramic insulator, 11 - the cavity for bunch length measurement.

A Prototype of RF Photogun with GaAs Photocathode for Injector of VEPP-5


Institute of Nuclear Physics, 630090 Novosibirsk, Russia.

L.Tecchio.

Dipartimento di Fisica Sperimentale dell’Università and INFN, Torino, Italy.
CW Normal Conducting RF Guns

Key Issues:
- Managing the heat load
- Managing the vacuum
- Managing the field emission

Figure 7: Low frequency, normal-conducting CW gun developed at LBNL [12, 13].
The Boeing Gun: Still the Demonstrated State-of-the Art

Cathode Parameters
$K_2CsSb$
5%-12% QE @ 527nm
Peak Current 45-132A
Average Current 35 mA
(140 mA @ 25% DC)
Lifetime 1-10 hrs

Gun Parameters
433 MHz
26 MV/m peak field
0.6 MW RF Power

Material Courtesy David Dowell and John Adamski

Photoinjector

SUPERFISH simulation

SW, TM

f = 1298.07726 MHz

Q₀ = 7.07 x 10⁹

P_d = 5.1 W

B_max/E_max = 2.2 mT/(MV/m)

E_max/E_cathode = 1.048

October 18, 2005
Planned SRF Injector

BNL/AES 703 MHz ½ cell

High Q         High I
e-cooler

f [MHz]    703.75
q/bunch [nC] 5     0.7
$\varepsilon_n$ [$\mu$m rad ] <10     2
E [MeV] 2.5
$P_b$ [MW] 0.1     1
$I_b$ [A] 0.05     0.5
$f_{rep}$ [MHz] 9.4  352
Cathode CsK$_2$Sb w/ Diamond Amplifier
QE [%] 1 (532nm) x100
5 (355 nm)

Cathode options
K$_2$CsSb (traditional & dispenser)
Diamond Amplified Cathode

R. Calaga, PhD Thesis
V. Litvinenko, et al, PAC07, 1347
Superconducting RF Photoinjector

New technology
Peak gradient >60 MV/m
CW RF operation
Cathode is challenging
  Superconductor
  RF choke filter
Cathode may pose risk to cavity due to Cs migration
Good vacuum due to cryo-pumping, typically ~10^{-11} Torr
Good for high peak current, high average current
  Future high peak brightness, high flux X-ray FELs
Electron cooler for RHIC

A. Michalke et al., EPAC92, 101
# Planned Choke Injectors

Rossendorf 1.3GHz 3.5 cell

<table>
<thead>
<tr>
<th></th>
<th>ELBE mode</th>
<th>High charge mode</th>
<th>BESSY-FEL</th>
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</thead>
<tbody>
<tr>
<td>SRF frequency [GHz]</td>
<td></td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>E [MeV]</td>
<td></td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>Operation mode</td>
<td></td>
<td>CW</td>
<td></td>
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<tr>
<td>Driving laser λ [nm]</td>
<td></td>
<td>262</td>
<td></td>
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<tr>
<td>Photocathode</td>
<td></td>
<td>Cs$_2$Te</td>
<td></td>
</tr>
<tr>
<td>QE [%]</td>
<td></td>
<td>&gt; 1</td>
<td>&gt; 2.5</td>
</tr>
<tr>
<td>$I_o$ [mA]</td>
<td>1</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Pulse duration [ps]</td>
<td>5</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>f repetition [kHz]</td>
<td>13 000</td>
<td>500</td>
<td>1</td>
</tr>
<tr>
<td>q/bunch [nC]</td>
<td>0.077</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>ε [µmrad]</td>
<td>1</td>
<td>2.5</td>
<td>3</td>
</tr>
</tbody>
</table>
Polarized Electron Source “Musts”

**Good Photocathode**
- High Polarization
- Many electrons/photon
- Fast response time
- Long lifetime

**Good Laser**
- “Headroom”
- Suitable pulse structure
- Low jitter

**Good Electron Gun**
- Ultrahigh vacuum
- No field emission
- Maintenance-free
Define “Good Gun”

Good Electron Gun
- Ultrahigh vacuum
- No field emission
- Maintenance-free

1) Ultra high vacuum
   - Static and Dynamic vacuum
   - Ion-bombardment limits operation
2) Happy at high voltage
   - Field emission from cathode electrode
3) Maintenance Free
   - Vent and Bake
   - Load locked
4) Long lifetime
   - dark lifetime
   - and while you run beam
Inverted Gun #2 at Test Cave
- Large grain niobium electrode
- Problematic field emission at 140kV
- Repeated BCP treatment, no measurable field emission at 225kV
- Have since demonstrated many months of beam delivery at 200kV
- Our spare gun......

Inverted Gun #1 at CEBAF
- Operational since July, 2009
- Stainless steel electrode
- Operated at 100kV for HAPPEx, PVDIS and PReX (70C @ 150uA)
- Operated at 130kV for Qweak (70C @ 300 uA), improved transmission
- Expected better lifetime....puzzling

Paid for by ILC
Illuminate GaAs with circularly polarized light near band gap.
First High Voltage GaAs Photogun

Polarized $e^{-}$ Gun for SLAC Parity Violation Experiment

Beam polarization, 35% to 45%
Beam current, 1 mA cw to 15 A peak
CEBAF’s First Polarized e-Source

First photogun similar to SLAC photogun from 1977.... just one small ion pump and NEG pump
CEBAF’s First Photoinjector

Very complicated spin manipulator
CEBAF’s Second Polarized e-Source

Now with 4000L/s NEG pumping
CEBAF’s Second Photoinjector

and a Wien-Spin Manipulator
CEBAF’s Third Photoinjector

Wien Filter Spin Manipulator

Laser Table

RF Chopper Sets Bunchlength

Emittance Filter

Spatial acceptance

- Vent/bake photoguns in horizontal plane
- No more short focal length electron optical elements
- Can deliver 100uA avg. current for about 1 week before “doing something”
CEBAF’s Third Photoinjector

- Two-Gun Photoinjector - One gun provides beam, the other is a “hot” spare
- vent/bake guns – good vacuum, long lifetime, but...
  - Cesium gets deposited on cathode electrode and eventually field emission kills photocathode
- 4 days to replace photocathode (can’t run beam from one gun while other is baking)
- Anticipated difficulties for Qweak (180uA and 1-year duration)
....now with “load-locked” e-gun

- Best vacuum inside HV chamber, which is never vented
- Photocathode activation takes place inside Preparation Chamber
- Use “Suitcase” to replace photocathodes
Vent/Bake versus Load Lock

Pros:
- Relatively simple and inexpensive
- Cesium gets applied to electrode
- Takes about four days to replace the photocathode, i.e. to “bake” the gun

Cons:
- Movable photocathode adds complication
- More expensive

Pros:
- Quick photocathode replacement
- No cesium in high voltage chamber

In my opinion...vent/bake is the right choice when getting started in polarized electron business
So after third or fourth photocathode activation, things get ugly....
CEBAF’s Inverted Photogun

Medical x-ray technology

New Ceramic
- Compact
- \$5k
- Less metal at HV
- No SF6 of N2
Key Features:
- 5 pucks can be stored in Storage Manipulators
- 8 hours to heat and activate new sample
- Mask to limit active area
- Suitcase for installing new photocathodes (one day to replace all pucks)
Prep Chamber Gets Complicated

I. Activate with different Masks: 5 mm, 7 mm, and No Mask (12.8 mm)

II. Measure Lifetime from different spots on Bulk GaAs with 532 nm green laser
# DC High Voltage GaAs Photoguns

<table>
<thead>
<tr>
<th>Facility</th>
<th>Beam Structure</th>
<th>HV [kV]</th>
<th>Avg. Current</th>
<th>Bunch Charge</th>
<th>Polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonn – ELSA</td>
<td>1us @ 50 Hz</td>
<td>50</td>
<td>5 μA</td>
<td>100 nC (1 μs)</td>
<td>+</td>
</tr>
<tr>
<td>CEBAF</td>
<td>cw: 1497 MHz</td>
<td>100</td>
<td>200 μA</td>
<td>0.13 pC</td>
<td>+</td>
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<tr>
<td>Mainz Microtron</td>
<td>cw: 2450 MHz</td>
<td>100</td>
<td>50 μA</td>
<td>0.02 pC</td>
<td>+</td>
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<tr>
<td>Nagoya/Hiroshima</td>
<td></td>
<td>200</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Darmstadt</td>
<td></td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIT Bates</td>
<td>25us @ 600 Hz</td>
<td>60</td>
<td>120 μA</td>
<td>250 nC (25 μs)</td>
<td>+ (bulk)</td>
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<tr>
<td>NIKHEV</td>
<td>2μs pulses @ 1 Hz</td>
<td>100</td>
<td>0.04 μA</td>
<td></td>
<td></td>
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<tr>
<td>SLAC–fixed Target</td>
<td>0.3μs pulses @ 120 Hz</td>
<td>120</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>SLAC – SLC</td>
<td>2ns pulses @ 120 Hz</td>
<td>120</td>
<td>2 μA</td>
<td>16 nC (2ns)</td>
<td>+</td>
</tr>
<tr>
<td>JLAB FEL</td>
<td>cw: 75 MHz</td>
<td>350</td>
<td>10 mA</td>
<td>135 pC</td>
<td>-</td>
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<tr>
<td>Daresbury ERLP</td>
<td>cw: 75 MHz</td>
<td>350</td>
<td></td>
<td></td>
<td>-</td>
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<tr>
<td>Cornell</td>
<td>cw: 1300 MHz</td>
<td>750</td>
<td>100 mA</td>
<td>77 pC</td>
<td>-</td>
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<tr>
<td>JAEA</td>
<td></td>
<td>250</td>
<td>50 mA</td>
<td></td>
<td></td>
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<tr>
<td>JLab 100kW FEL</td>
<td>cw: 750 MHz</td>
<td>500</td>
<td>100 mA</td>
<td>135 pC</td>
<td>-</td>
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<tr>
<td>ILC</td>
<td>1ms w/ 1ns pulses @ 5Hz</td>
<td>140 - 200</td>
<td>~100 μA</td>
<td>5 nC (1ns)</td>
<td>+</td>
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<tr>
<td>CLIC</td>
<td>207ns w/ 100ps pulses @ 50Hz</td>
<td>140 - 200</td>
<td>15 μA</td>
<td>0.6 nC (100ps)</td>
<td>+</td>
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<tr>
<td>EIC – ELIC</td>
<td></td>
<td>100</td>
<td>100 μA</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>EIC - eRHIC</td>
<td>cw</td>
<td>&gt;100</td>
<td>25 mA</td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>

- Historical or diminished scope
- Under construction
- Proposed
- Operating
Stanford Linear Accelerator PES


- First load-locked gun used at an accelerator (?)
- High bunch charge, low avg. current, very long operating lifetime
- Four days to replace photocathode, because load lock at HV...
SLAC Inverted Gun

Experimented with coating to bleed off charge

- Load lock at ground potential
- Cathode cooling via two of the tube insulators
- But still adding Cs to electrode

MIT Bates Polarized Electron Gun

- 60 kV gun provides > 5 C/day,
- Spare guns prolong operating lifetime,
- Gun swaps every few weeks.
Every lab prepares for Plan B, in this case, a spare photogun for when the production gun breaks.
NIKHEF Load-Locked Polarized Photogun

- Designed and built at Novosibirsk
- Double insulator design, load lock apparatus at ground potential
- Pulsed-high voltage

From Doctoral Thesis, Boris Leonidovich Militsyn
200keV Polarized e-source at Nagoya University
200keV gun basic performance

Base pressure: \(2 \times 10^{-9}\) Pa
- 200 baking for >100 hours
- 360 L/s IP, 850 L/s NEG

Maximum field gradient (200kV):
- 7.8MV/m (Cathode)
- 3.0MV/m (Photocathode)

Electrode
- Cathode: Molybdenum (>99.6%)
- Anode: Titanium (JIS-grad 2)
- Finishing: electro-buff polishing

Ceramic
- Dividing five segments w/ guard rings.
  (to avoid field concentration)
- 500MΩ connection for each
  <0.3MV/m for each segment at the junctions

M.Yamamoto, PESP2008 Oct.1-3, @JLAB
Bonn- ELSA Polarized Electron Gun

- 60kV “inverted” gun (insulator not exposed to field emission)
- Clever use of commercial inexpensive HV electrical feedthrough
- Load-lock apparatus at ground potential
100kV load locked gun
The 2\textsuperscript{nd} load locked gun used at an accelerator
Load lock apparatus at ground potential
Multiple photocathode samples in vacuum
Allows rapid photocathode swaps.
Mainz Microtron Source

Polarized electron source installation at the injector of MAMI
Replacing Photocathodes
Features; compact, inexpensive, 56 L/s turbo pump, baked at 150 C, pressure \( \sim 10^{-10} \) Torr.
Operating voltage ~ 320 kV. Field emission is the limiting factor to achieve desired voltage/field

Bulk GaAs, unpolarized beam, pumped with green light Nd:YLF laser at repetition rates to 75 MHz

Average CW operating current as high as 5 mA

Modification allows cesiation behind electrode

Note: Field strengths calculated for 500 kV
Jlab FEL DC photoemission gun

1 meter

2.54 cm

Anodized GaAs photocathode
DC Photoinjector

Typical cathode bias of -100kV to -500kV

Open structure, typically very good vacuum (<10^{-11} Torr)

  Allows use of chemically sensitive cathodes (Cs: GaAs)

Typical gradient of 5 MV/m, limits peak current density to ~10 A/cm²

Good for low peak current, high average current applications

  Energy recovery linac based free electron lasers (Jlab FEL)

Ion back-bombardment is the primary source of cathode degradation (lifetime measured in Coulombs extracted)

B. M. Dunham et al., PAC07
C. Hernandez-Garcia et al., PAC05
ALICE ERL Photocathode gun

- ALICE photocathode gun is successfully operated since 2008 with double ceramic insulator with reduced high voltage of 230 kV in different operation modes.

- During current shutdown the temporary insulator is going to be replaced with a newly brazed single ceramic unit after that the operation voltage of 350 kV is expected.

- Gun upgrade has been designed and delivered but its installation has been postponed.

<table>
<thead>
<tr>
<th>Gun operation mode</th>
<th>Gun voltage, kV</th>
<th>Micropulse charge, pC</th>
<th>Micropulse repetition rate, MHz</th>
<th>Train length, µs</th>
<th>Train repetition rate, HZ</th>
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</thead>
<tbody>
<tr>
<td>Single pulse ERL mode</td>
<td>230</td>
<td>Up to 200</td>
<td>81.25</td>
<td>Single micropulse</td>
<td>Up to 10</td>
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<tr>
<td>FEL Mode</td>
<td>230</td>
<td>60</td>
<td>16.25</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>THz mode</td>
<td>230</td>
<td>60</td>
<td>40.125</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>EMMA injection mode</td>
<td>230</td>
<td>40</td>
<td>81.25</td>
<td>Single micropulse</td>
<td>5</td>
</tr>
</tbody>
</table>

Courtesy B.L. Militsyn
Cornell 750 kV Gun

- Ceramic with bulk resistivity and improved braze design installed
- Measured resistivity of $6.45 \times 10^{10}$ Ohm-cm gives 30 µA current draw at 500 kV
- Ceramic by Morgan, brazing and welding by Kyocera

Similar initiatives at JLab FEL and Daresbury ERLP

Courtesy Bruce Dunham, Cornell
500 kV photocathode DC gun at JAEA

- High DC voltage >= 500kV
  - CockCroft Walton power supply
  - Segmented insulator with guard rings
- High voltage testing
- Electrodes and vacuum
  - Cathode and anode electrodes
- Low outgassing material (titanium)
- NEG pumps

Courtesy N. Nishimori, Japan Atomic Energy Agency
R251 (gun chamber)

R198 (NEG)

Courtesy N. Nishimori, Japan Atomic Energy Agency
Cathode electrode: POISSON calculation

- NEG: 64.5mm, 10.51 MV/m
- Cathode: R=67, 100mm, 6.75 MV/m, 10.32 MV/m
Status of 500kV DC gun at JAEA, N. Nishimori

HV testing of segmented ceramics with a stem electrode

- HV processing up to 550 kV
- 500 kV for eight hours without any discharge

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Courtesy N. Nishimori, Japan Atomic Energy Agency

R. Nagai et al., RSI 81 033304 (2010).
The CEBAF 200kV Inverted Gun

Higher voltage = better beam quality.
The inverted design might be the best way to reach voltages > 300kV
Old Gun Design

New “Inverted” Design

Present Ceramic
• Exposed to field emission
• Large area
• Expensive (~$50k)
• Lots of metal at HV

New Ceramic
• Compact
• ~$5k
• Less metal at HV
• No SF6 of N2

Medical x-ray technology

We had low level field emission

Move away from “conventional” insulator used on most GaAs photoguns today – expensive, months to build, prone to damage from field emission.

High gradient locations not related to beam optics, lots of metal to polish
350kV Inverted Gun

Minimum field gradient at cathode

spheres: \( \frac{r_2}{r_1} = 2 \)

cylinders: \( \frac{r_2}{r_1} = e \)
Our design has one region of “unintended” high gradient – could be problematic.....exploring new designs via electrostatic modeling.

Work of Ken Surles-Law
And maybe even higher gradient at the joint.....??

HV breakdown in capacitors with delamination gap

\[ E = \frac{V}{d} \]

\[ E_2 = \frac{V}{d_2 + d_1 \left( \frac{\varepsilon_2}{\varepsilon_1} \right)} \sim \frac{V \varepsilon_1}{d_1} \]
Plan A

Plan C

In hand, but untested

Plan B

Plan D

Insulator sleeve

Test this year

No Improvement
350kV Inverted Gun

Minimum field gradient at cathode

spheres: $\frac{r_2}{r_1} = 2$

cylinders: $\frac{r_2}{r_1} = e$
• Condition to 600kV, operate at 500kV
• 3x bigger inverted insulator compared to CEBAF gun
• One insulator for HV: one for cooling
• Niobium electrode – no diamond paste polishing
• Work in-progress

Courtesy: M. Marchlick, G. Biallis, C. Hernandez-Garcia, D. Bullard, P. Evtushenko, F. Hannon, and others from JLab-FEL
HV Issues: inside and outside the gun

600 kV supply at FEL gun test stand, with SF6 tank

Learn to apply high voltage without breakdown, dielectric plug inside insulator,
Then address the field emission problems inside the gun
Electrostatic Modeling
Electrostatic Modeling

~10MV/m, maybe bring dielectric further in (2cm)
Electrostatic Modeling

Same scale.
CEBAF top, FEL bottom. Note lower field at rod entrance.

Dielectric is curved, and the placement/shape of the HV connection is different. For FEL I tried to ‘shield’ triple points.

18MV/m
From clamp
~30MV/m
7MV/m
What the heck is this?
MIT-Bates eRHIC Polarized e-Source

50mA of polarized beam

Courtesy Evgeni Tsentalovich, MIT Bates
Cathode – anode assembly

Fluorinert (cooling agent)

Courtesy Evgeni Tsentalovich, MIT Bates
Cathode – anode assembly

Fluorinert (cooling agent)

Courtesy Evgeni Tsentalovich, MIT Bates
Cathode – anode assembly
Pack with a crystal

Courtesy Evgeni Tsentalovich, MIT Bates
Heat exchanger

Courtesy Evgeni Tsentalovich, MIT Bates
Preparation chamber

Courtesy Evgeni Tsentalovich, MIT Bates
General assembly – top view

Courtesy Evgeni Tsentalovich, MIT Bates
General assembly – top view

GUN
PREP. CHAMBER
LOAD LOCK
FIRST DIPOLE

Courtesy Evgeni Tsentalovich, MIT Bates
Courtesy Evgeni Tsentalovich, MIT Bates
BNL eRHIC “Gatling gun”

The lowest requirement for the “Gatling gun” is to verify that the cathode lifetime is not affected running at multiple (2) cathode mode.

Courtesy X. Chang, BNL
BNL “Gatling gun”

Green indicates Laser, Blue indicates electron beam paths

Courtesy X. Chang, BNL
Depressed Collector can reduce the HV power supply current, reduce radiation.

Courtesy X. Chang, BNL
BNL “Gatling gun”

Gatling Gun Chamber
Cathode Transport Line
Cathode Preparation Chamber

Courtesy X. Chang, BNL