Building a Higher Voltage Polarized e-Source: The CEBAF 200kV Inverted Gun

M. Poelker, P. Adderley, M. BastaniNejad, J. Clark, J. Grames, J. Hansknecht, C. Hernandez-Garcia, J. McCarter, M. Stutzman, R. Suleiman, K. Surles-Law

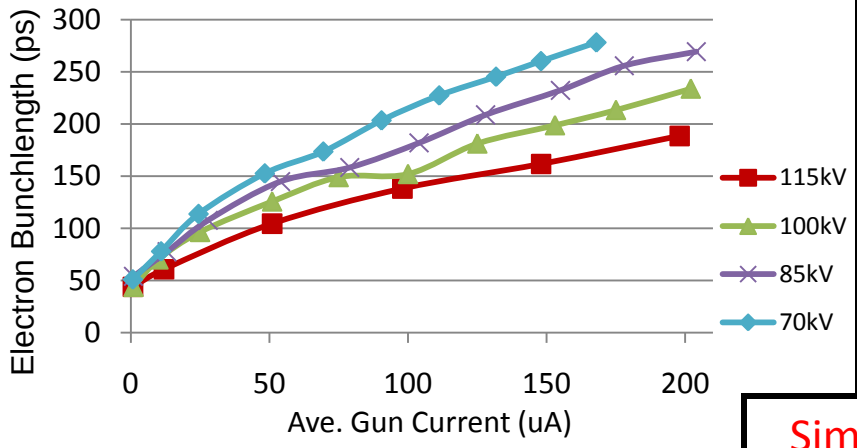
Benefit of Higher Gun Bias Voltage

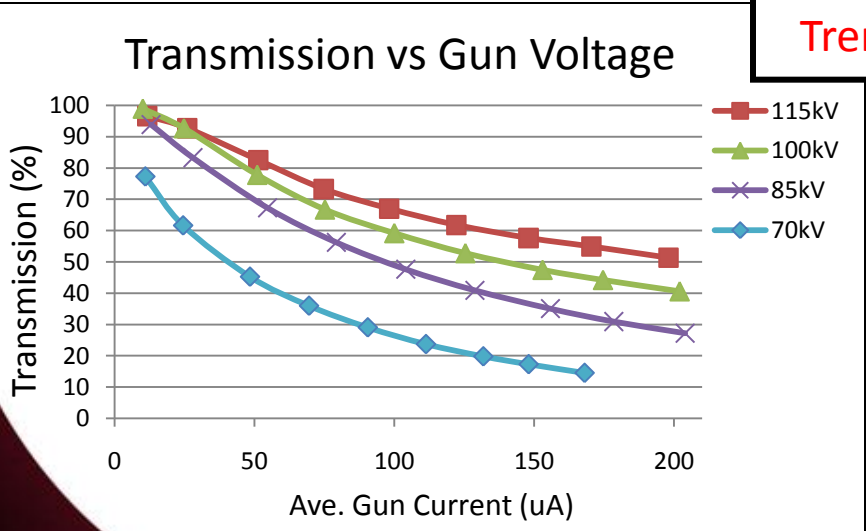
- Reduce space-charge-induced emittance growth, maintain small transverse beam profile and short bunchlength
  - In other words, make a "stiff" beam right from the gun
  - Particularly important for high bunch charge beam
- CEBAF guns have always operated at 100kV (β = 0.55)
- Expect better transmission for Qweak at 140kV (and ILC Baseline design) (β = 0.62)
- Later, we envision an improved CEBAF photoinjector with a 200kV gun and SRF capture section (β = 0.69)
- Indentify what it takes to reach 350kV bias voltage or higher (β= 0.8+). For ILC, CLIC, EIC, etc.,

Biggest obstacle: Field emission and HV breakdown… which lead to Photocathode Death

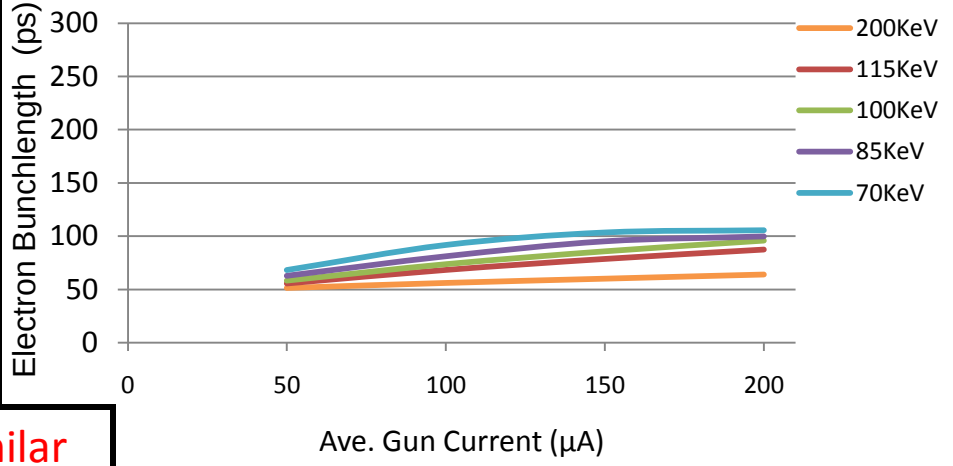
Benchmarking PARMELA Simulation Results Against Beam-Based Measurements at CEBAF/Jefferson Lab – work of Ashwini Jayaprakash, JLab

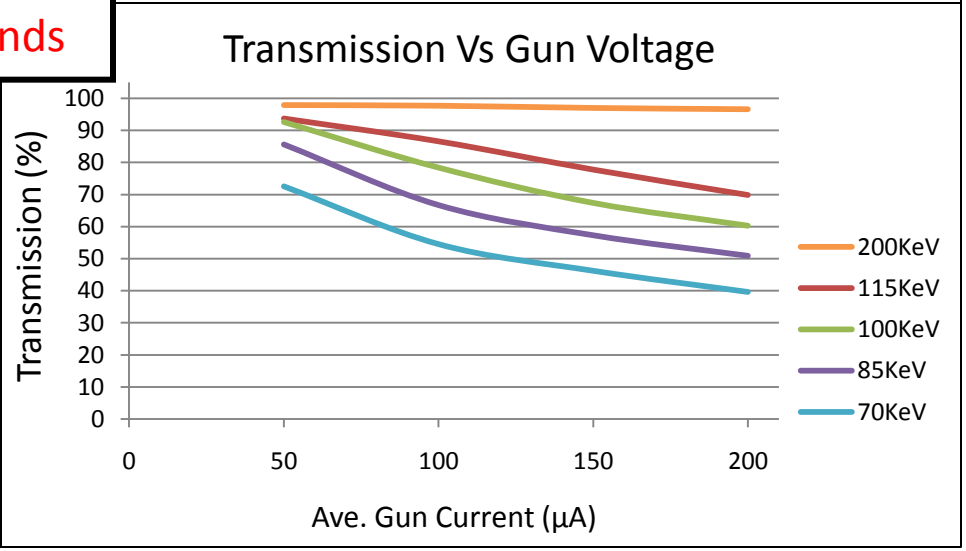
Measurements at CEBAF/JLab





PARMELA Simulation Results

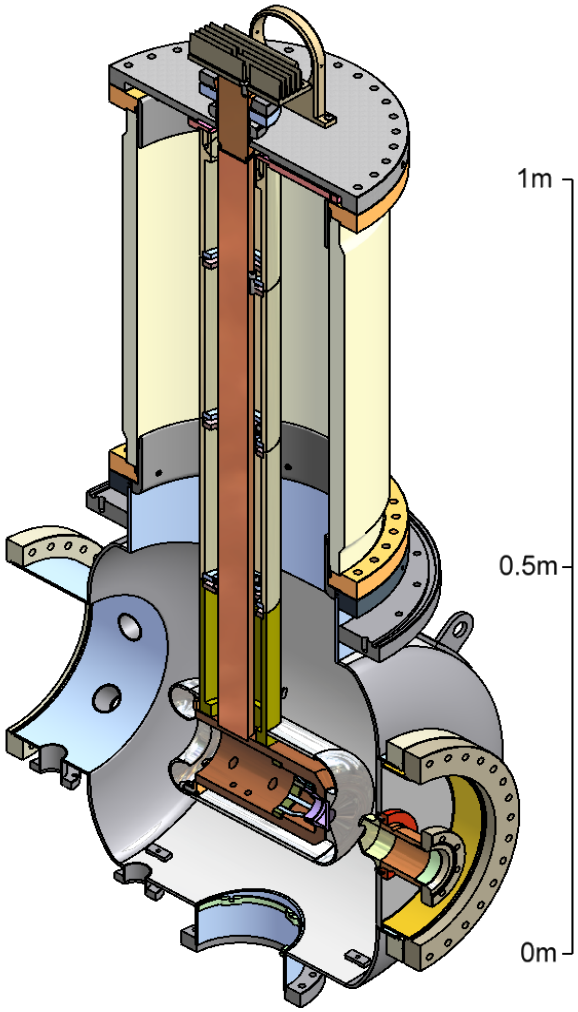


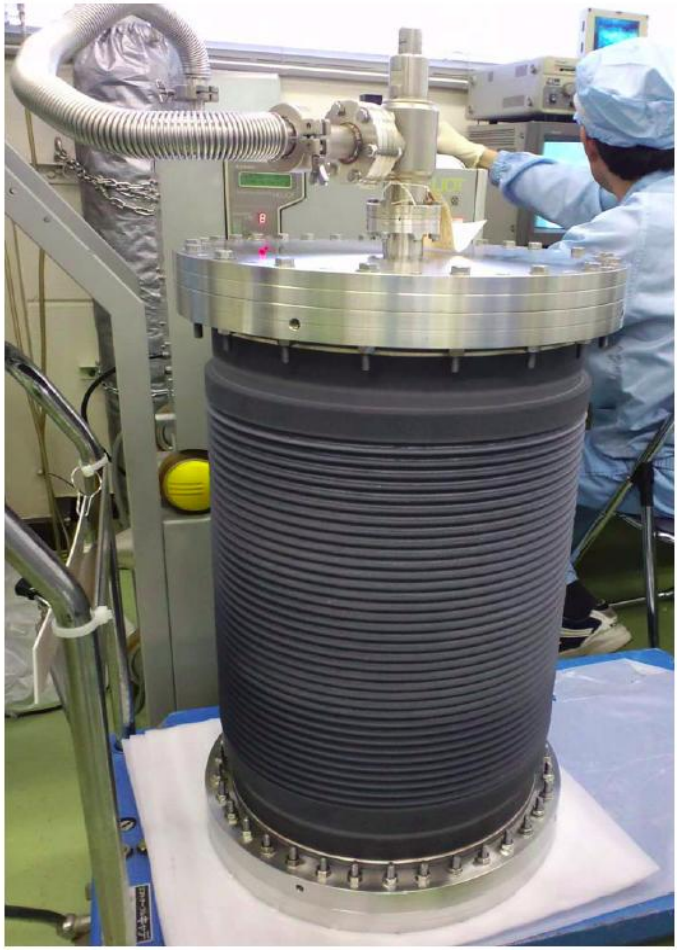


Similar Trends

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

Cornell 750 kV Gun





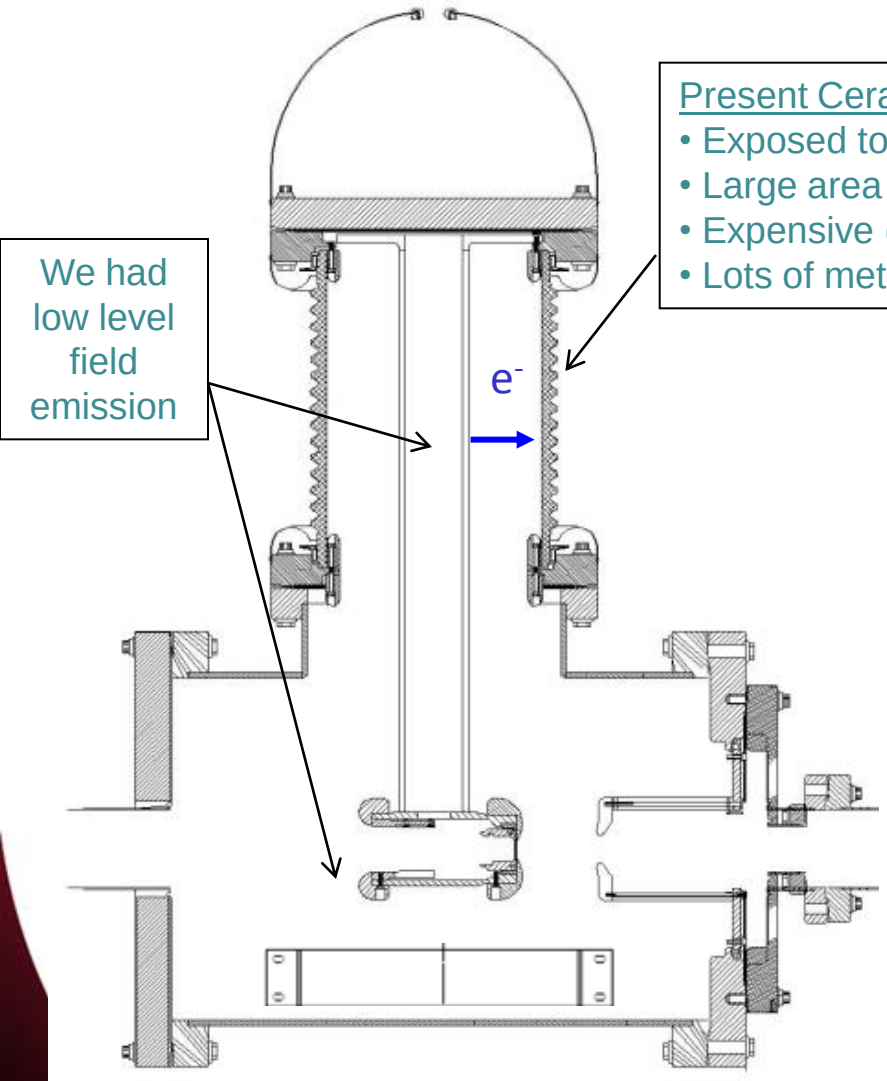
- Ceramic with bulk resistivity and improved braze design installed
- Measured resistivity of 6.45 x 10^{10} Ohm-cm gives 30 μA current draw at 500 kV
- Ceramic by Morgan, brazing and welding by Kyocera

Similar initiatives at JLab FEL and Daresbury ERLP

Courtesy Bruce Dunham, Cornell

Old Gun Design

"Inverted" Gun

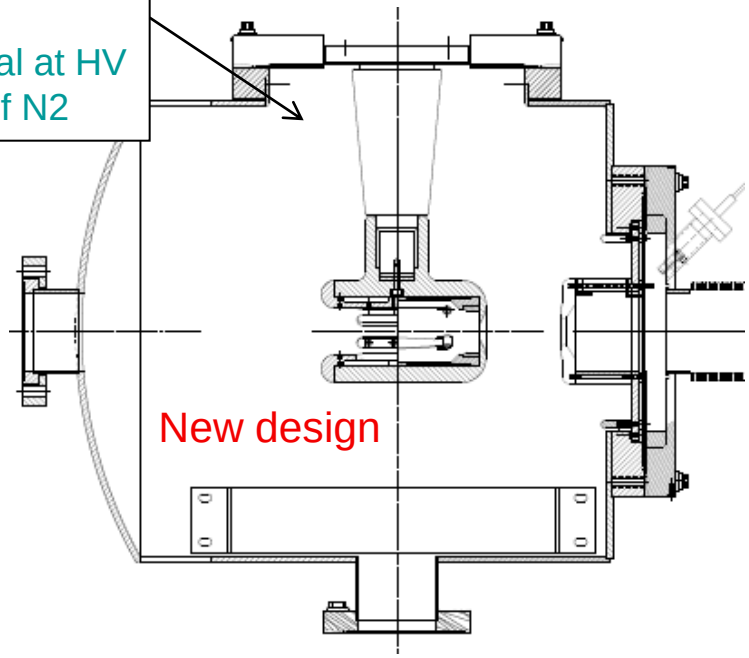


We had low level field emission

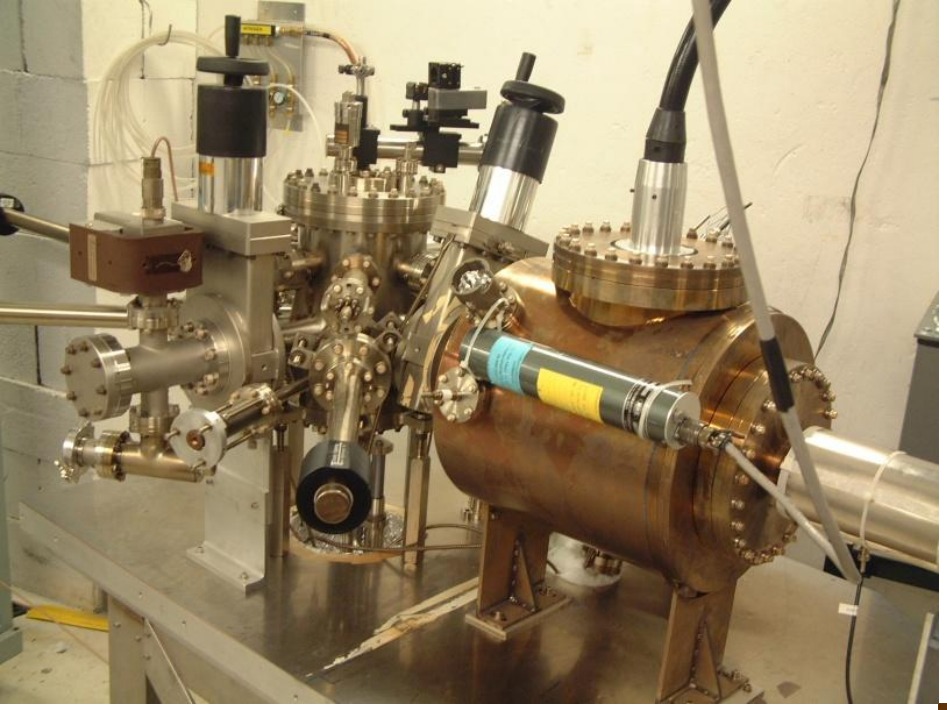
Present Ceramic
- Exposed to field emission
- Large area
- Expensive (~$50k)
- Lots of metal at HV

Medical x-ray technology

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



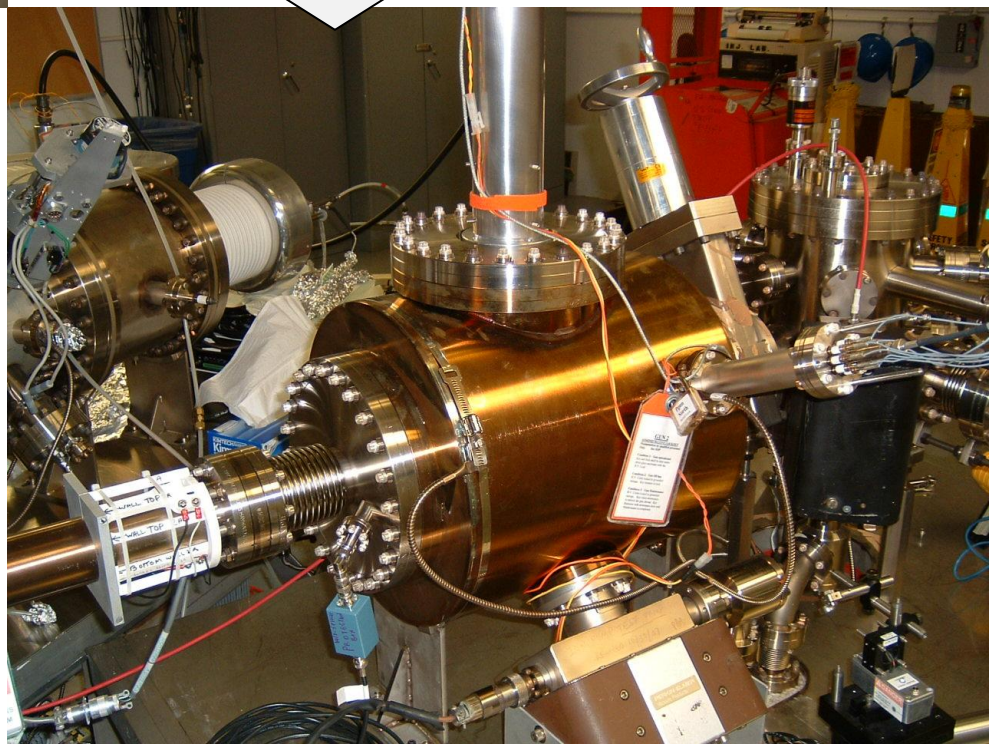
Move away from "conventional" insulator used on most GaAs photoguns today – expensive, months to build, prone to damage from field emission.
High gradient locations not related to beam optics, lots of metal to polish



ILC-funded Project

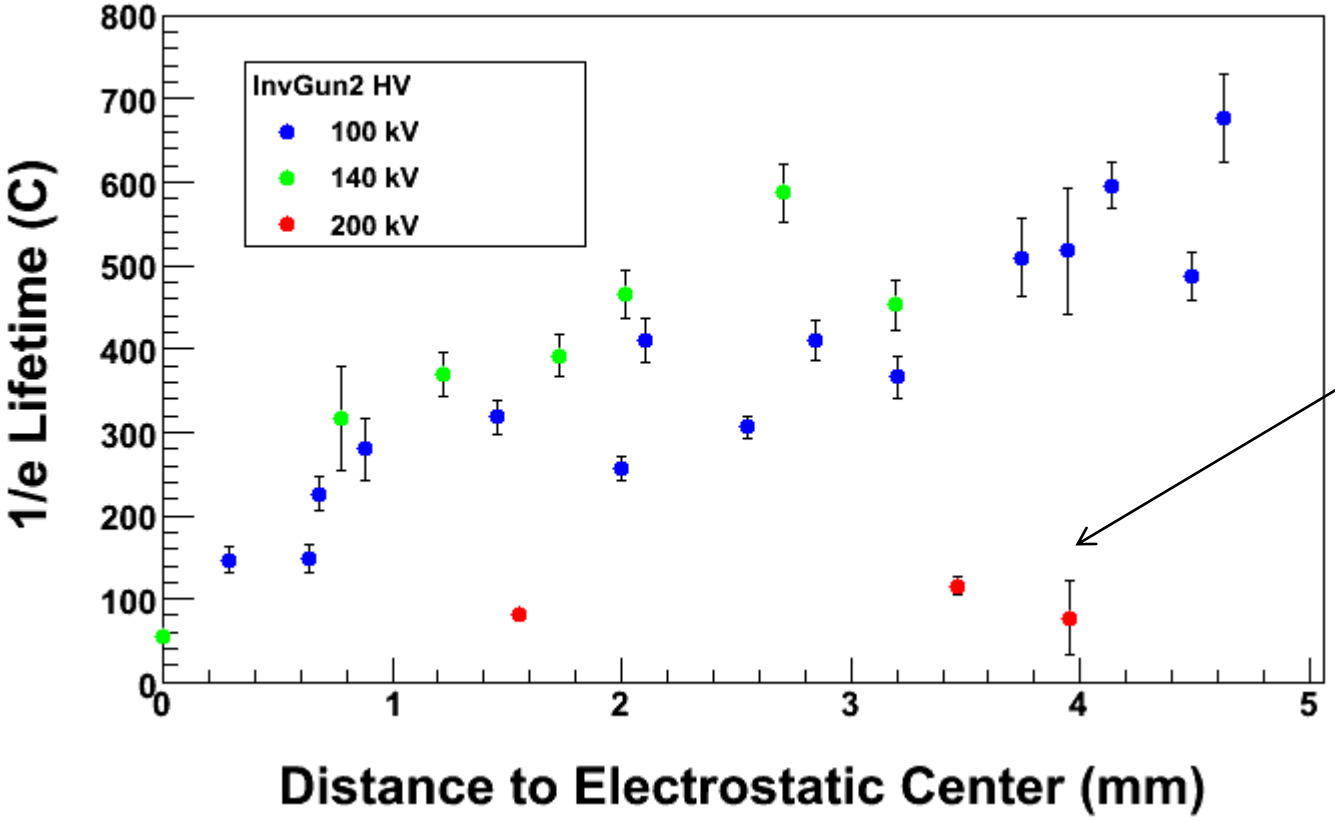
- Inverted Gun#1 installed at CEBAF, operational since July 23, 2009
- Extractor gauge 2×10^{-12} Torr (raw value)
- 100kV Lifetime ~ 70C at 150uA avg. current
- Conditioned to 150kV, operated at 130kV since September 2010

- Inverted Gun#2 at Test Cave
- Conditioned to 225kV, with large grain Nb electrode
- InvGun2 performs well at 140kV
- Problematic ops at 200kV. Small field emission (~nA) and occasional vacuum bursts that ruin QE
- Preparing for “plan B”



Charge Lifetime vs Bias Voltage

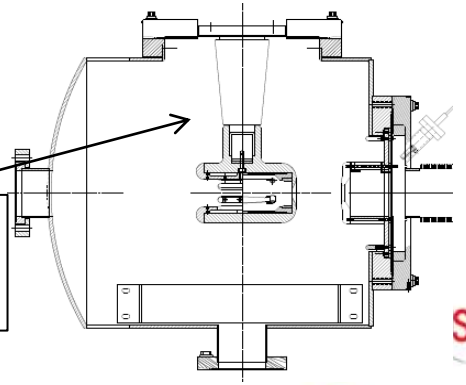
2mA avg. current (unpolarized, DC beam), 350um laser spot and 5mm active area



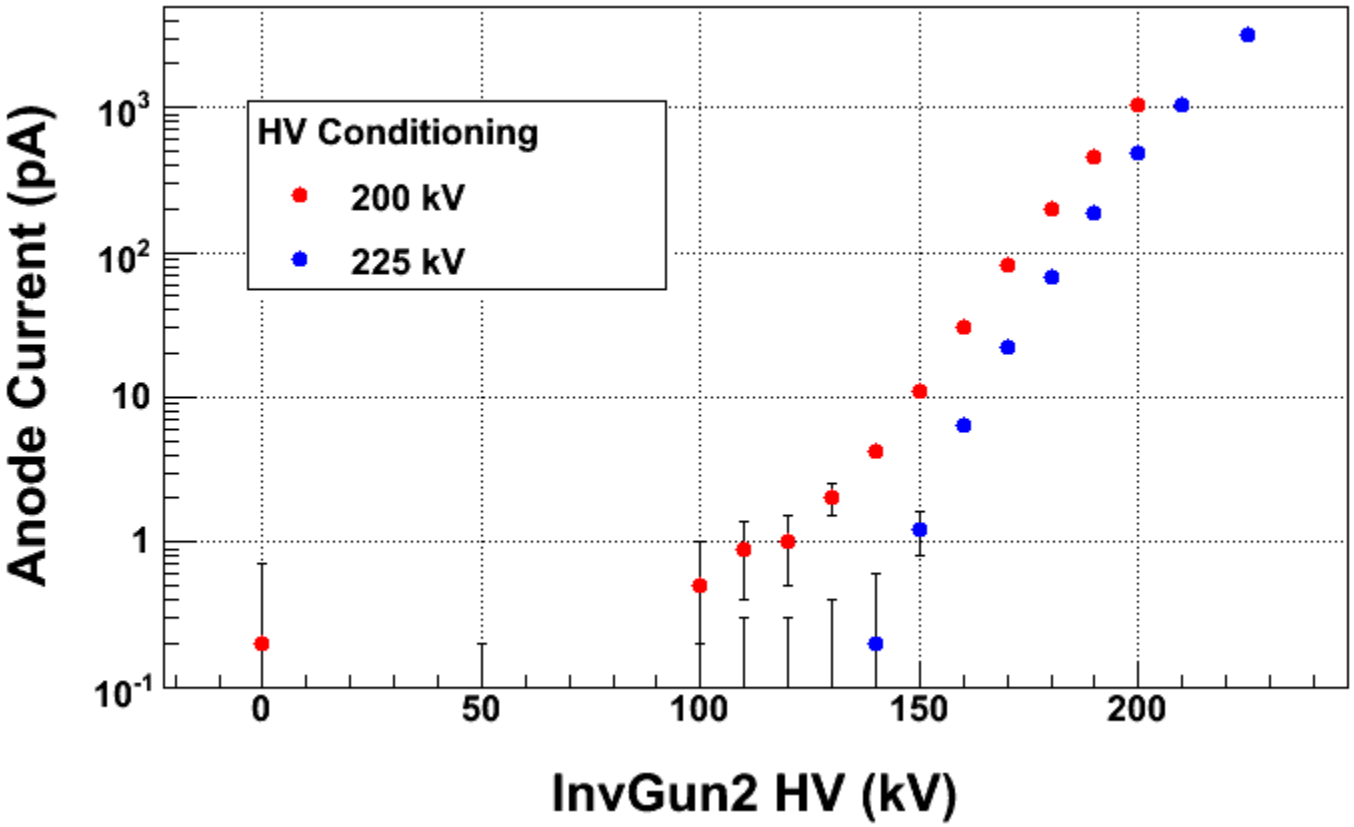
Poor lifetime at 200kV likely due to low-level field emission (next slides)

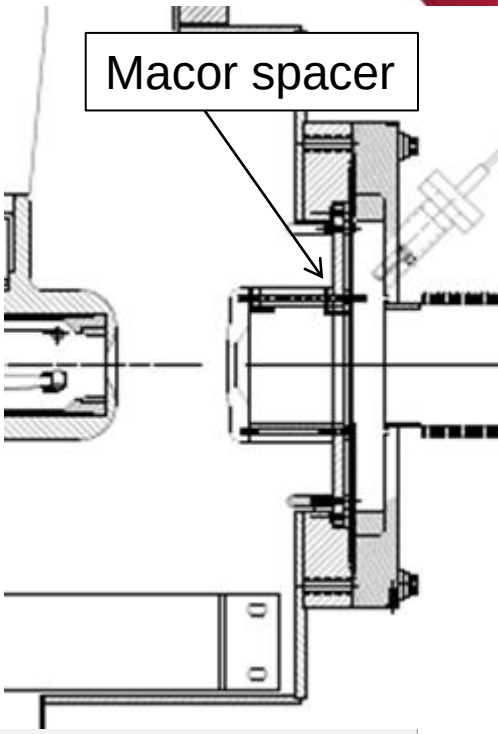
And vacuum bursts often killed QE completely…

Redesigning electrode to get rid of high gradient region at electrode/insulator joint, gradient ~ 15MV/m (more later)

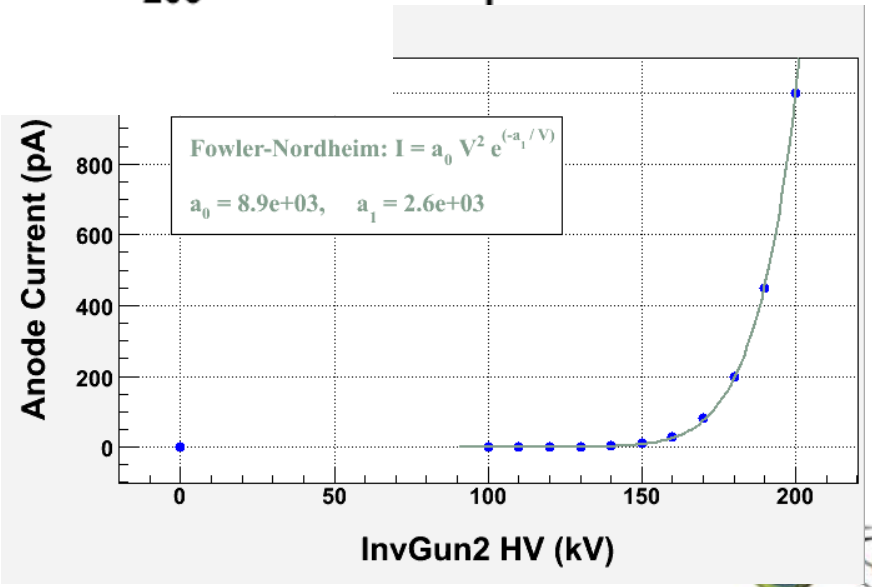


Field Emission measured at (floating) anode versus Gun Bias Voltage



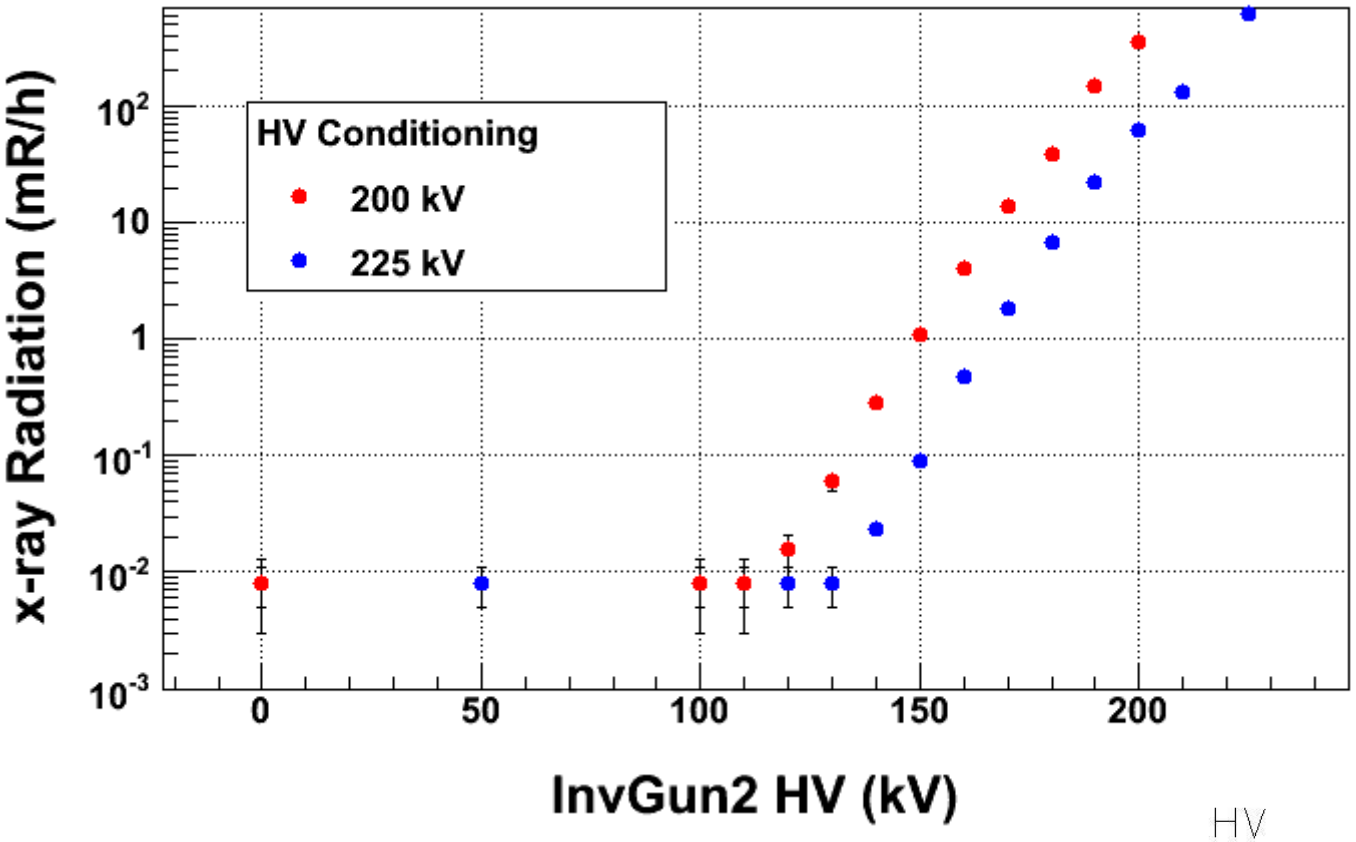


How much field emission is acceptable?
unfortunately, it seems if you can measure it, it's too much



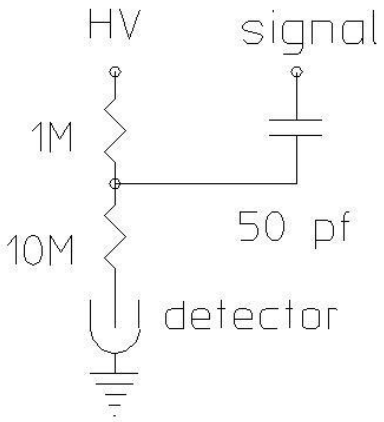
Work of Riad Suleiman

Anode won't always capture all FE…. Better to look for x-rays….



LND, INC.
OCEANSIDE, NEW YORK, USA

Building an inexpensive radiation monitoring system: lots of GM tubes, powered by one HV supply and data stream to computer via RS232



LND 712

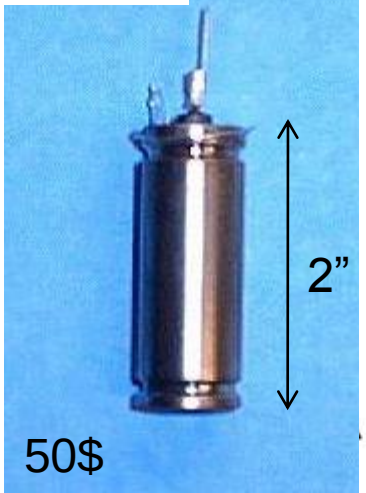
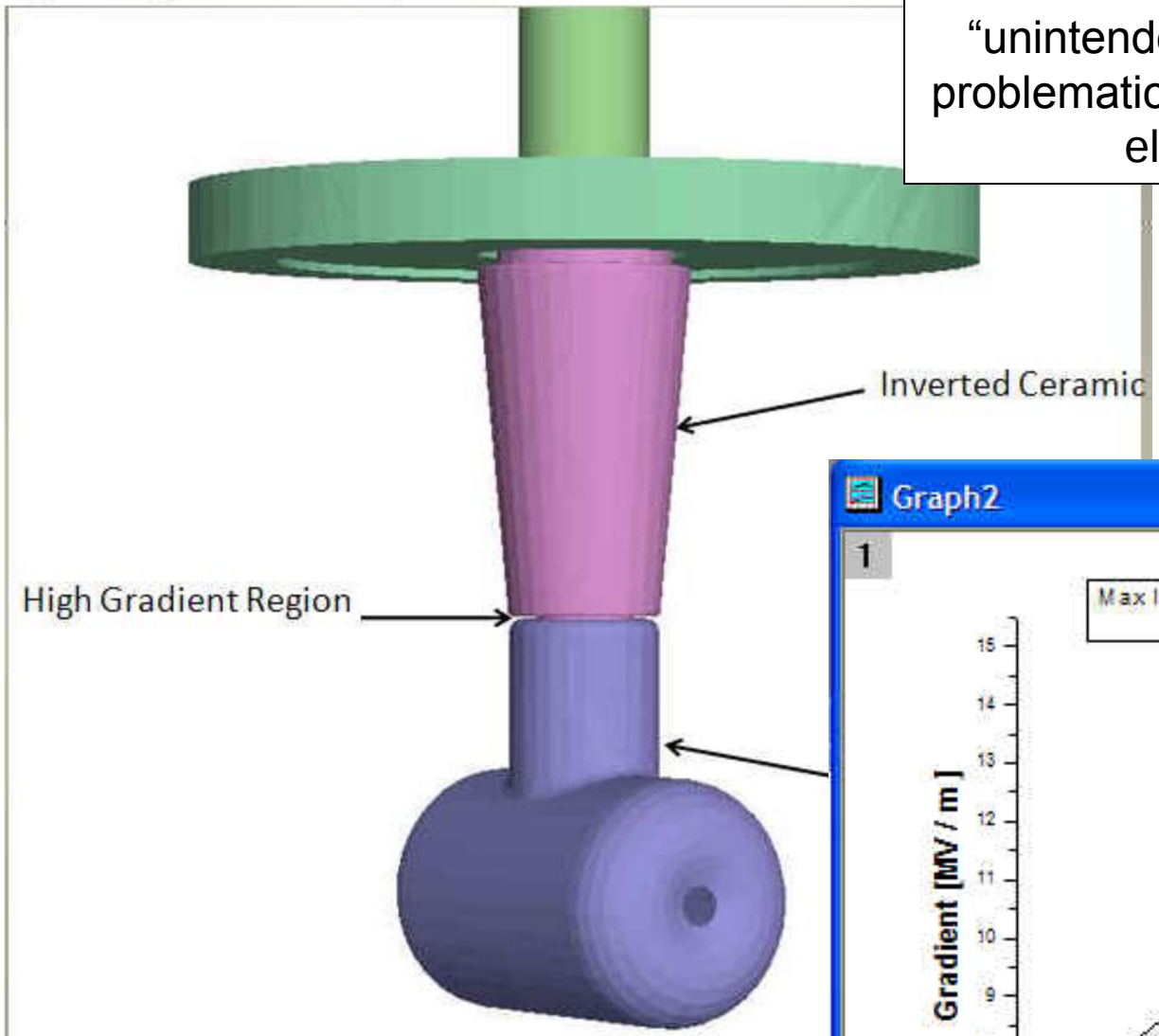


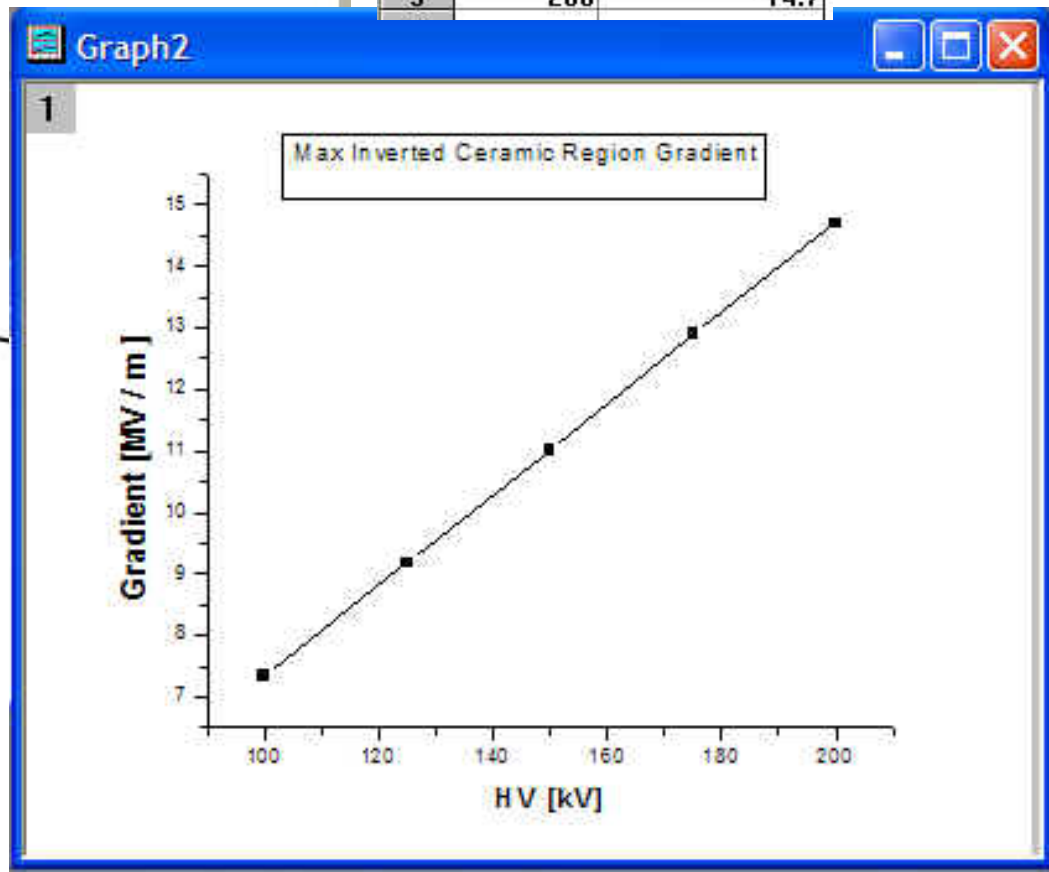
Figure 1: Highest Gradient Region



Our design has one region of "unintended" high gradient – could be problematic…..exploring new designs via electrostatic modeling

Data2 - InvCeramic Region Max ...

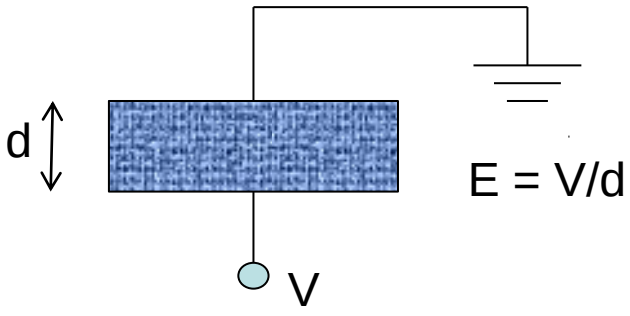
	A1(X)	A2(Y)
	HV (kV)	Gradient (MV/m)
1	100	7.35
2	125	9.18
3	150	11
4	175	12.9
5	200	14.7

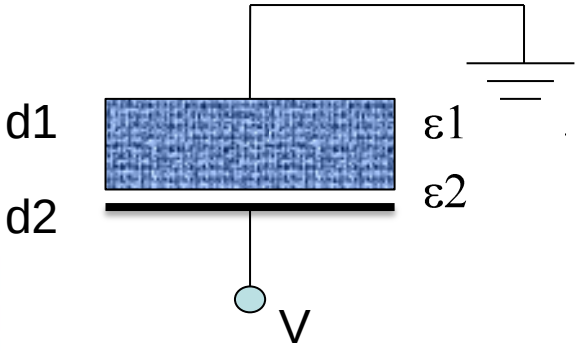


Work of Ken Surles-Law

And maybe even higher gradient at the joint…..??

HV breakdown in capacitors with delamination gap

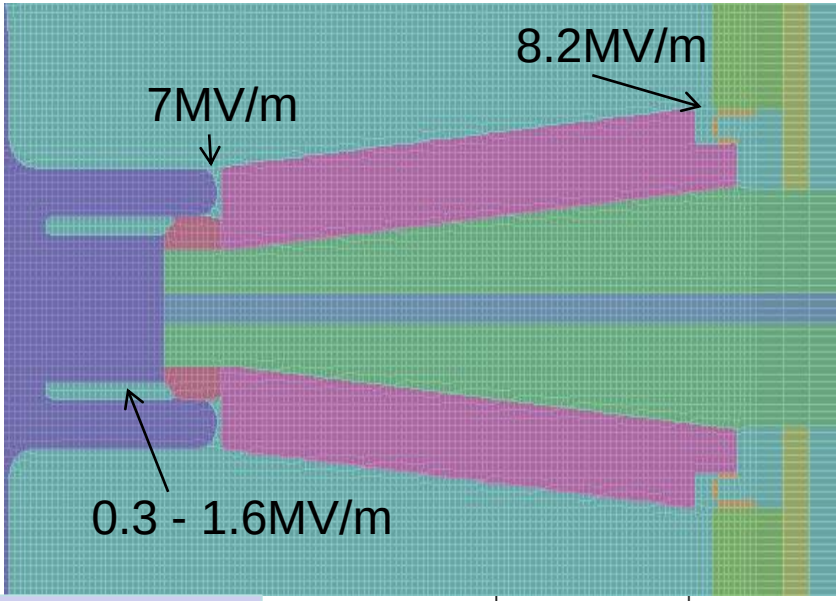


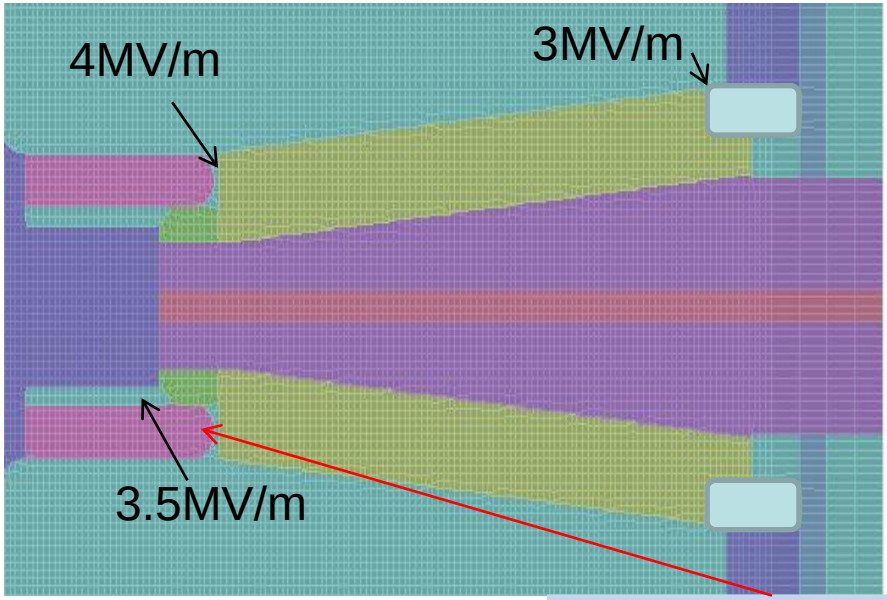


$$E2 = \frac{V}{d2 + d1\left(\frac{\varepsilon 2}{\varepsilon 1}\right)} \sim \frac{V\,\varepsilon 1}{d1}$$

"High Voltage Engineering: Fundamentals", Kuffel, Zaengl, Kuffel

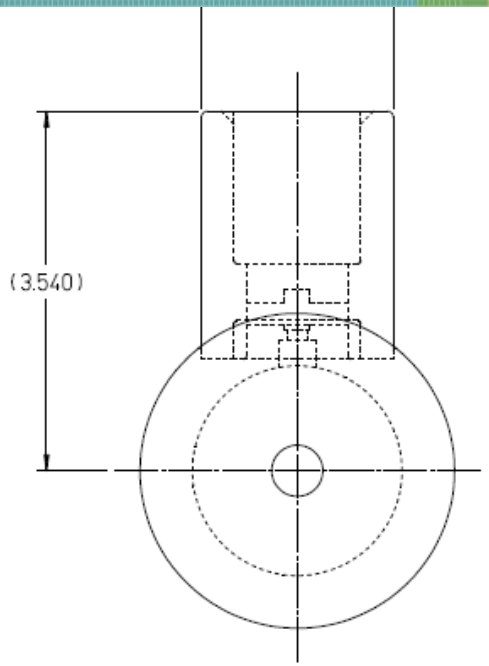
Plan B…..

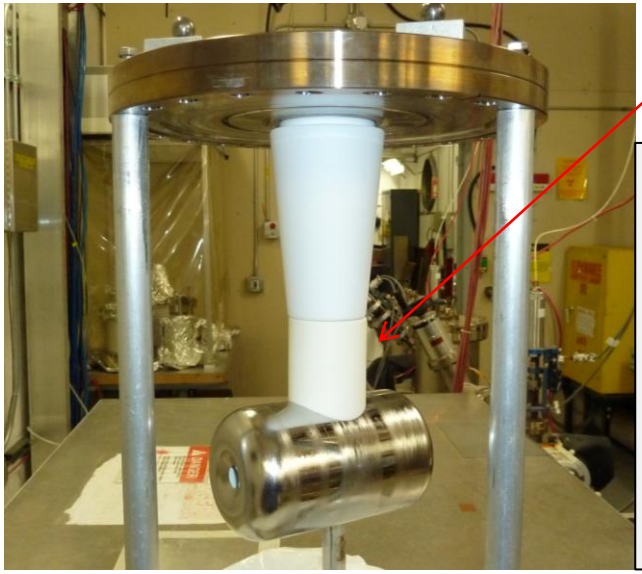




At 100kV bias

Ceramic sleeve…..





Fine grain Nb electrode

Bakeout complete, preparing for operation

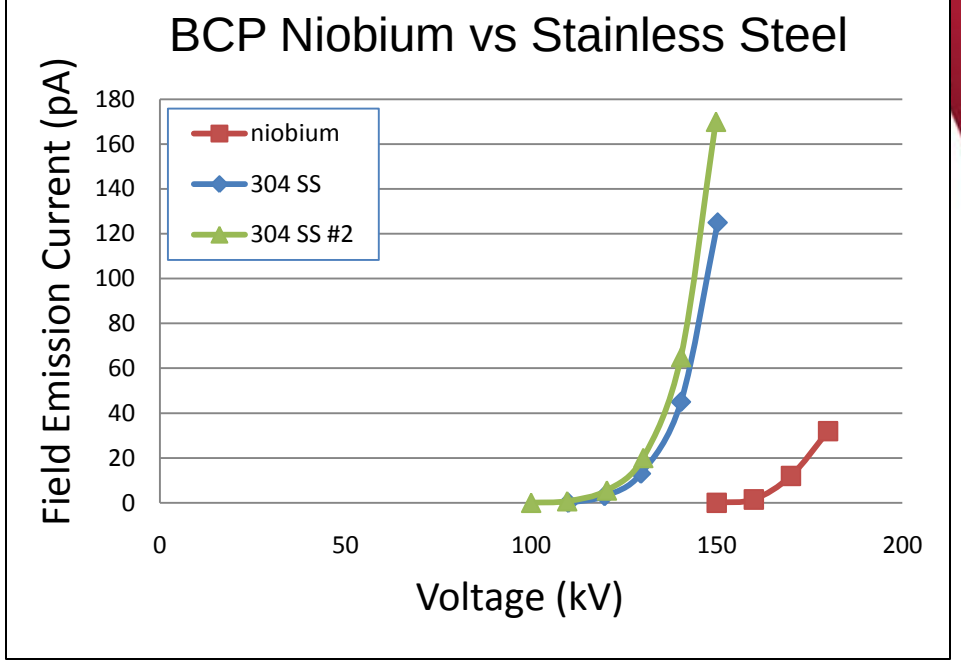
Work of Ken Surles-Law

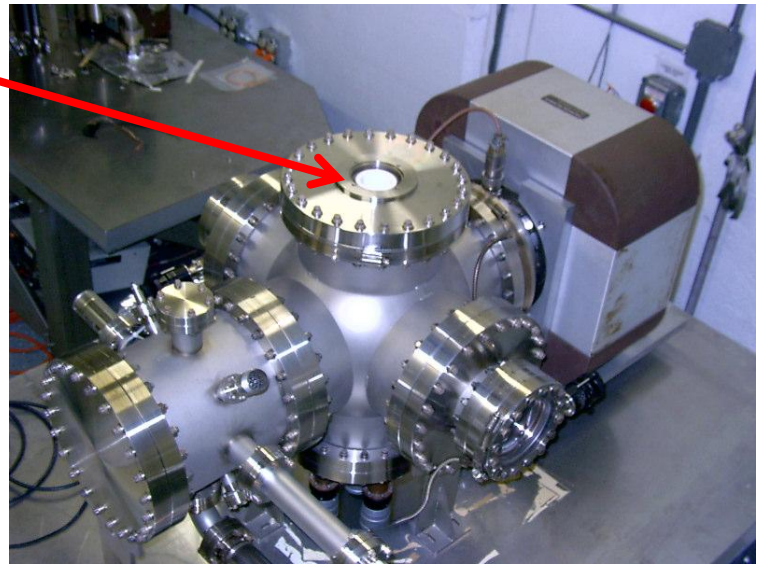
Why Niobium?

- Capable of operation at higher voltage and gradient?
- Buffer chemical polish (BCP) much easier than diamond-paste-polish

Conventional geometry: cathode electrode mounted on metal support structure

Replace conventional ceramic insulator with "Inverted" insulator: no SF6 and no HV breakdown outside chamber

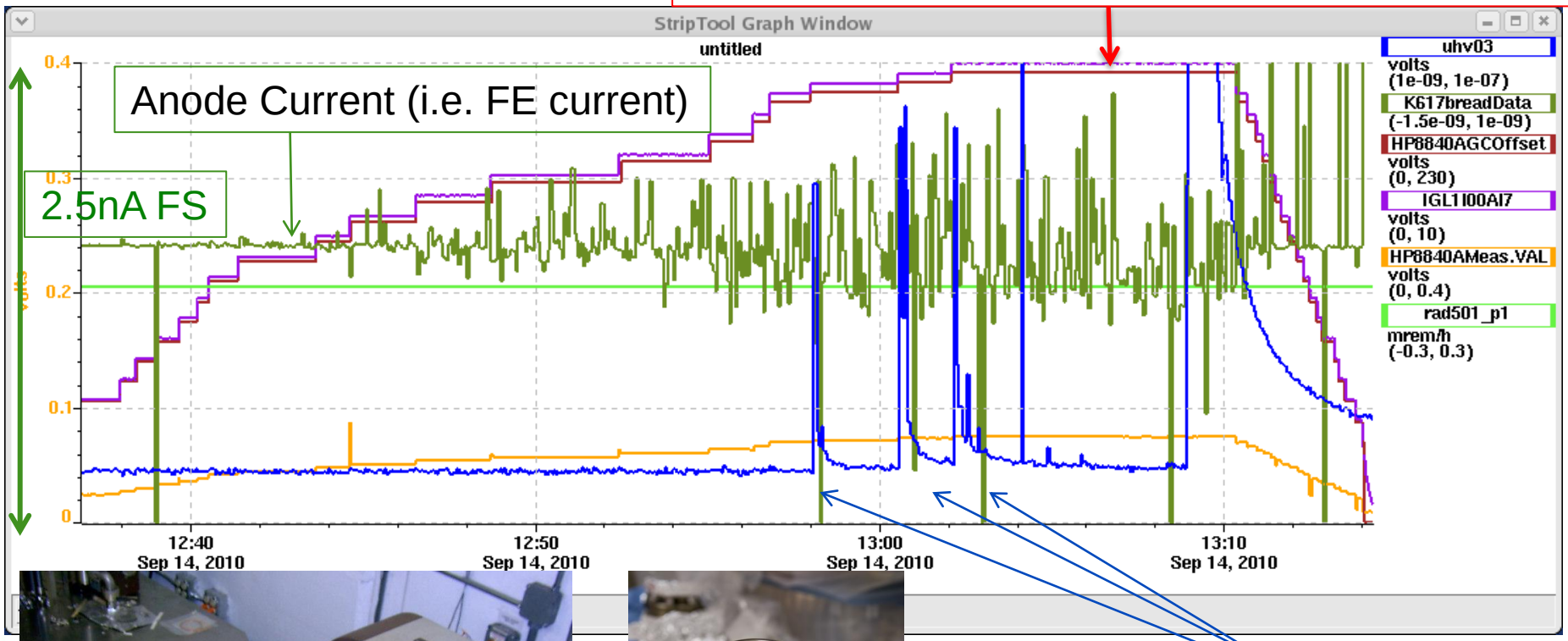


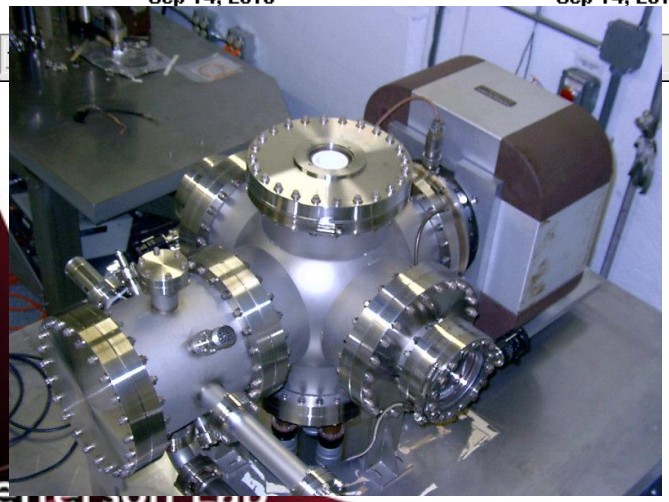


Work of Ken Surles-Law, Jefferson Lab

Single Crystal Nb: Good Cathode Electrode Material

~ No field emission at 225kV bias and 50mm gap

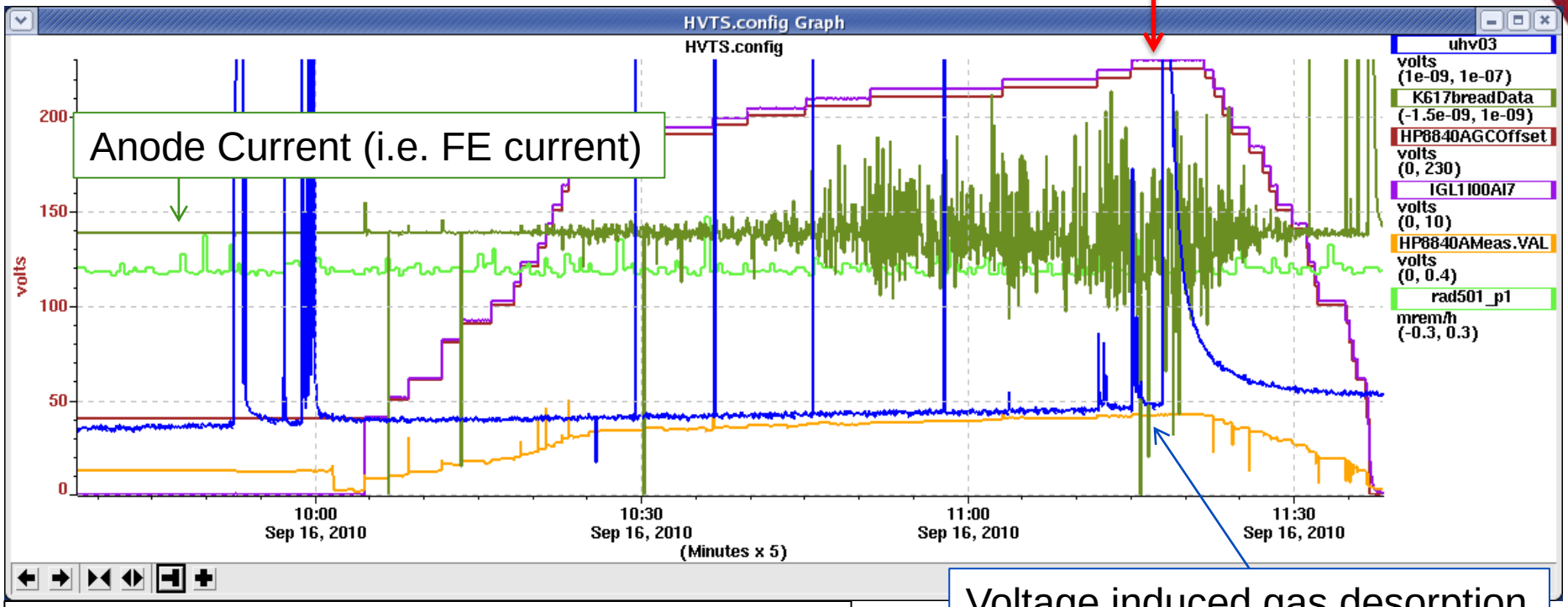




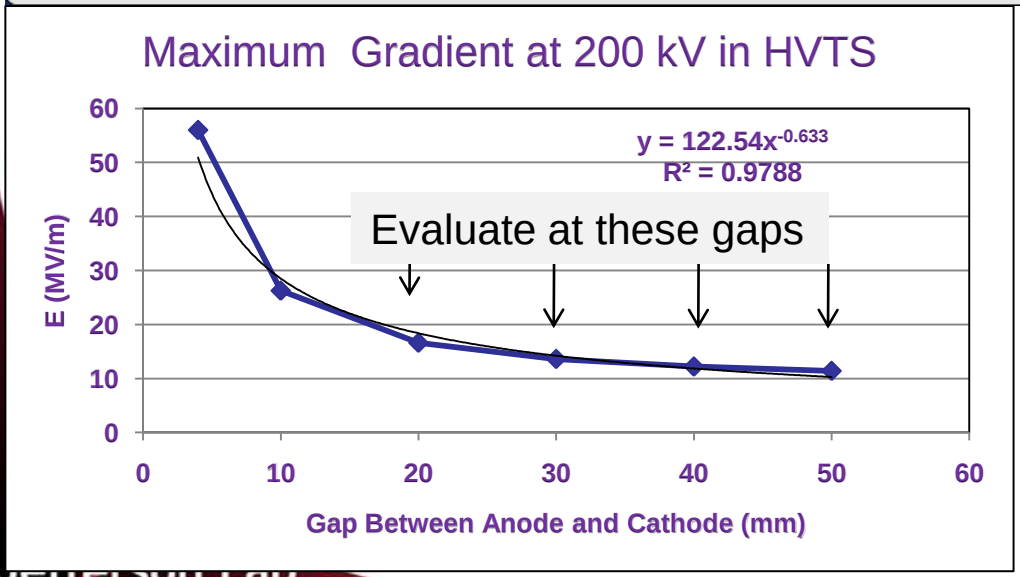
Voltage induced gas desorption
(tells us the cathode is at voltage)

Work of M. BastaniNejad

No field emission at 225kV bias and 20mm gap



Voltage induced gas desorption

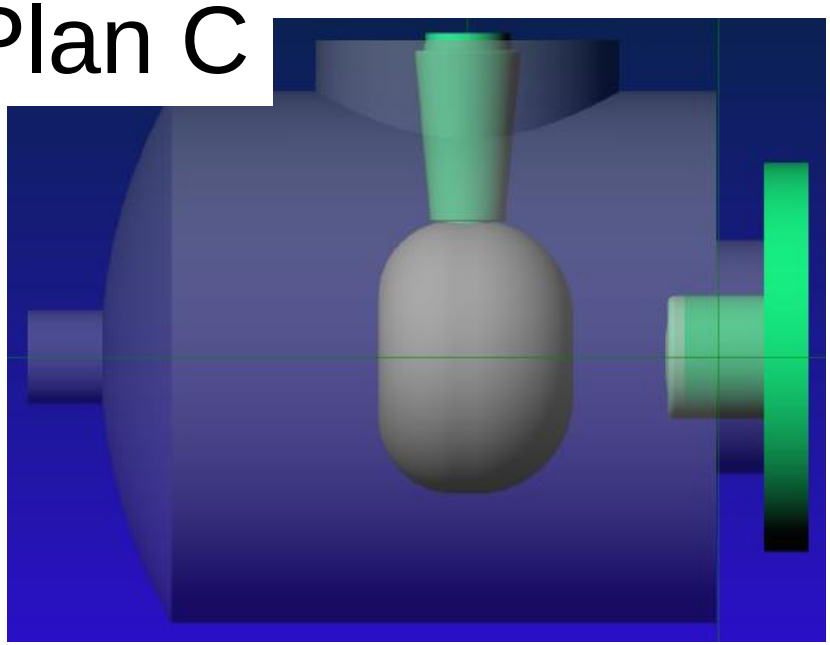


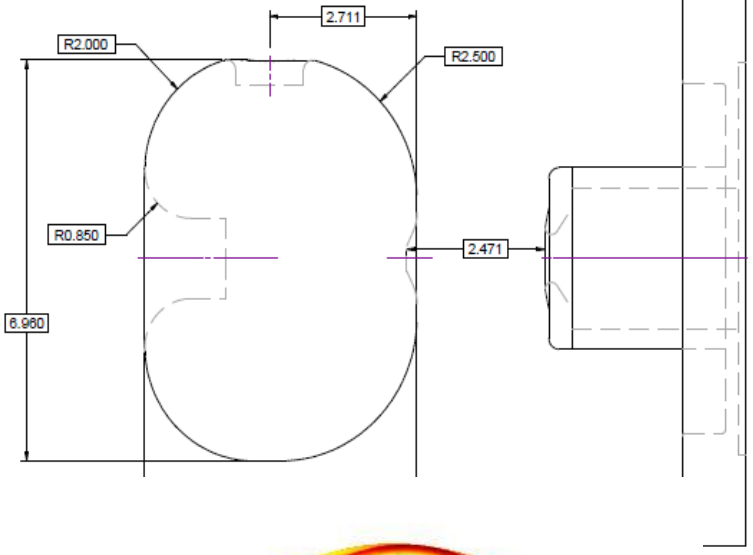
- But Niobium can be pushed too far, producing (many?) field emission sites. Avoid small gaps.
- These field emission sites can be difficult to process out
- Sometimes, electrode needs to be re-BCP-ed
- Fine Grain Nb also good material

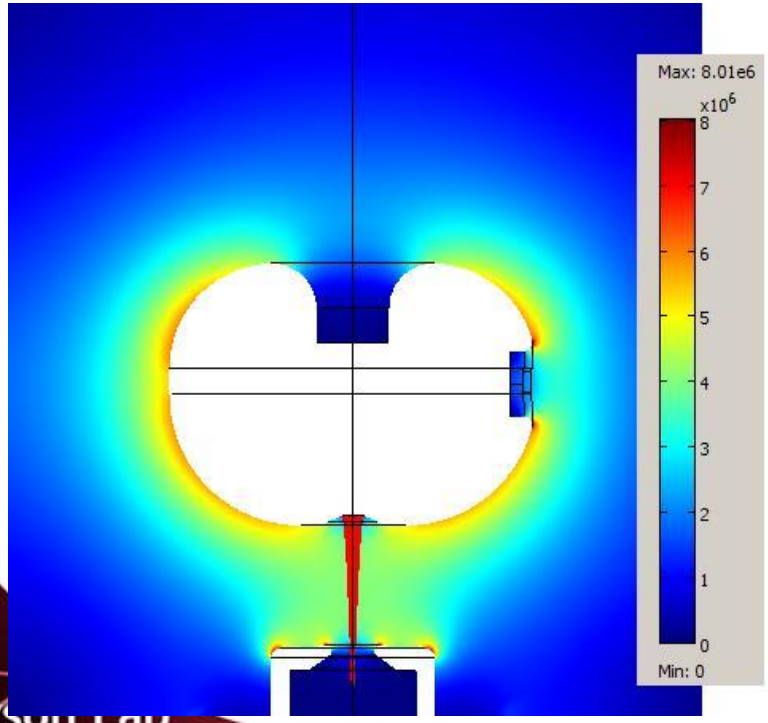
Backup Slides

Plan C

From Al Dudas and Mike Neubauer, Muons Inc.







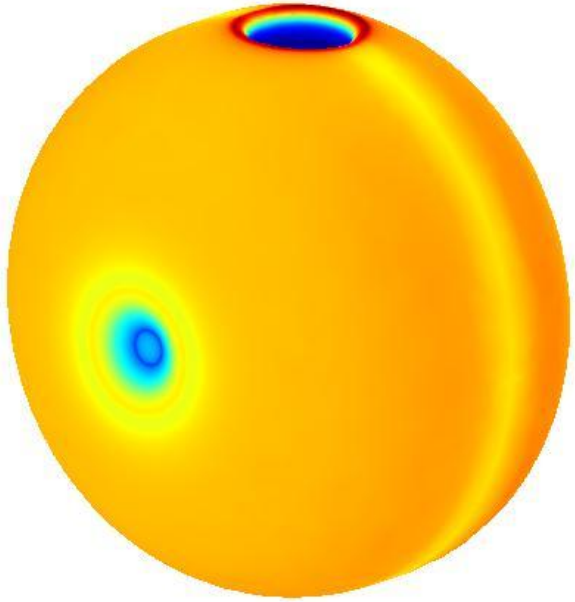
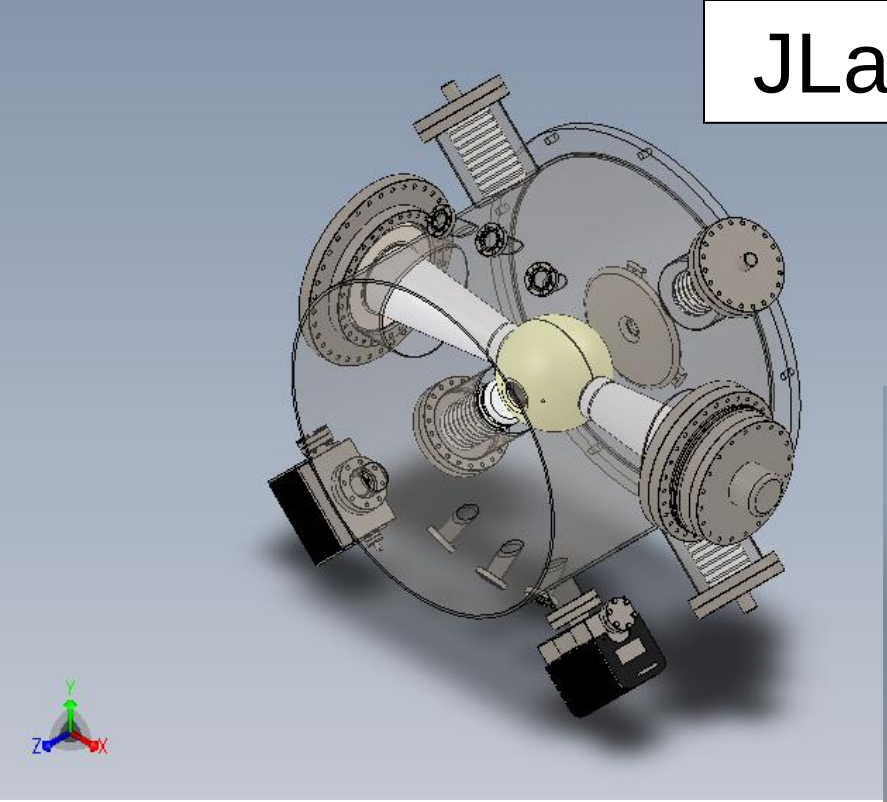
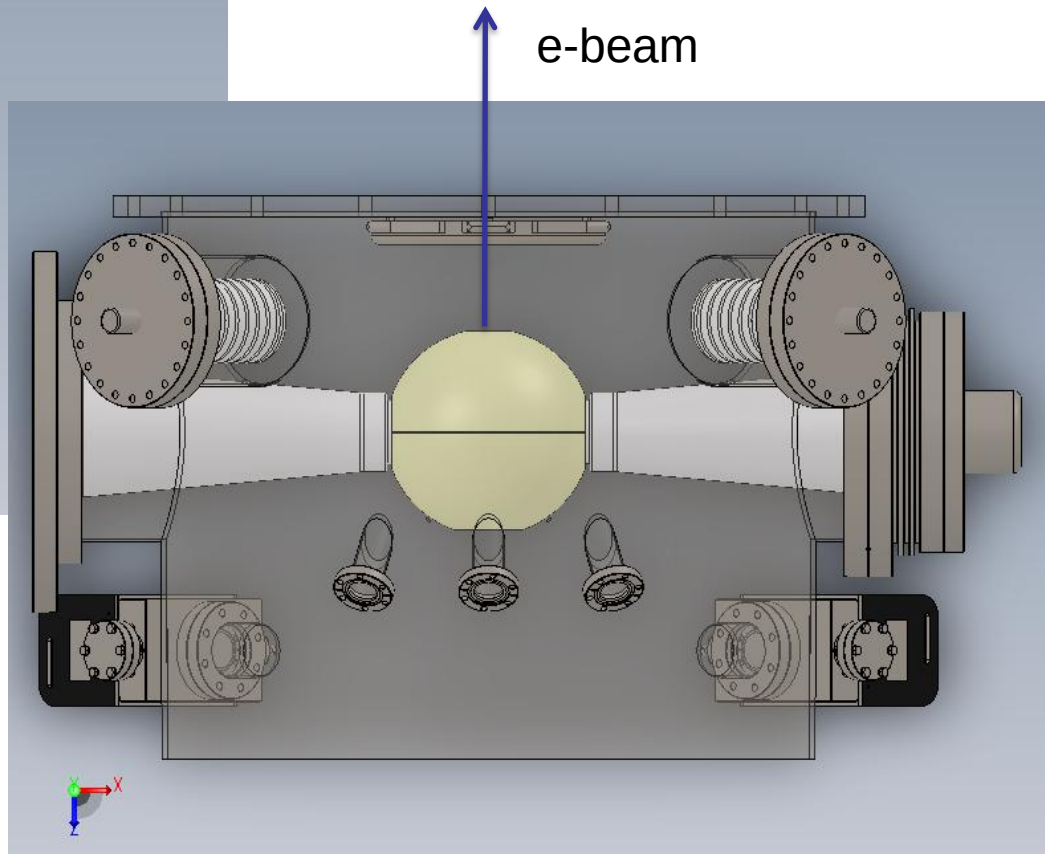


Figure 10. "Ball" type gun electrode with a side support for the inverted ceramic calculated for 250 kV. The maximum gradient was 8 MV/m and but the region around the ceramic is not shielded from the max gradient.

JLab FEL 500kV inverted gun

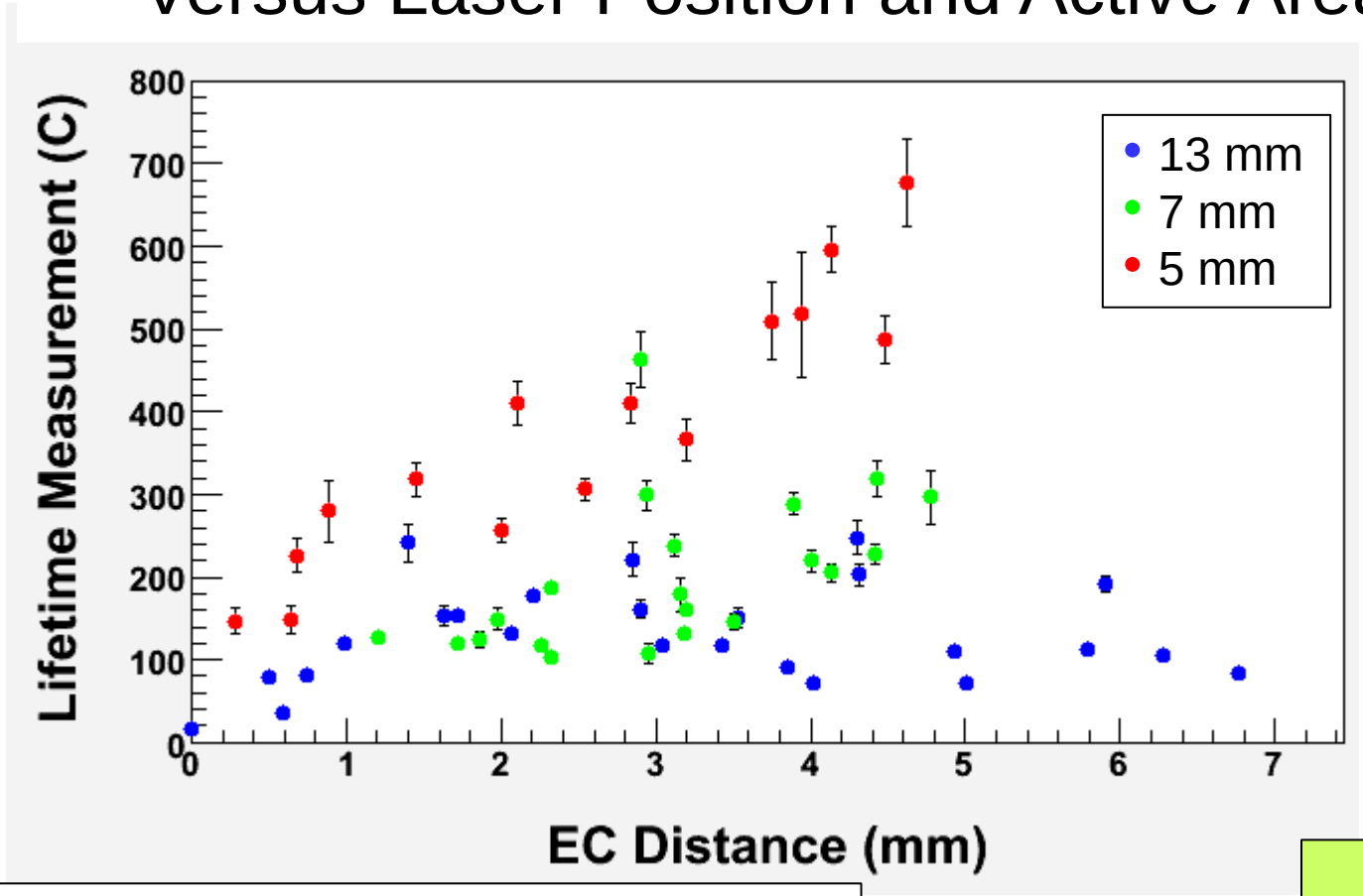




- Condition to 600kV, operate at 500kV
- 3x bigger inverted insulator compared to CEBAF gun
- One insulator for HV: one for cooling
- Niobium electrode – no diamond paste polishing
- Work in-progress

Courtesy: M. Marchlick, G. Biallis, C. Hernandez-Garcia, D. Bullard, P. Evtushenko, F. Hannon, and others from JLab-FEL

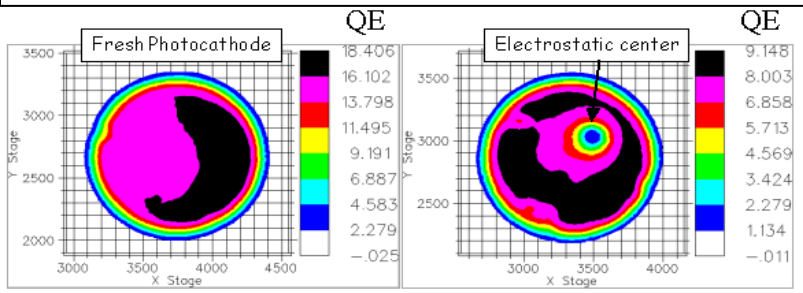
InvGun2 : Lifetime at 2mA and 100kV bias: Versus Laser Position and Active Area



DC beam from bulk GaAs, green light and 350um spot.

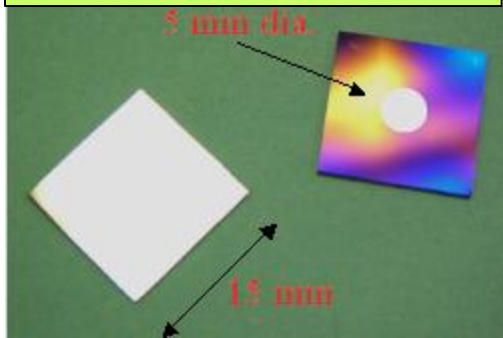
Similar (good) results as with older guns, at 100kV

Finite lifetime due to ion back-bombardment

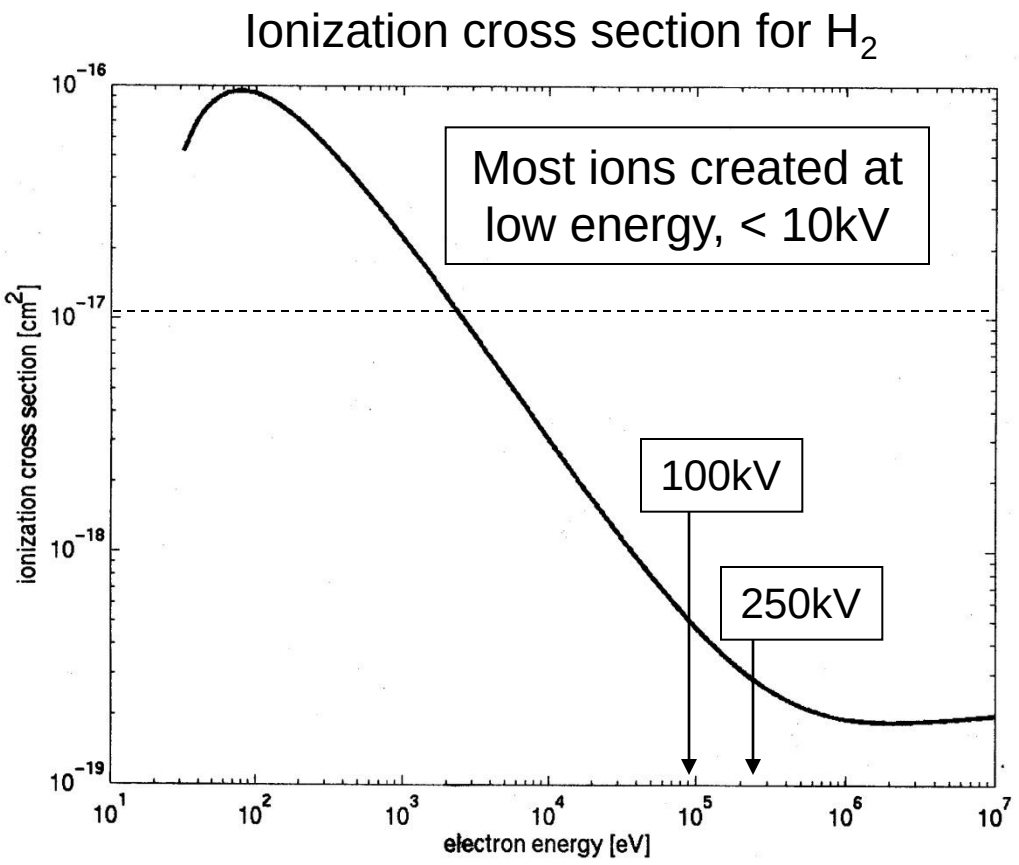


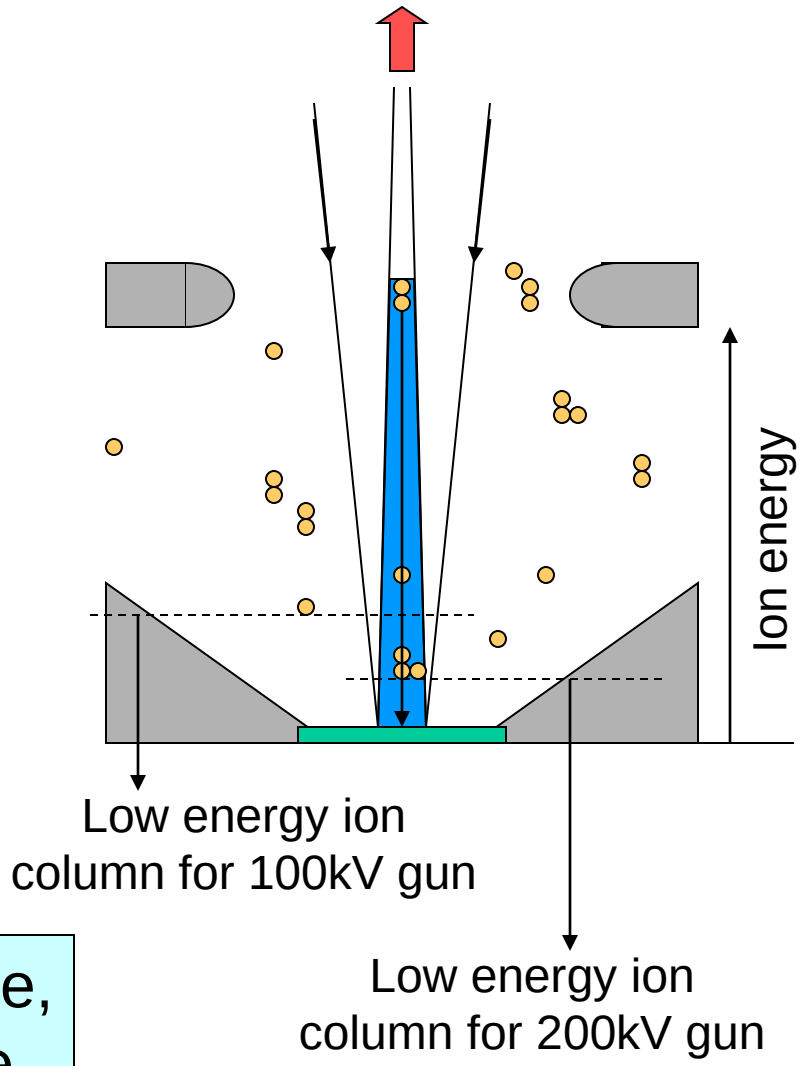
Work of Riad Suleiman

Now we mask…



Improve Lifetime with Higher Bias Voltage?

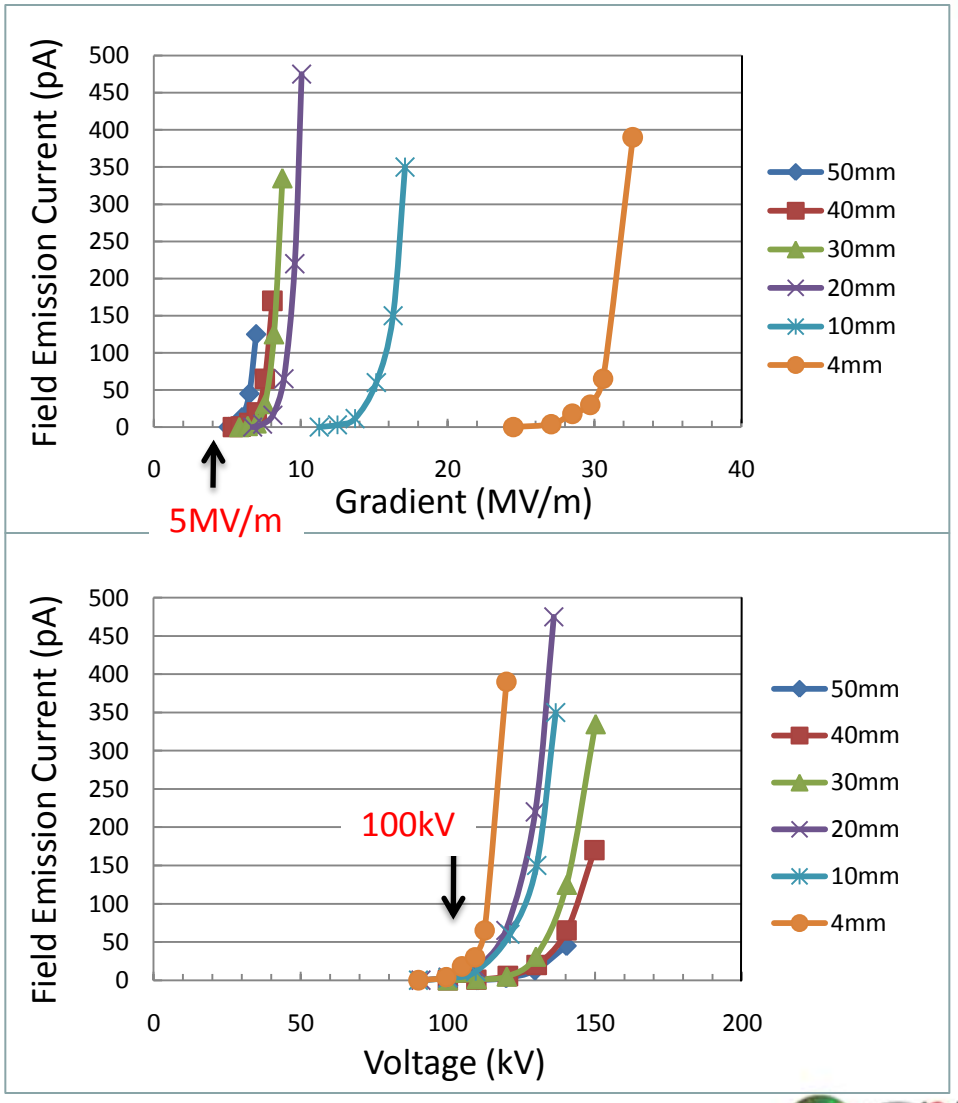




Hypothesis: Double the gun voltage, halve the # of “bad” ions, improve lifetime by 2

Field Emission – Most Important Issue

Stainless Steel and Diamond-Paste Polishing
Good to ~ 5MV/m and 100kV.



- Previous measurements with flat electrodes, small gaps and low voltage - not very useful
- Want to keep gun dimensions about the same – suggests our 200kV gun needs “quiet” electrodes to 10MV/m

Work of Ken Surles-Law, Jefferson Lab