The Jefferson Lab 200 kV Inverted Gun: Lifetime Measurements Using Strained Superlattice GaAs and K_2CsSb Photocathodes

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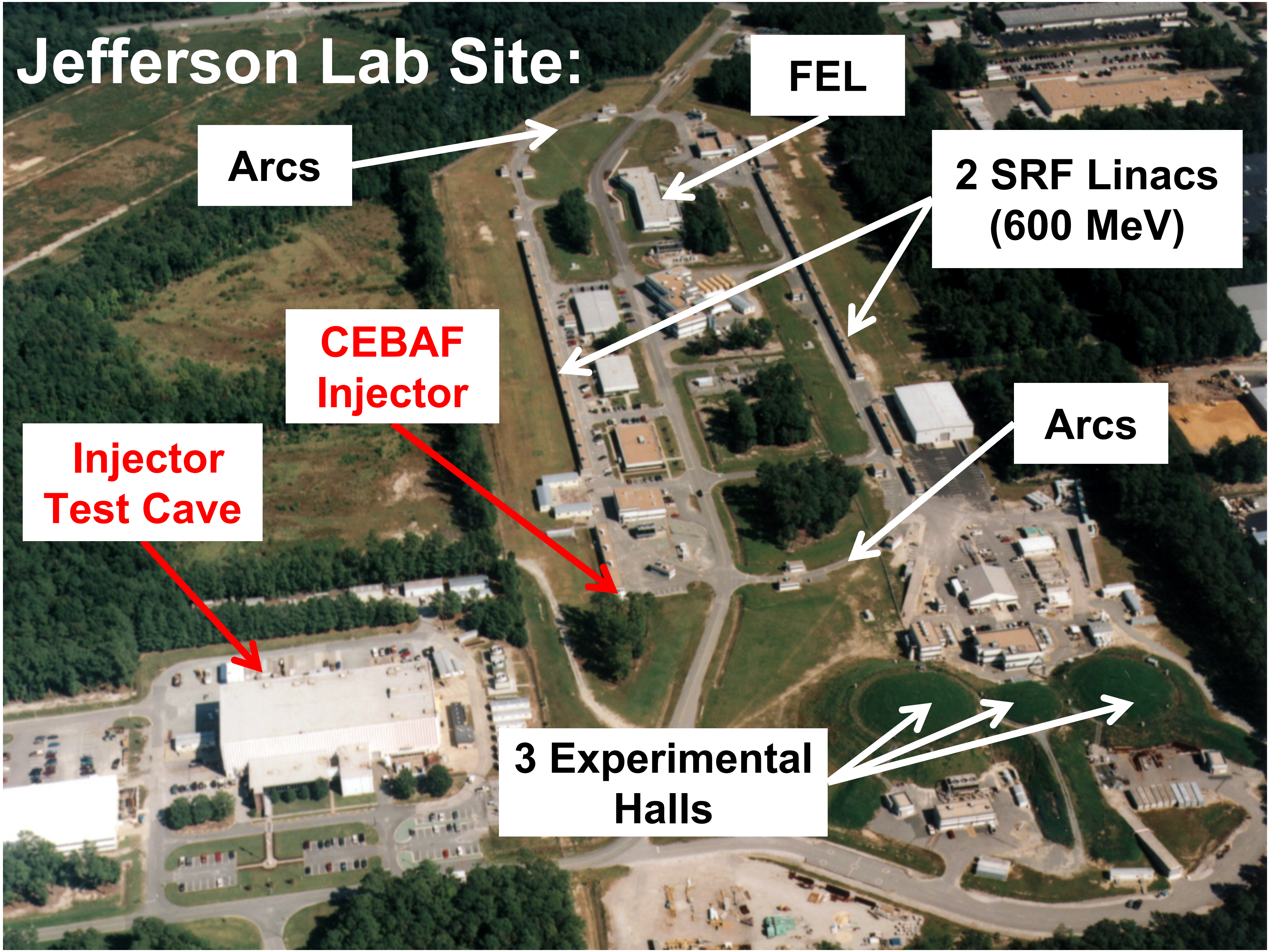
KEK, Japan, October 20, 2011


Jefferson Lab Site:
Arcs
FEL
2 SRF Linacs
(600 MeV)
CEBAF
Injector
Injector
Test Cave
Arcs
3 Experimental
Halls

Benefit of Higher Gun Bias Voltage

- ➢ Reduce space-charge-induced emittance growth, maintain small transverse beam profile and short bunch-length. In other words, make a “stiff” beam right from the gun - particularly important for high bunch charge beam

- ✓ CEBAF guns have always operated at 100 kV ($\beta = 0.55$)
- ✓ Achieved better transmission in CEBAF Injector at high beam current with 130 kV ($\beta = 0.60$)
- ✓ Later, we envision an improved CEBAF photo-injector with a 200 kV gun and SRF capture section ($\beta = 0.70$)
- ✓ Indentify what it takes to reach 350 kV bias voltage or higher (β= 0.8+). For ILC, CLIC, EIC, etc.

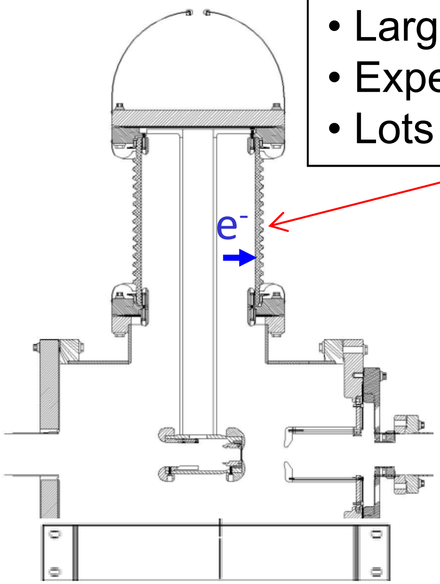
Biggest obstacle: Field emission and HV breakdown…

which lead to Photocathode death

Road to Higher Gun Voltage

Old Gun

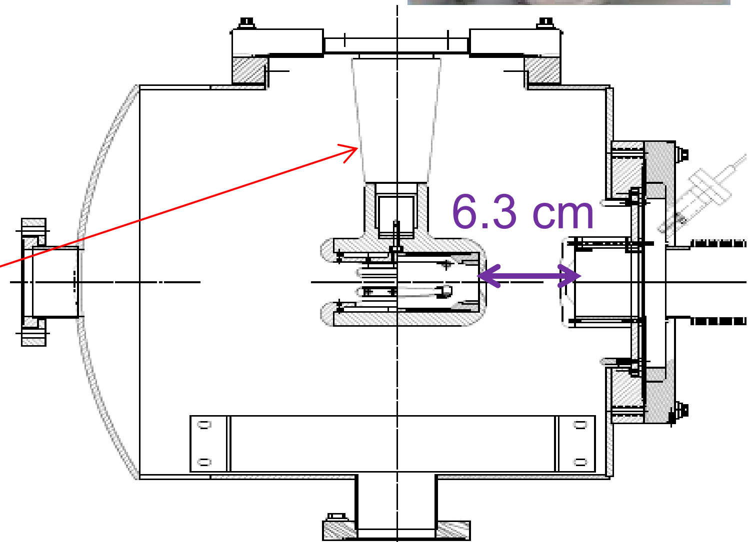
Old Ceramic
- Exposed to field emission
- Large area
- Expensive ($50k)
- Lots of metal at HV



New Inverted Gun

Medical x-ray technology

New Ceramic
- Compact
- $5k
- Less metal at HV
- No SF_6 of N_2



- ✓ Moved away from "conventional" insulator – expensive, months to build, prone to damage from field emission.
- ✓ High gradient locations not related to beam optics, lots of metal to polish.
- ✓ Less flanges material, less outgassing, better vacuum:
    - o Outgassing rate: 1.0×10^{-13} Torr·L/s·cm^2
    - o Extractor Gauge: 2.0×10^{-12} Torr (raw value)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **13**, 010101 (2010)

Load-locked dc high voltage GaAs photogun with an inverted-geometry ceramic insulator

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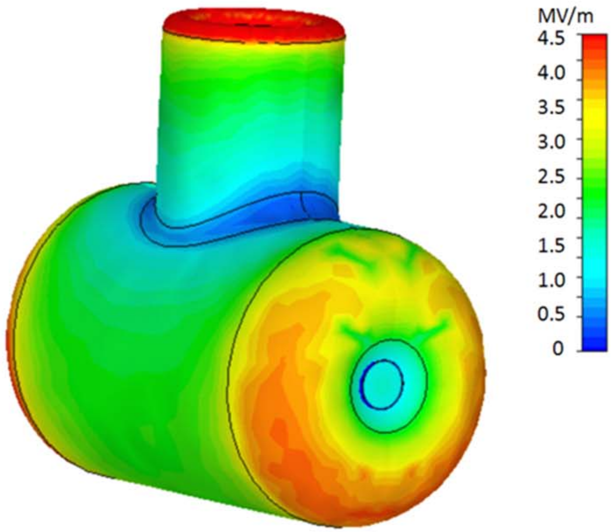
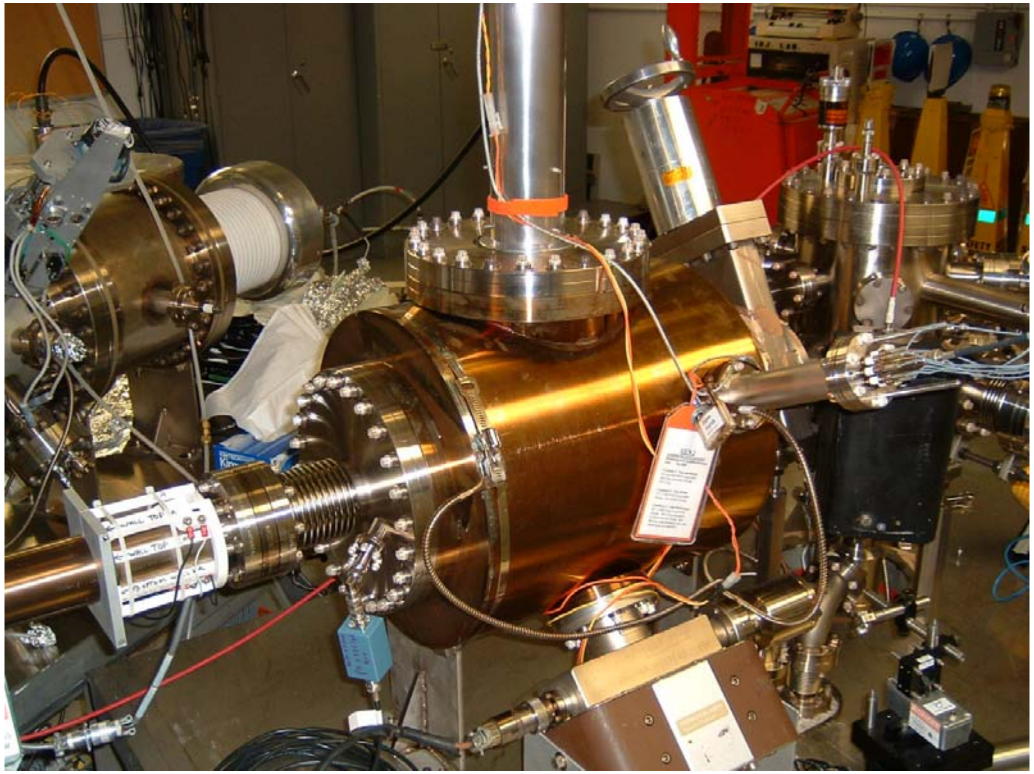
(Received 24 November 2009; published 26 January 2010)

A new dc high voltage spin-polarized photoelectron gun has been constructed that employs a compact inverted-geometry ceramic insulator. Photogun performance at 100 kV bias voltage is summarized.



Jefferson Lab

First Inverted Gun @ CEBAF

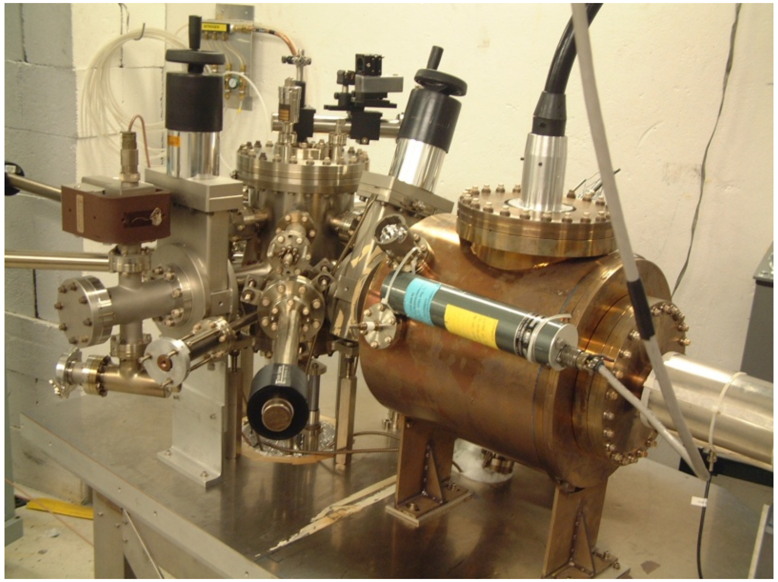


I. 100 kV: Lifetime ~ 100 C at 180 μA with transmission of 85%

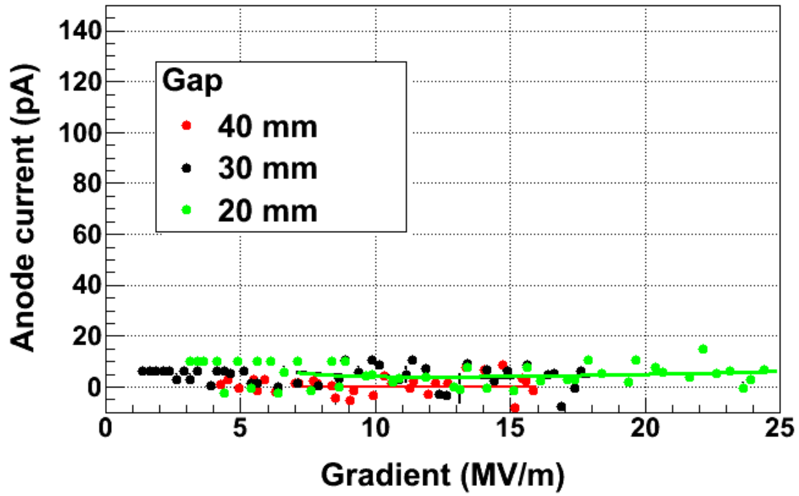
II. 130 kV: Lifetime ~ 100 C at 180 μA with transmission of 95%

- Spring, 2009 – Built first inverted gun (stainless steel cathode electrode)
- July, 2009 – Installed at CEBAF
- HV Power Supply: Glassman 150 kV, 12 mA
- Ran CEBAF program @ 100 kV
- September, 2010 – Conditioned to 150 kV successfully
- Since – Operating at 130 kV (limited by present injector design)

Second Inverted Gun @ Injector Test Cave



Large grain Niobium (Nb) to 225 kV

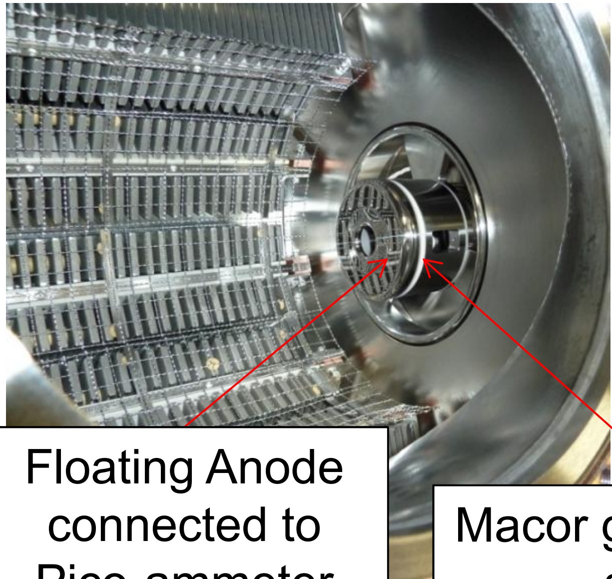


- Large grain Niobium (Nb) cathode electrode
- HV Power Supply: Spellman 225 kV, 30 mA

- Why a Niobium electrode?
  I. Buffered-chemical polishing (BCP) for ~ 1 hour, no need for hand-polishing (takes weeks)
  II. No field emission at high field gradients

HV Conditioning and Field Emission

- Problematic field emission at 200 kV
- Conditioned to 225 kV helpful (limited by HVPS)



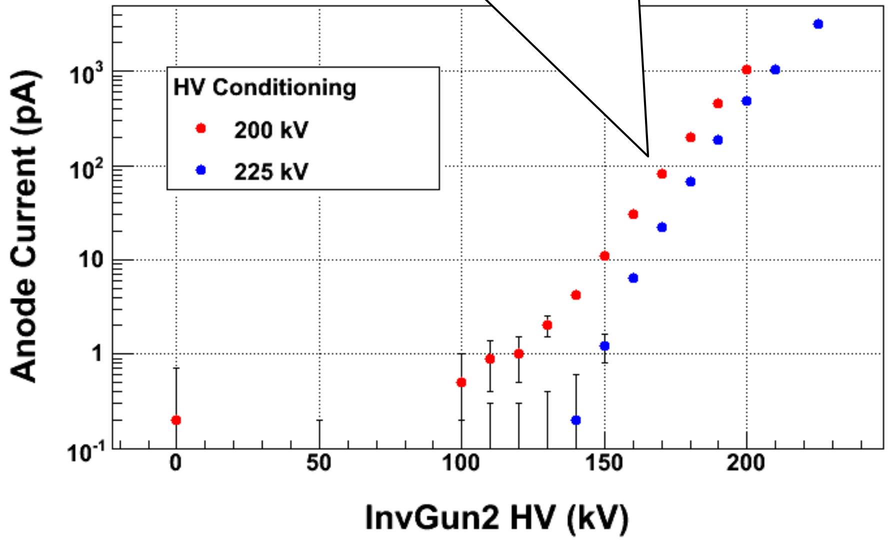
Floating Anode connected to Pico-ammeter

Macor glass-ceramic spacer

100 MΩ Conditioning Resistor

UNIVOLT Transformer Oil Tank

A Short for Beam Delivery



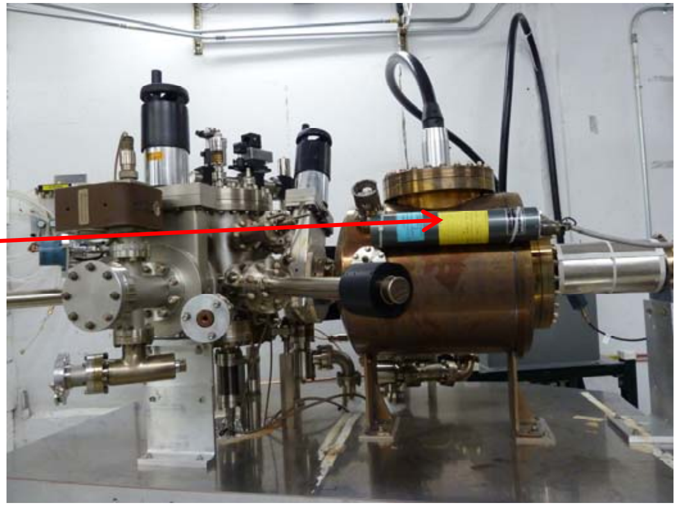
Measure x-rays

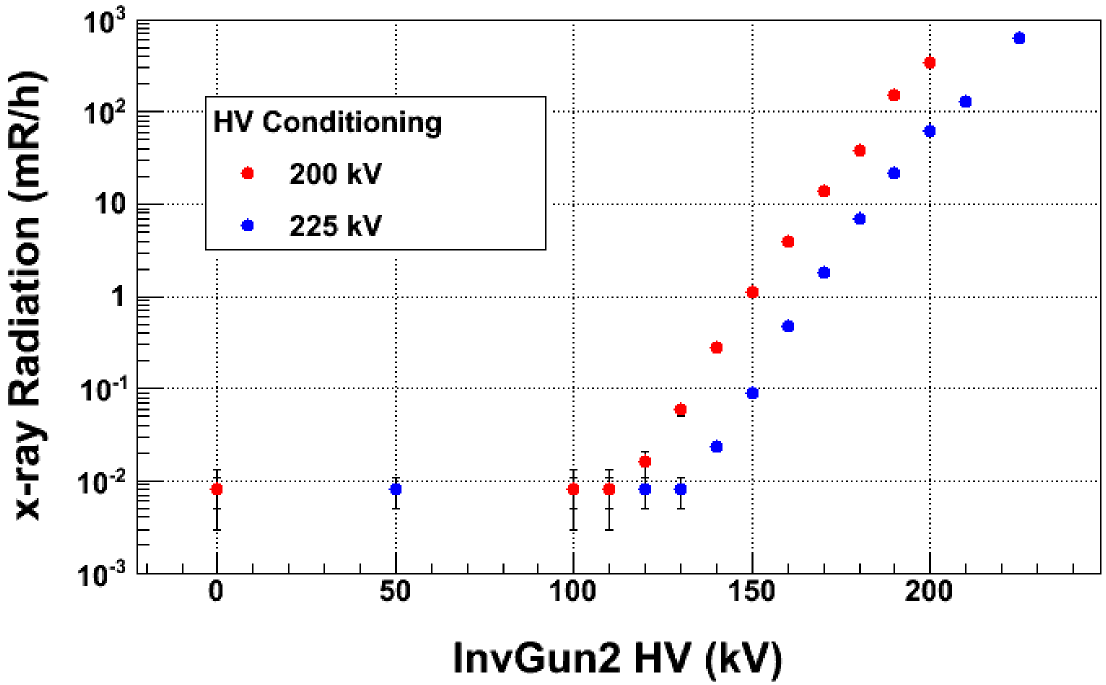
- ➢ Anode may not capture all field emission current

- o Ion Chamber Detector: Model IP 100

- o Energy threshold of 50 keV

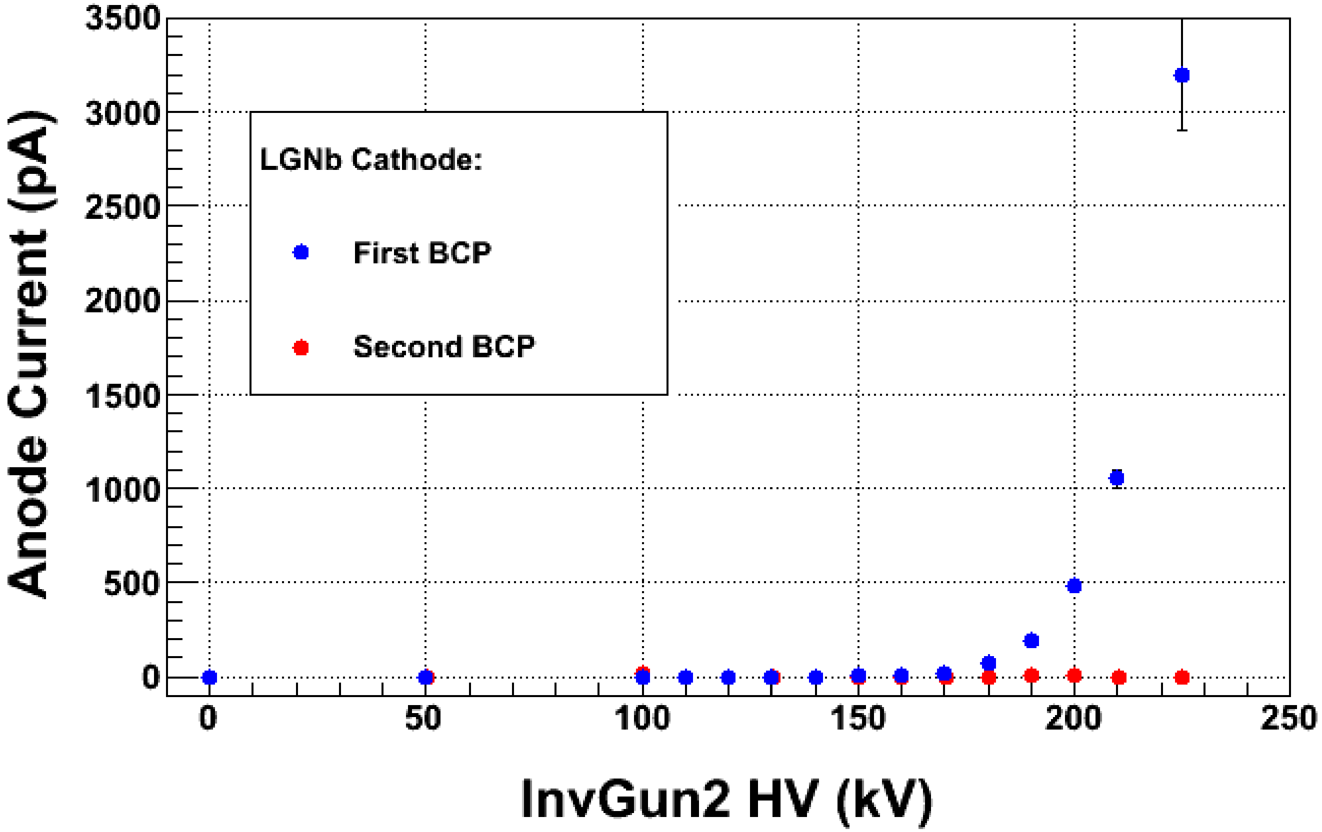
- o Readout: CANBERRA ADM 616



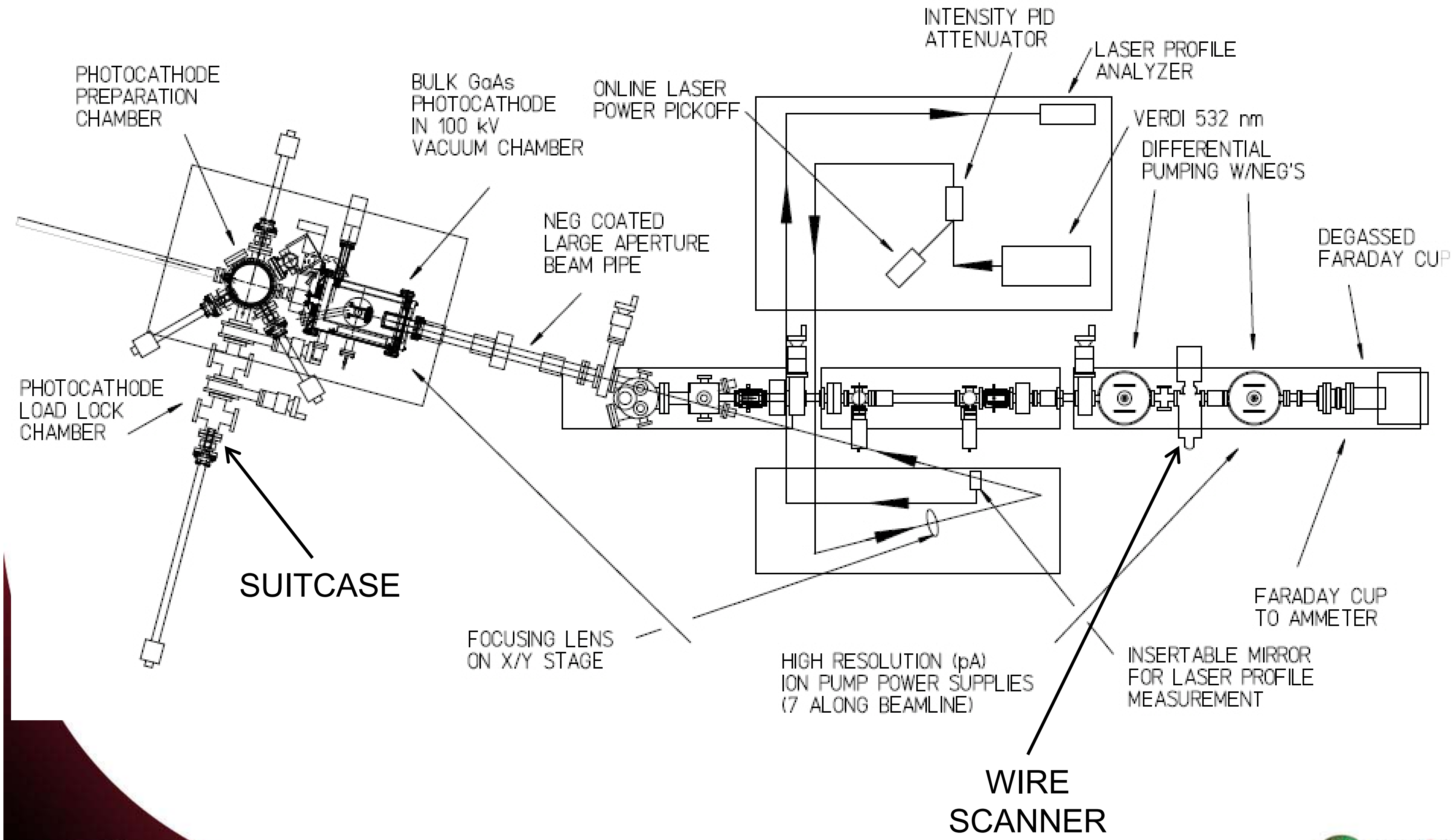


Re-polished Large Grain Nb Electrode

- Longer buffer-chemical polish (BCP) was successful
  - No field emission up to 225 kV
  - x-ray stayed at background level (8 E-3 mR/h)



Injector Test Cave

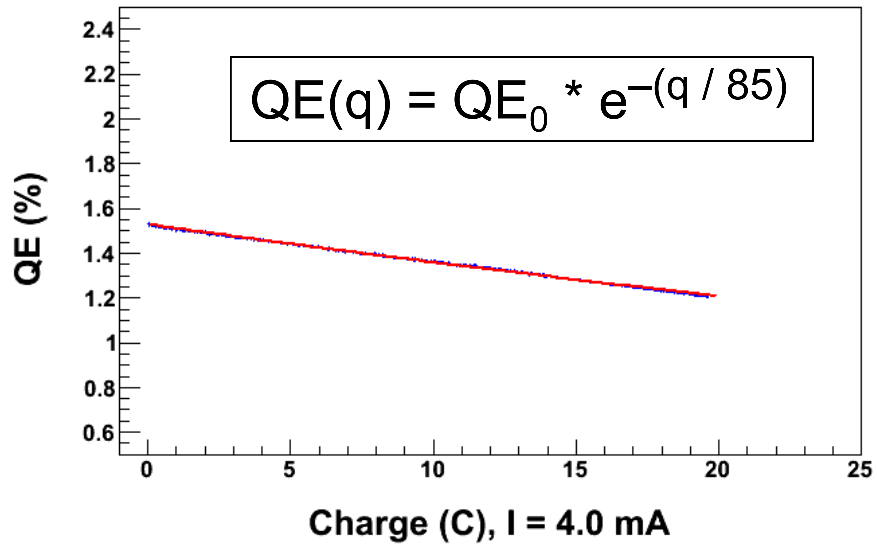



EXIT

High Polarization SSL @ 4 mA

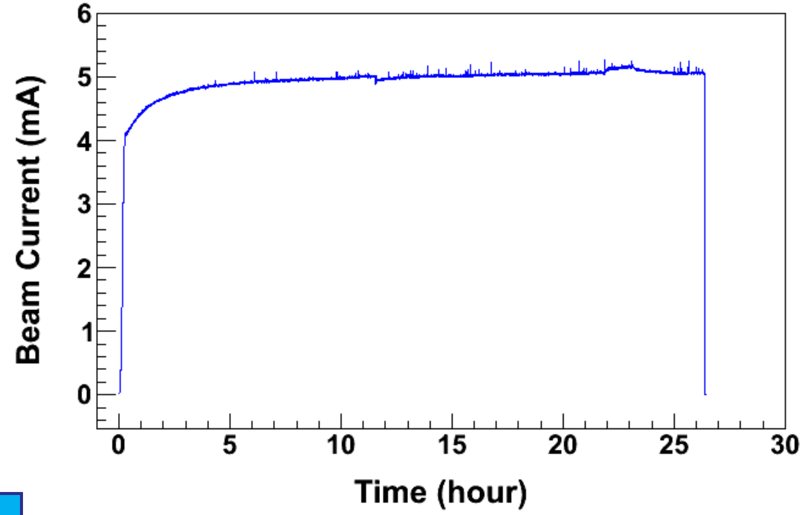
Parameter	Value
Gun Bias Voltage	200 kV
Laser Rep Rate	1500 MHz
Laser Pulselength	50 ps
Laser Wavelength	780 nm
Laser Spot Size	350 µm (FWHM)
Photocathode	GaAs/GaAsP
Beam Current	4 mA
Bunch Charge	2.7 pC
Duration	1.4 hr
Extracted Charge	20 C
Lifetime	85 C

- High initial QE ~ 1.5%
- Higher 200 kV voltage → superseding 1 mA demo (PAC'07)
- Push technology in support of Electron Ion Colliders > 50 mA

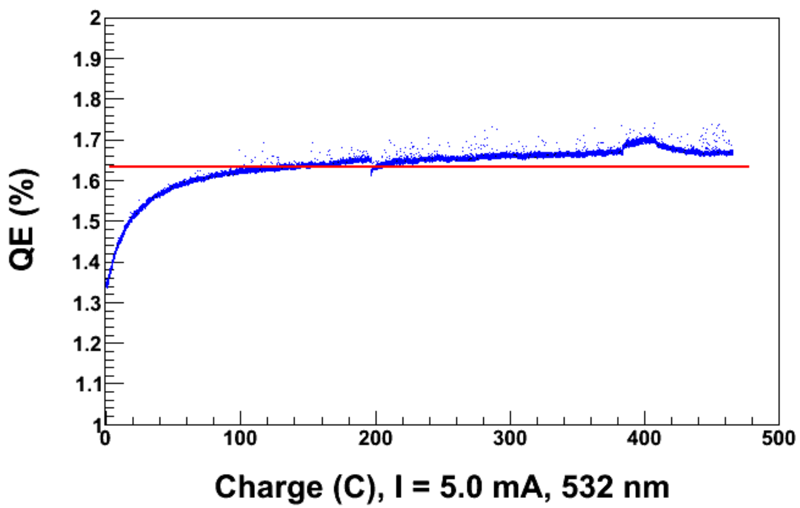


K_2CsSb Photocathode Lifetime

- Photocathode made at Brookhaven National Lab
- Transferred to UHV suitcase and driven down to Jefferson Lab
- K_2CsSb exhibits very long dark lifetime
- Measured lifetime at different beam currents and laser wavelengths
- See Poster Session for more details

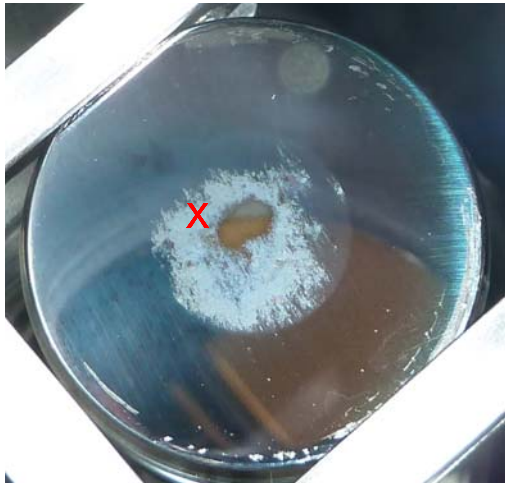


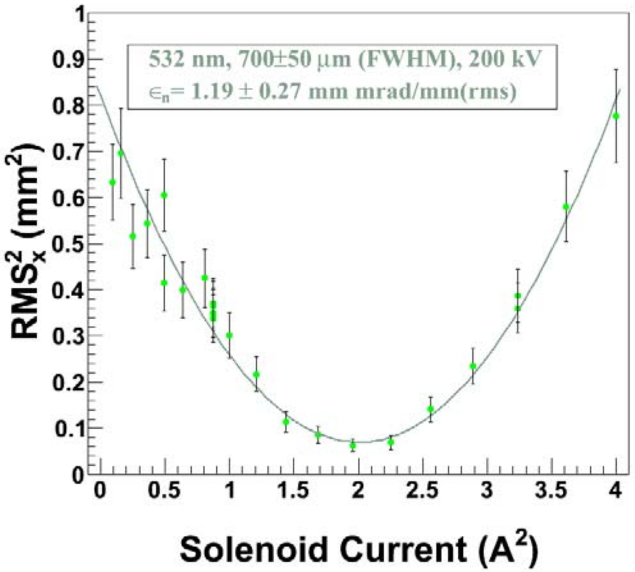
Parameter	Value
Gun Bias Voltage	200 kV
Laser	532 nm, dc
Laser Spot Size	350 µm (FWHM)
Beam Current	5 mA
Duration	26 hr
Extracted Charge	465 C
Lifetime	No Change in QE



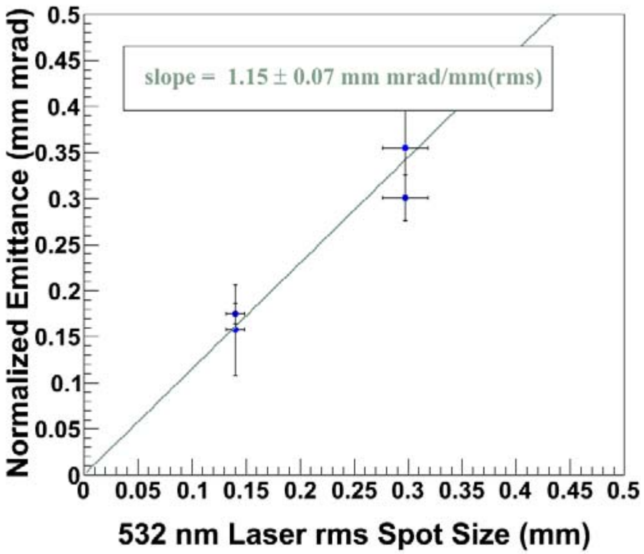
K_2CsSb Photocathode Emittance

- Measured the Emittance after lifetime measurements





- Used a solenoid scan technique and a wire scanner to measure beam size
- Measured at two Gun HV: 100 kV and 200 kV with 3 μA beam current
- Measured at two 532 nm laser spot sizes: 0.35 mm and 0.70 mm (FWHM)



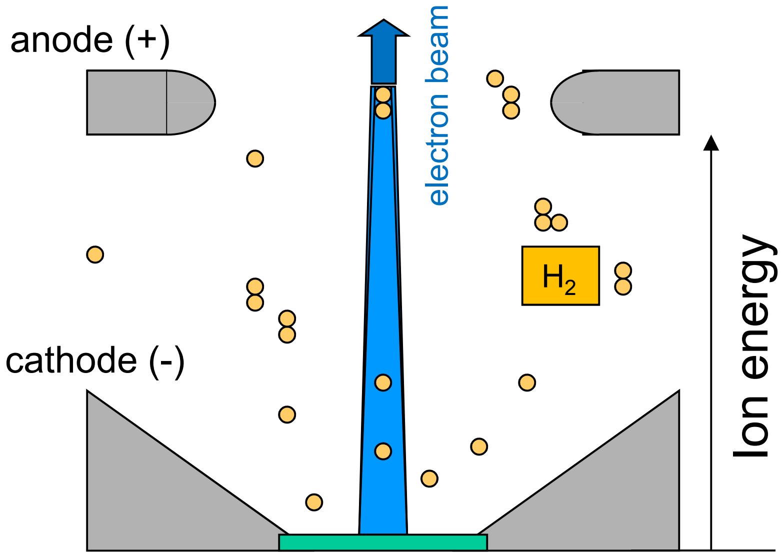
Summary and Outlook

I. Inverted Gun #1 – Stainless steel electrode operating at 130 kV (conditioned to 150 kV) at CEBAF for precision parity violation experiments requiring high beam current (180 µA)

II. Inverted Gun #2 – Large grain Niobium electrode operating at 200 kV (conditioned to 225 kV) at Injector Test Cave for studies of Photocathodes operating at milliampere current

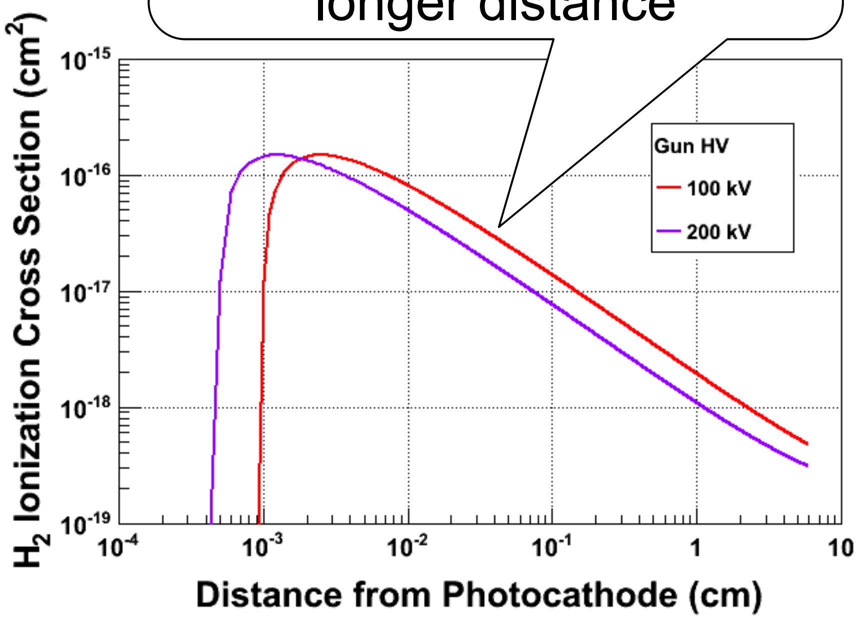
III. Future research …. next

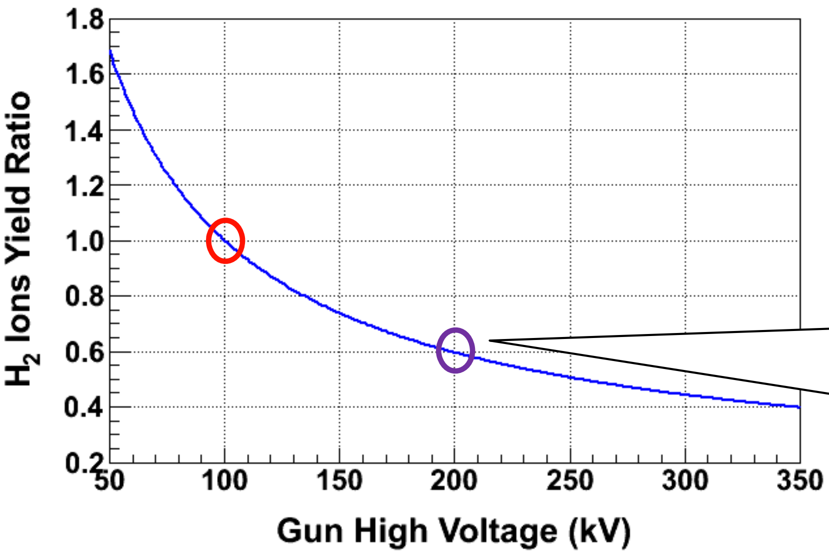
Will Higher HV Improve SSL Lifetime?



Lifetime is limited by ion back-bombardment

At lower Gun HV, the cross section is larger over longer distance



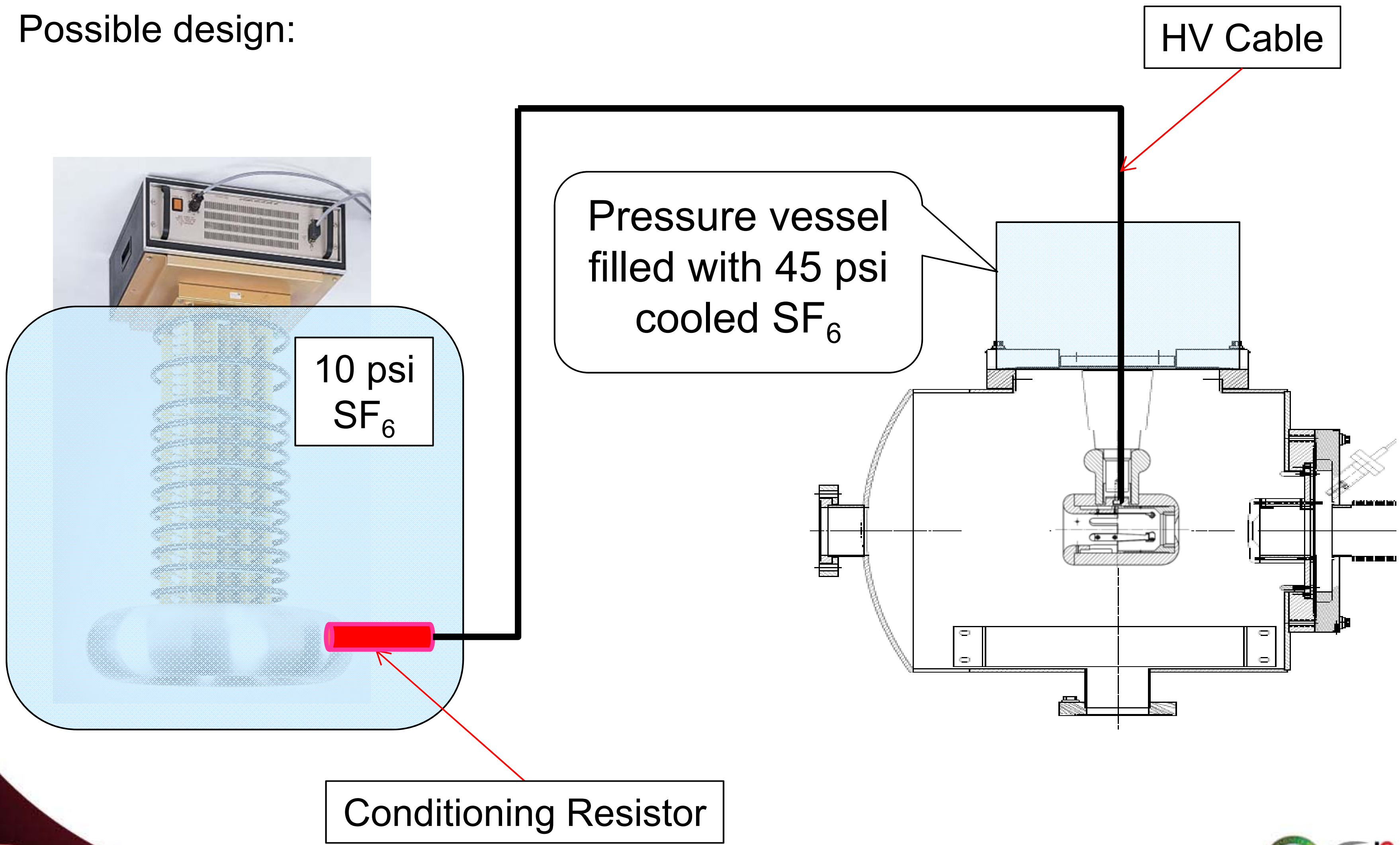


At 200 kV, only 60% of ions are created compared to 100 kV, Longer lifetime?

Any lifetime dependence on ion energy?

Build 350 kV Inverted Gun

I. Use FEL spare HV Power Supply: Glassman 500 kV, 5 mA
II. Use a cable from HVPS → Gun
III. Possible design:



Backup Slides

Emittance and Brightness

- Normalized Emittance from GaAs:

$$\varepsilon_{n,x,y} = \sqrt{\frac{q}{4\pi\varepsilon_0 E_s} \frac{k_B T_{eff}}{m_e c^2}}$$

q	Bunch Charge (= 0.4 pC, 200 μA and 499 MHz)
E_s	Electric Field at GaAs surface
T_{eff}	Effective Temperature of GaAs (= 300 – 400 K, 780 nm)
$k_B T_{eff}$	Thermal Energy (= 34 meV)

Gun HV (kV)	E_s (MV/m)	ε_n (μm)
100	2.0	0.011
140	2.8	0.009
200	4.0	0.008

- Normalized Brightness:

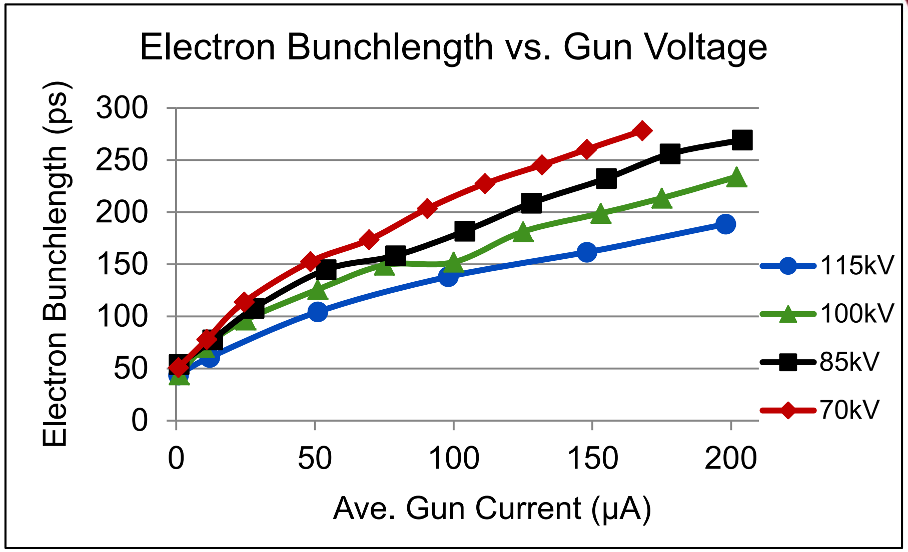
$$B_n \propto \frac{1}{\varepsilon^2} \propto E_s$$

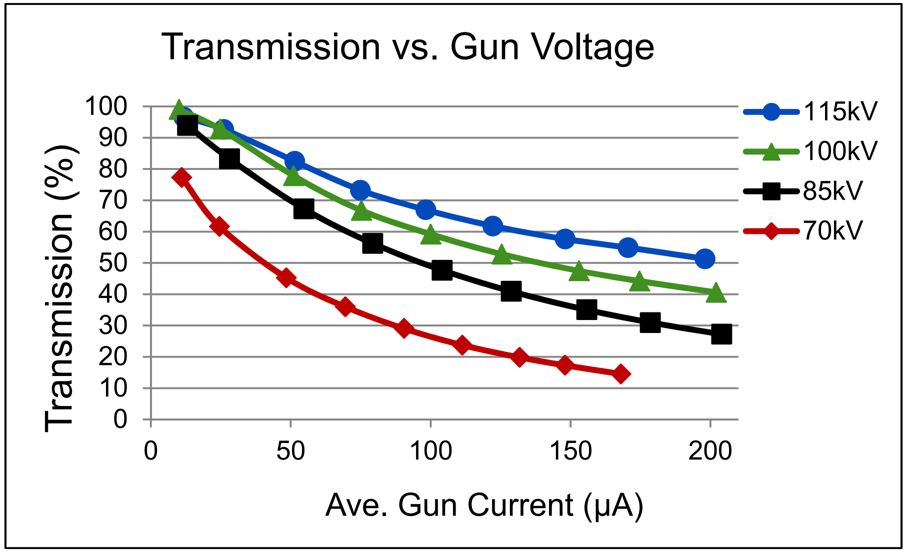
Brightness is proportional to Gun HV

Bunchlength and Transmission

- At higher gun HV, bunchlength is shorter – when Chopper Slit is fully open, it passes 111 ps - and space charge emittance blow-up is suppressed

- Transmission through Injector, improves at higher gun voltage
- Better transmission prolongs lifetime:
  - Less beam loss that degrades vacuum
  - Lower current from gun creates less ions and thus slows NEA damage
- Better transmission reduces current fluctuations and thus improves Hall measurement of helicity-correlated charge asymmetry





Space Charge Limit at CEBAF

- Maximum current density that can be transported across cathode-anode gap is (for an infinite charge plane):

Child's Law (1D): $j_1 = \left(2.33\times10^{-6}\right)V^{3/2}/d^2$ [A/cm²]

- For electron emission from a finite circular spot on the cathode:

Child's Law (2D) (PRL **87**, 278301) : $j_2 \sim j_1\left(1+\frac{1}{4}\frac{d}{r}\right)$

- For CEBAF electron beam (499 MHz):

Short Pulse (PRL **98**, 164802): $j_{SCL} = j_2\left(2\frac{1-\sqrt{1-3X_{CL}^2/4}}{X_{CL}^3}\right),$

$$X_{CL} = \frac{t_b}{\tau_{CL}},\ \tau_{CL} = \frac{3}{2}\tau_{Single-electron}$$

V	Gun Voltage
D	Cathode-anode Gap (6.3 cm)
R	Laser Spot Size (0.5 mm = *2r*)
T_b	Bunchlength (50 ps)
τ_{CL}	Gap Transit Time (0.96 ns at 100 kV)