USPAS Course on Photocathode Physics

John Smedley, BNL and Matt Poelker, TJNAF

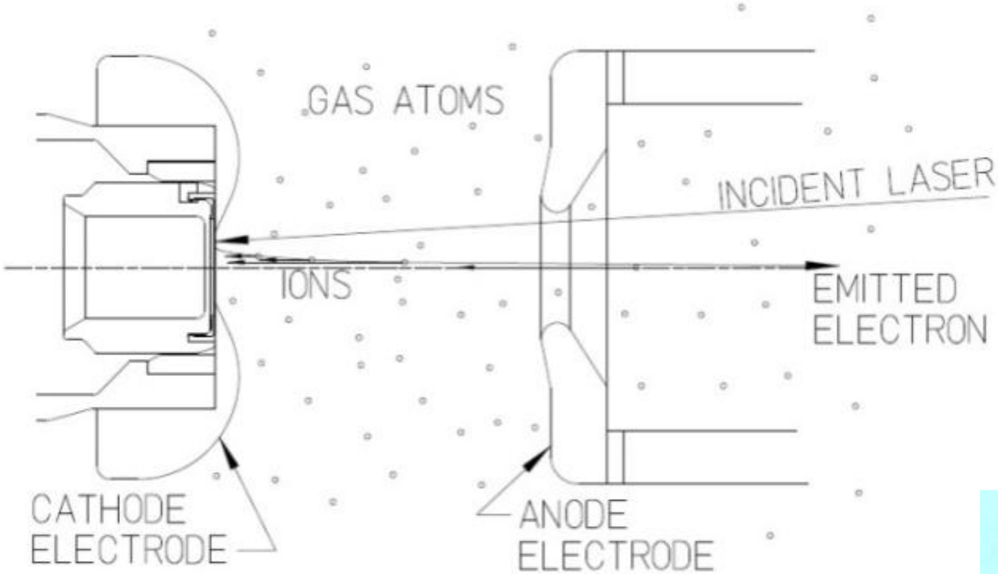
Lecture 8
Practical Matters

Austin, TX   January 16-20, 2011

Lecture 8:

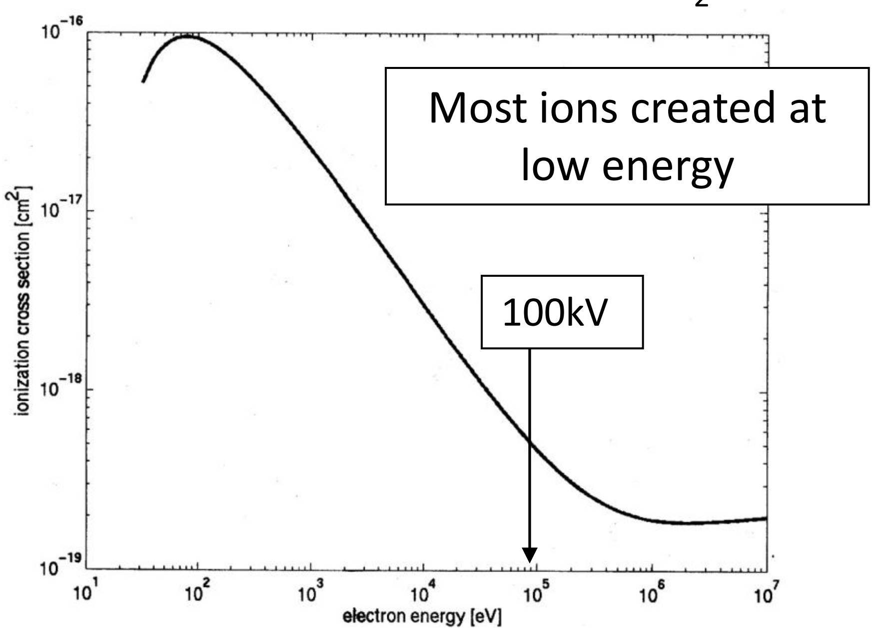
- Ion Bombardment
- High Voltage: avoiding breakdown and field emission
- A clean photocathode
- Vacuum Hot Filament Gauges

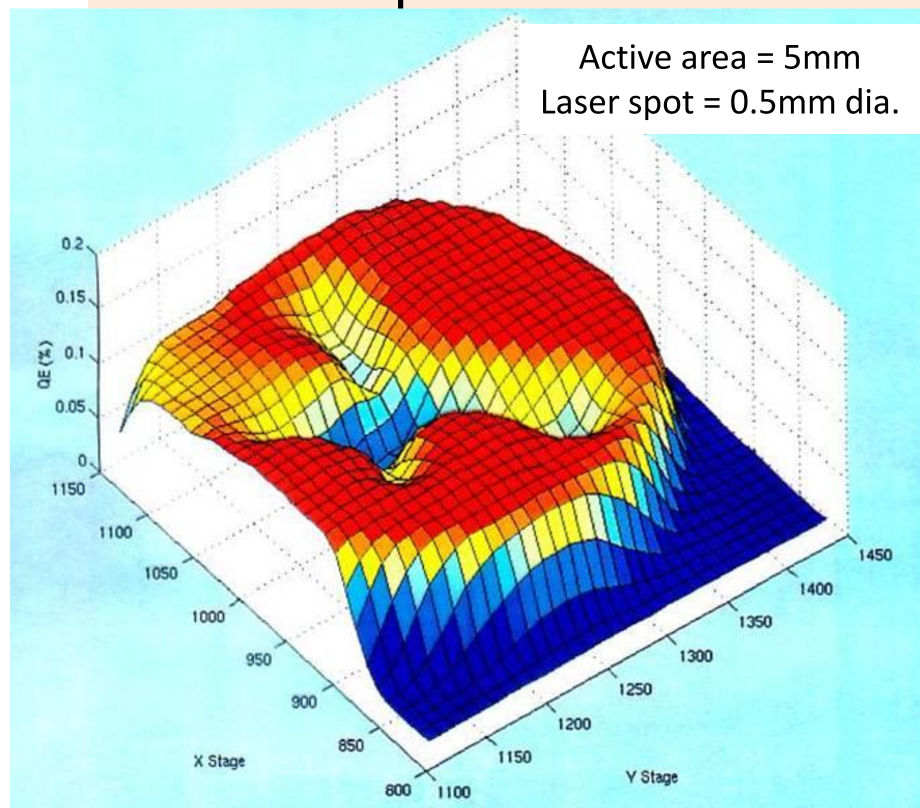
Imperfect Vacuum = Finite Lifetime



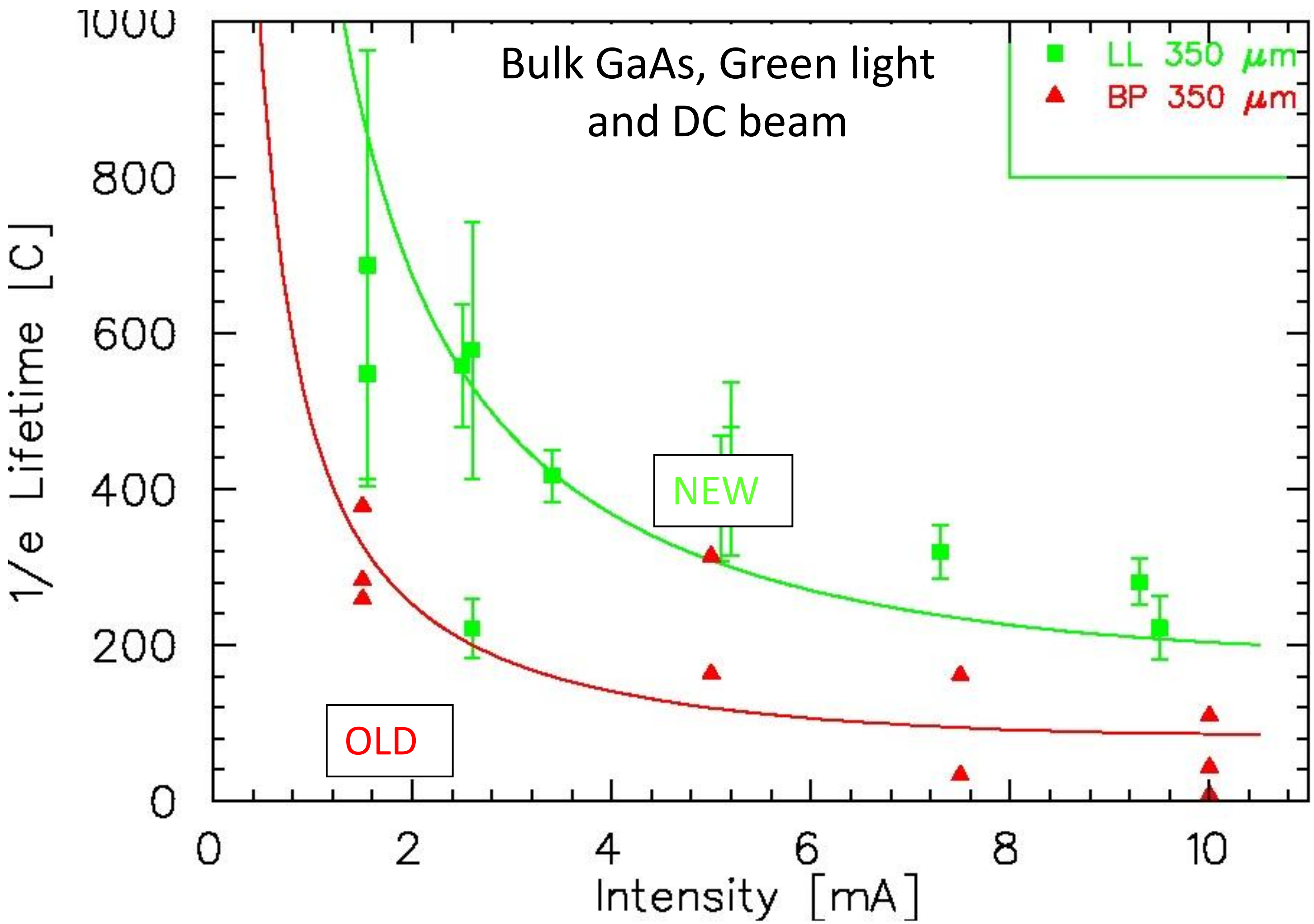
- What about while you run beam?
- Ion bombardment – notice characteristic "trench" from laser spot to electrostatic center of photocathode

Ionization cross section for H_2





Compare NEW and OLD load locked guns



Better Vacuum in New Gun ➡ better Lifetime!

"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

But Sometimes Lifetime is Still Not Good!!

- ✓ OK, good vacuum. What else matters?

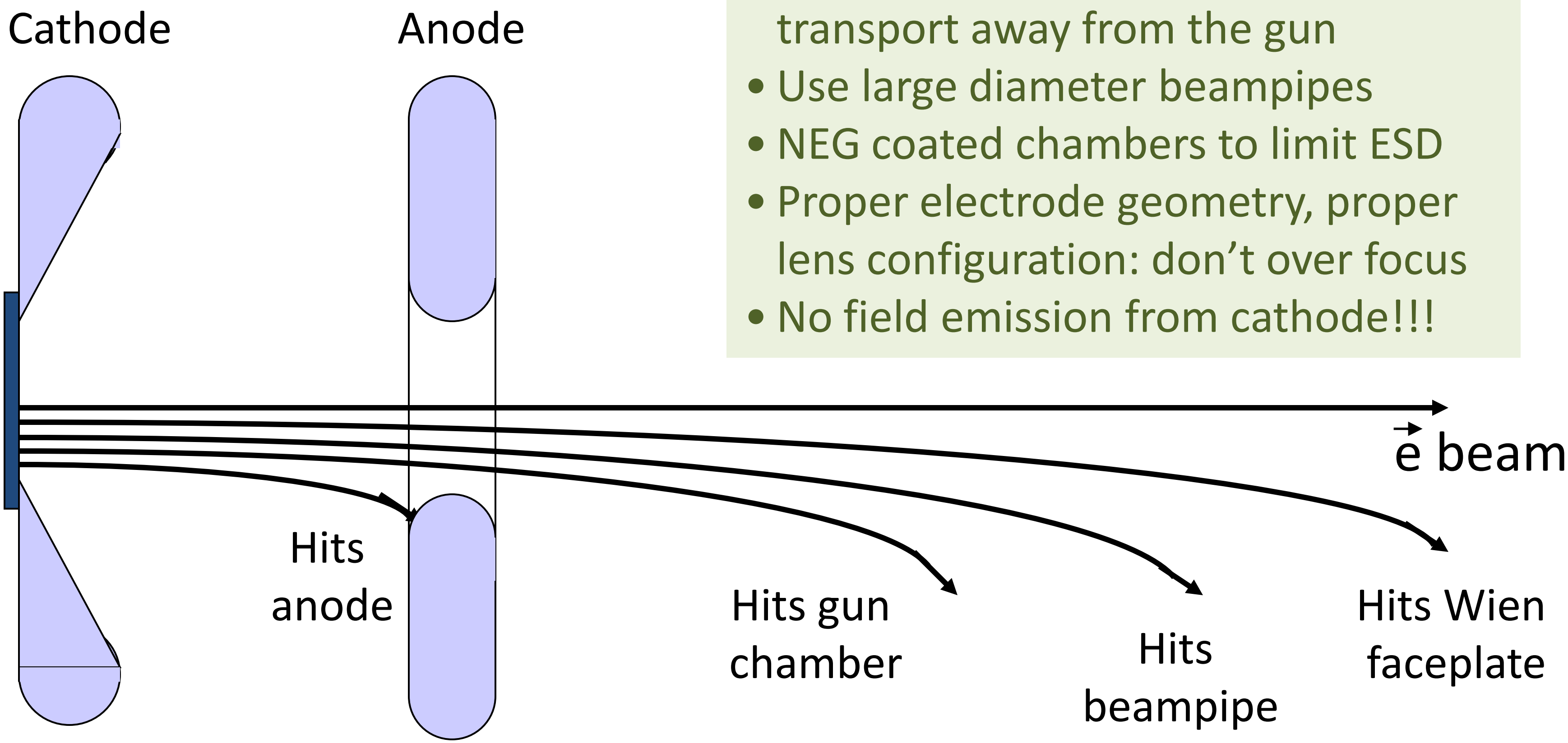
- ❖ Clean laser beam, no stray light
- ❖ Good orbit, proper electron beam optics
- ❖ No field emission from cathode

- ➢ Reduce the active area of photocathode
- ➢ Move the laser away from the electrostatic center
- ➢ Increase the size of the laser beam
- ➢ Apply bias to the anode
- ➢ Operate at Higher Bias Voltage?

Good beam versus Bad Beam

The beam that doesn't make it to the experiment only serves to degrade vacuum. This leads to ion-bombardment and QE decay

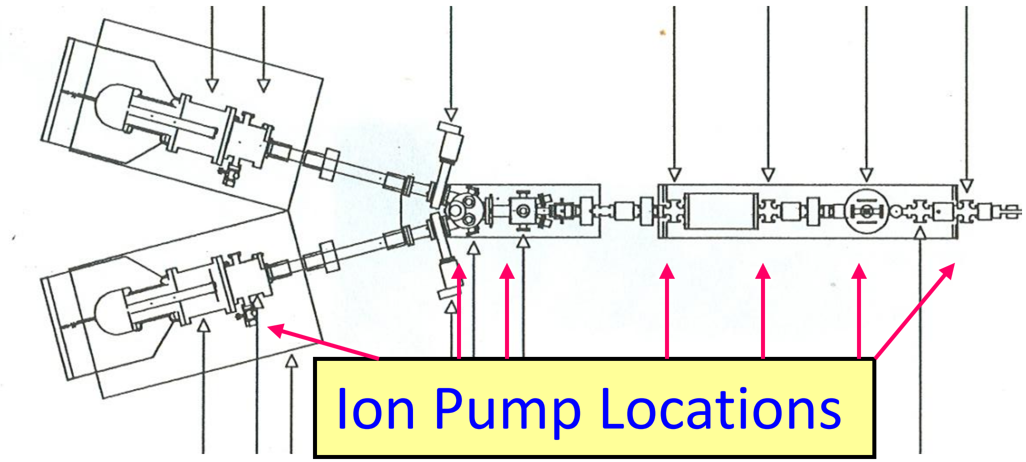
- Eliminate stray light
- Generate only electrons you can transport away from the gun
- Use large diameter beampipes
- NEG coated chambers to limit ESD
- Proper electrode geometry, proper lens configuration: don't over focus
- No field emission from cathode!!!



“Free” beam loss monitoring

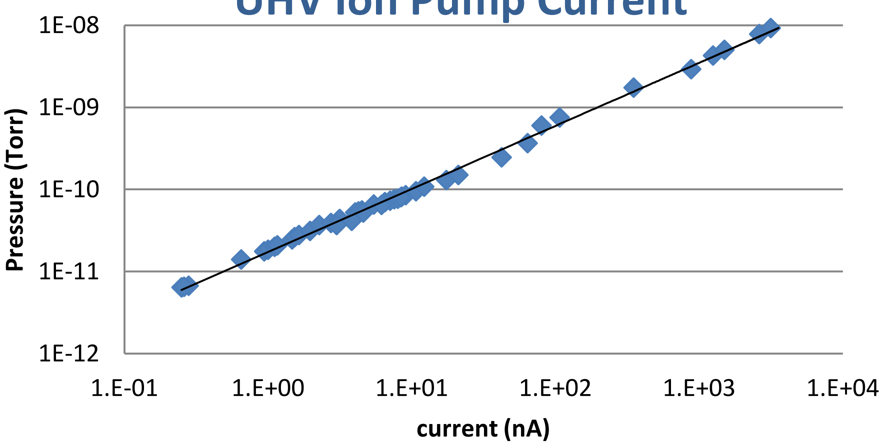
Designed and constructed by J. Hansknecht

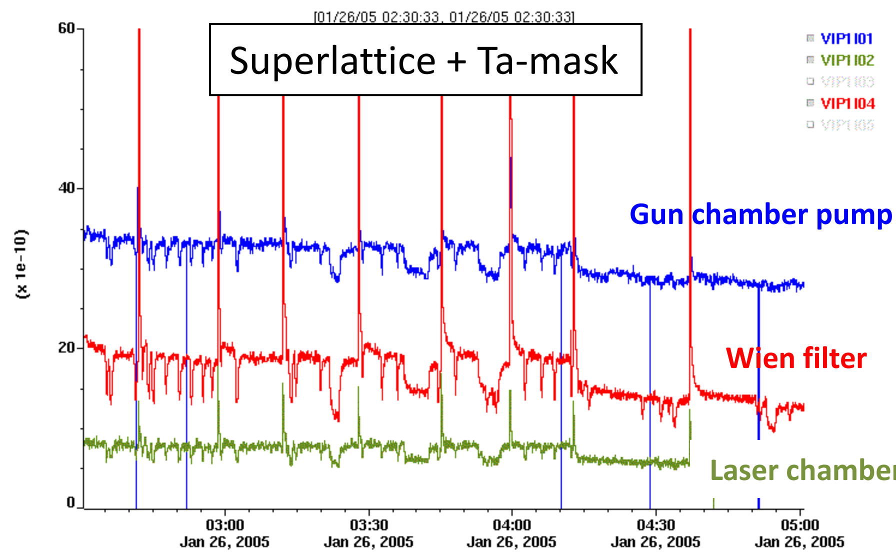
UHV Ion Pump Power Supplies



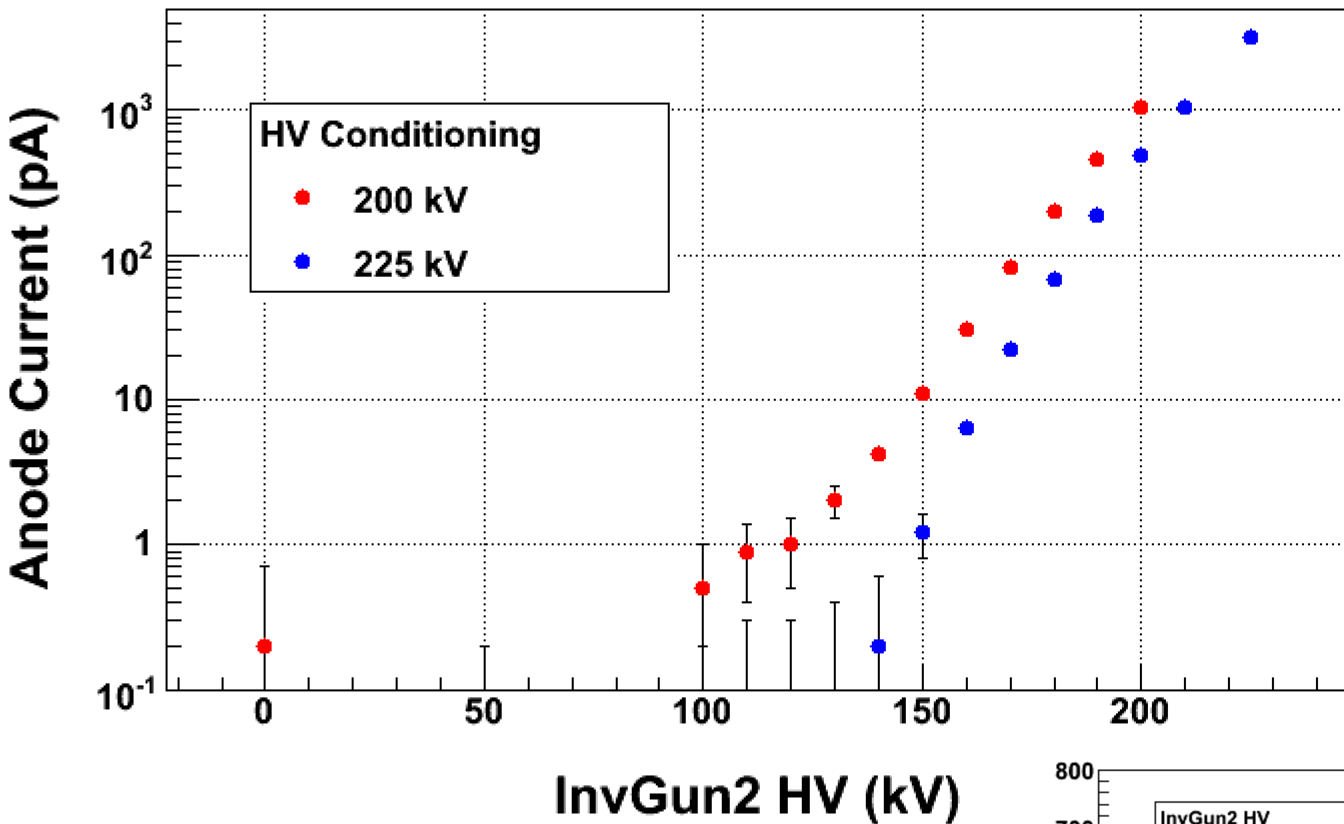
Ion Pumps detect bad orbit and beamloss

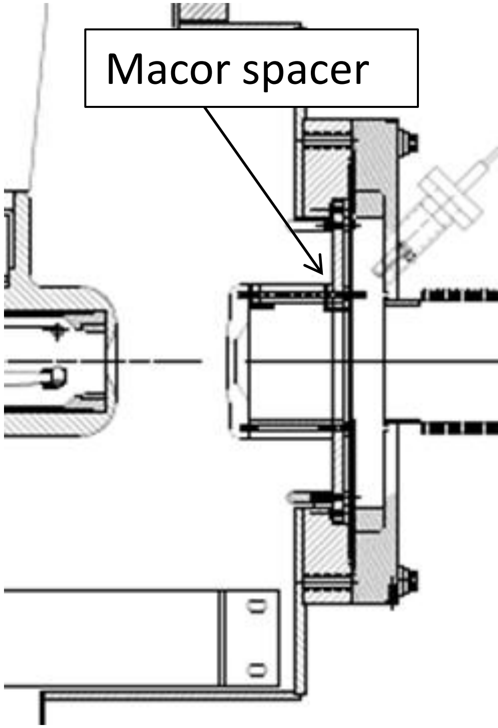
Extractor Gauge Pressure vs. UHV Ion Pump Current



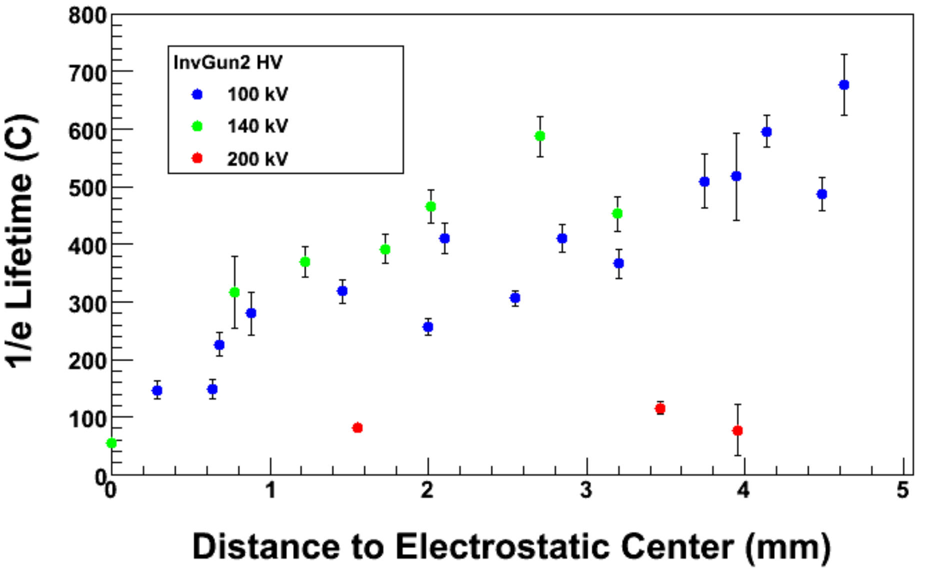


Field Emission measured at (floating) anode versus Gun Bias Voltage



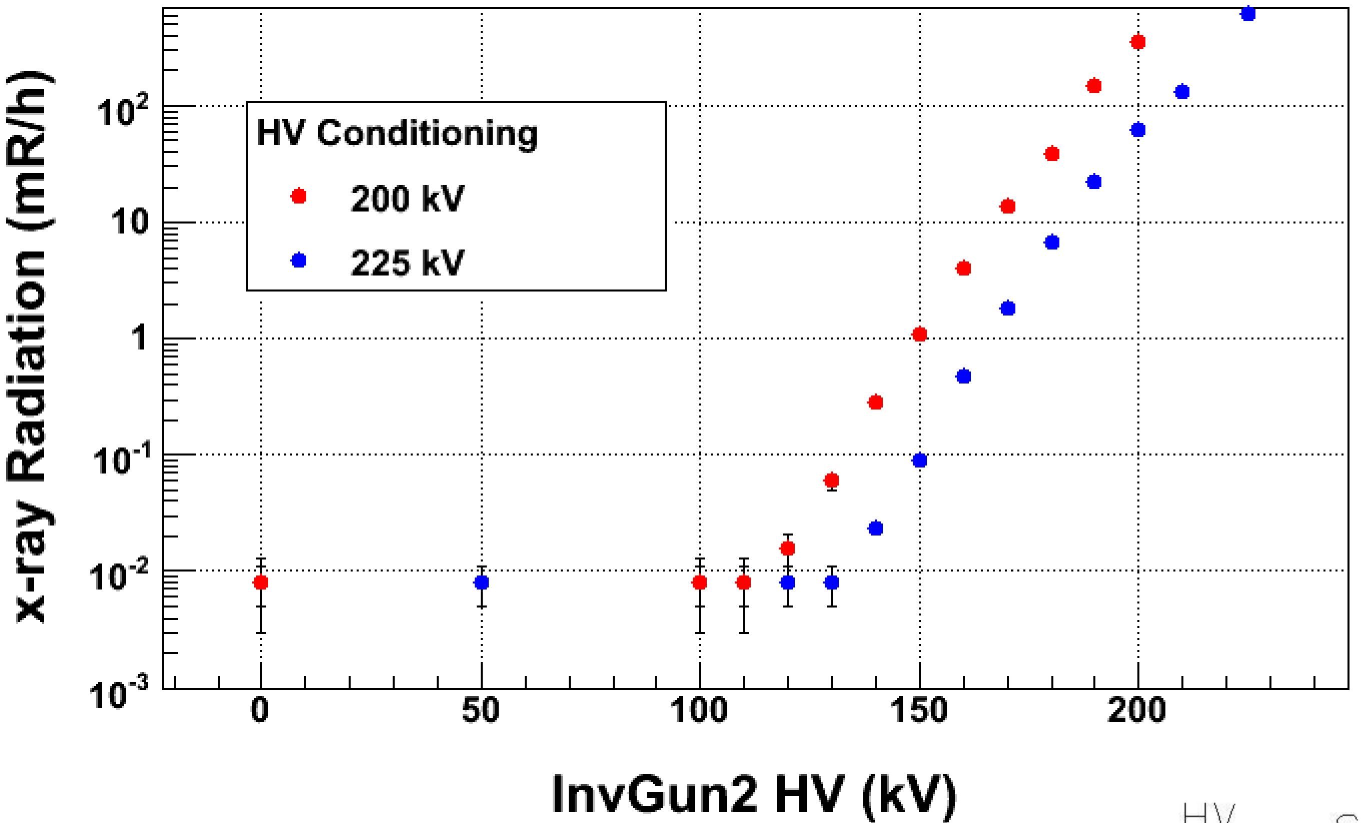


How much field emission is acceptable?
unfortunately, it seems if you can measure it, it's too much



Work of Riad Suleiman

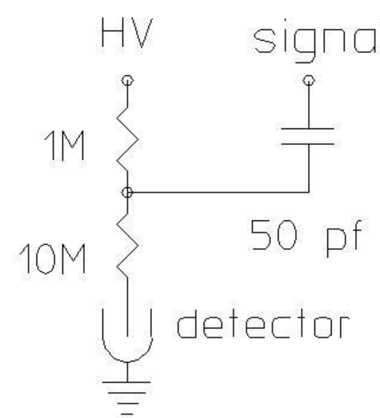
Anode won't always capture all FE…. Better to look for x-rays….

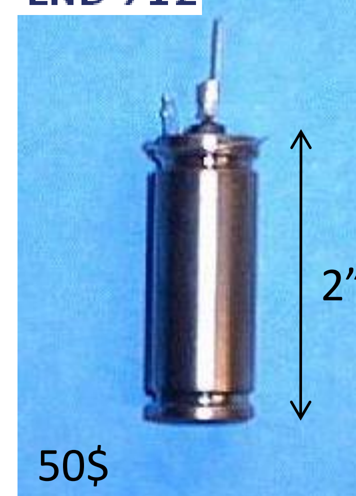


CANBERRA ADM 616 with Model IP100 Ion Chamber Detector

LND, INC.
OCEANSIDE, NEW YORK, USA

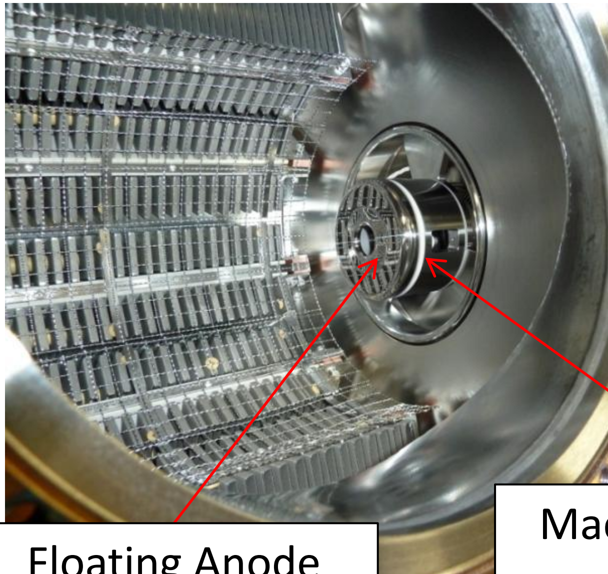
LND 712





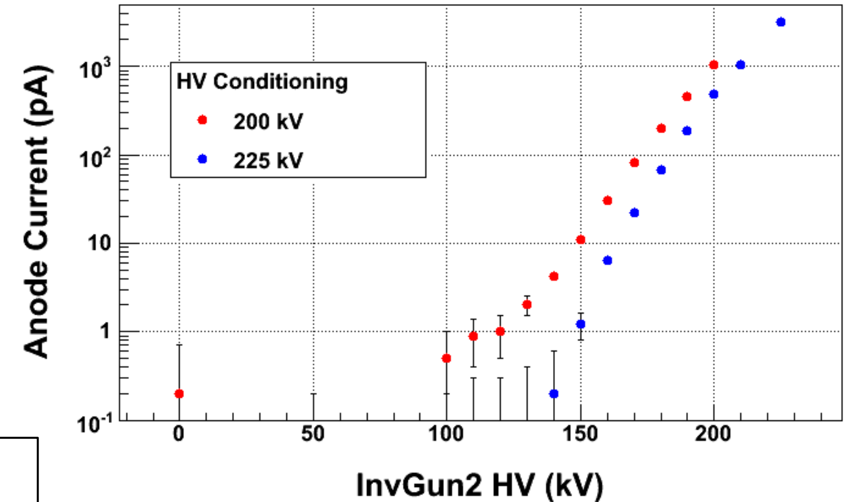
Built an inexpensive radiation monitoring system: lots of GM tubes, powered by one HV supply and data stream to computer via RS232

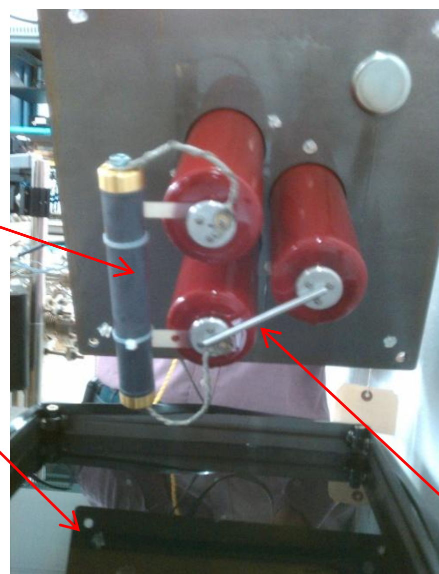
HV "Conditioning": sometimes it works



Floating Anode connected to Pico-ammeter

Macor glass-ceramic spacer

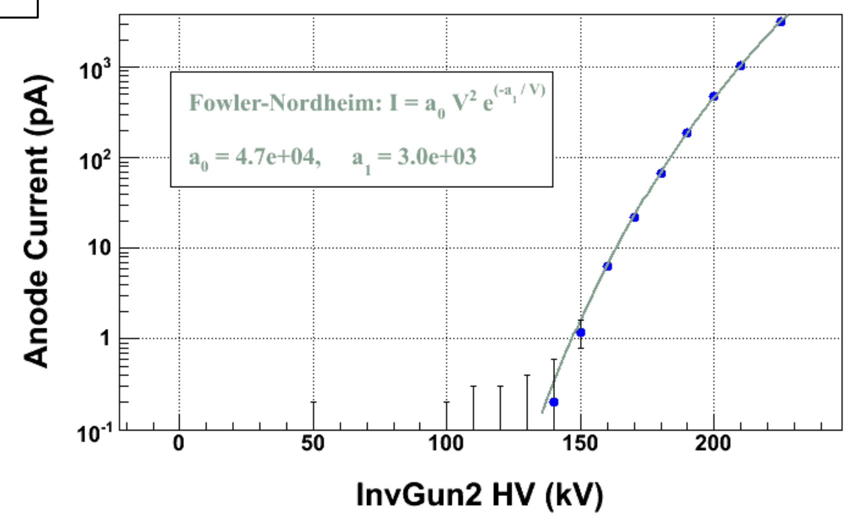




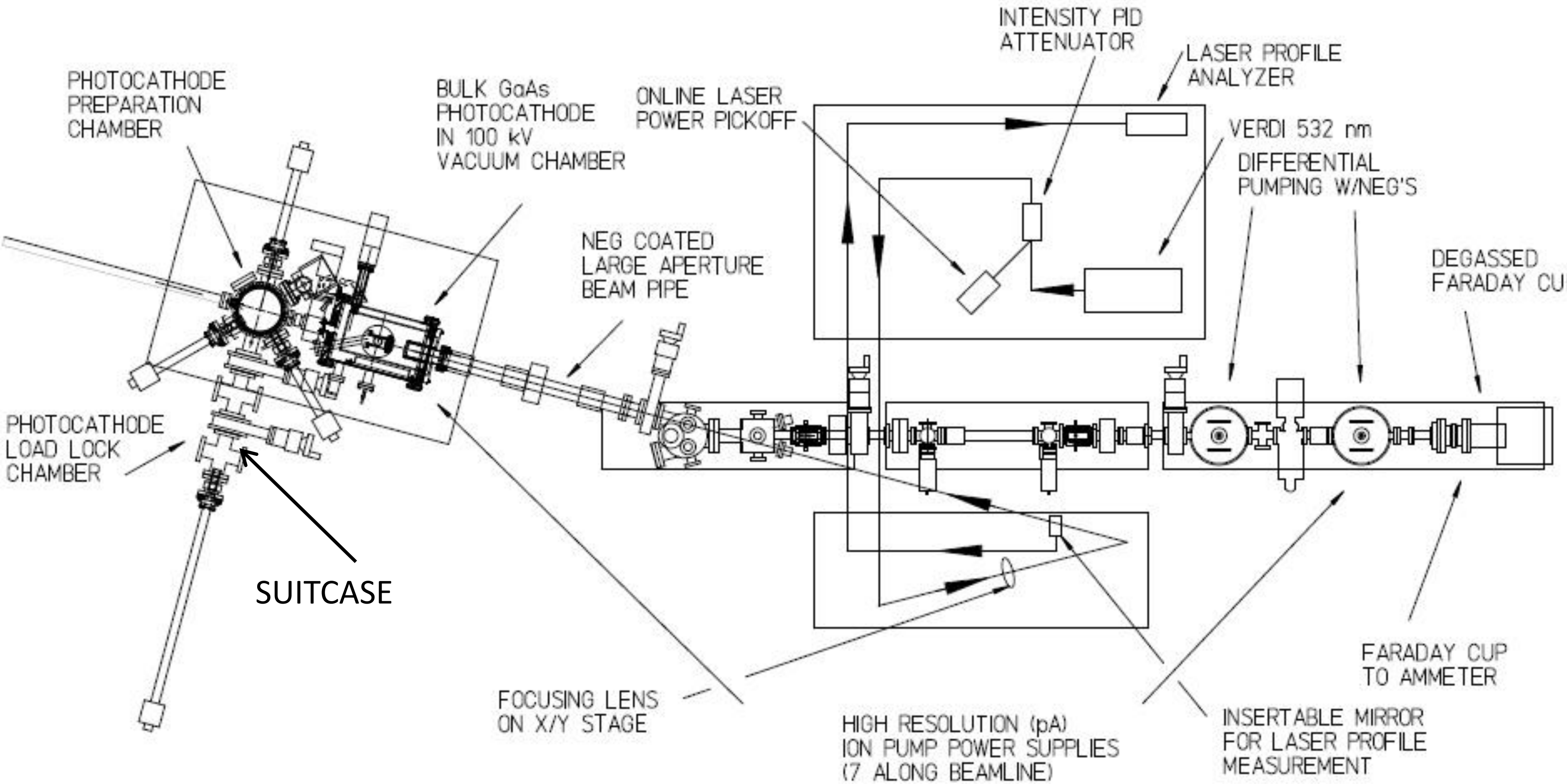
100 MΩ Conditioning Resistor

Oil Tank

A Short for Beam Delivery

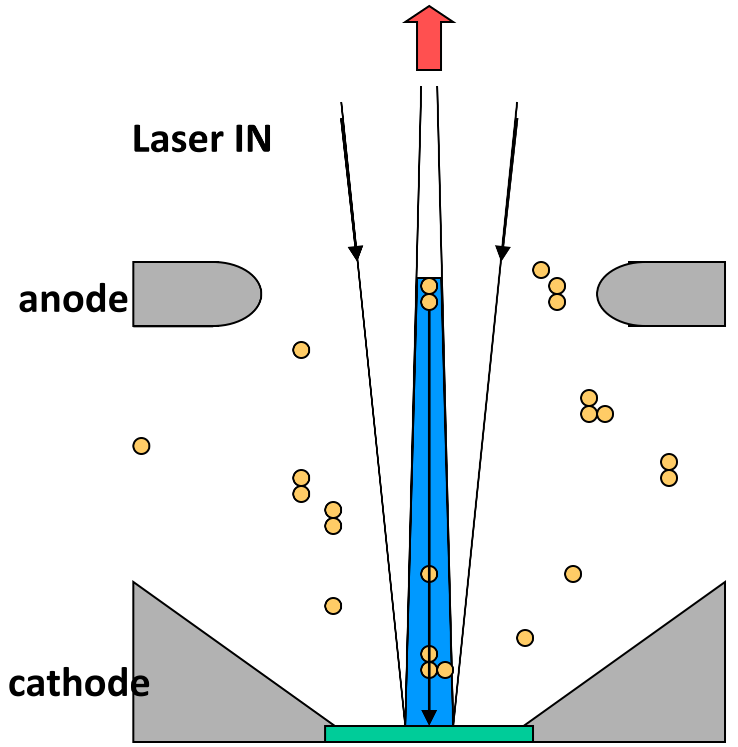


Lifetime Experiments at the Injector Test Cave

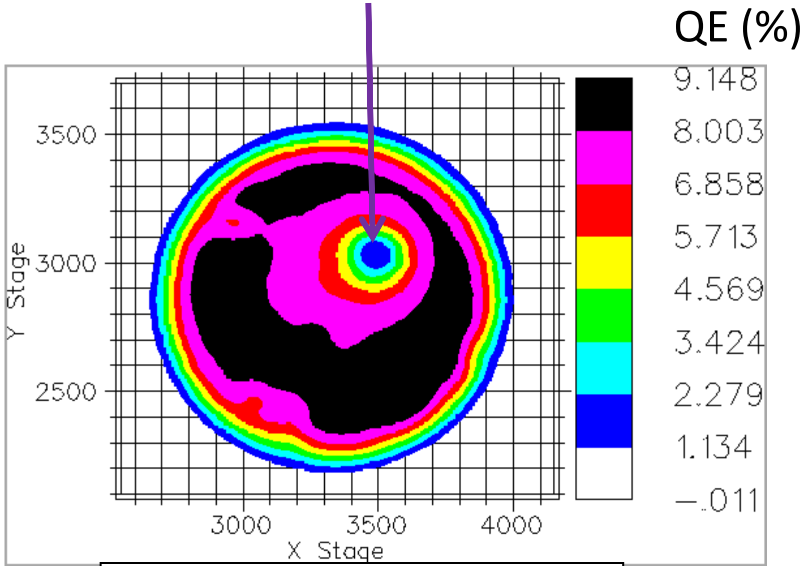



DANGER
EXIT
CAUTION

Imperfect Vacuum and Ion Bombardment



The electrostatic center



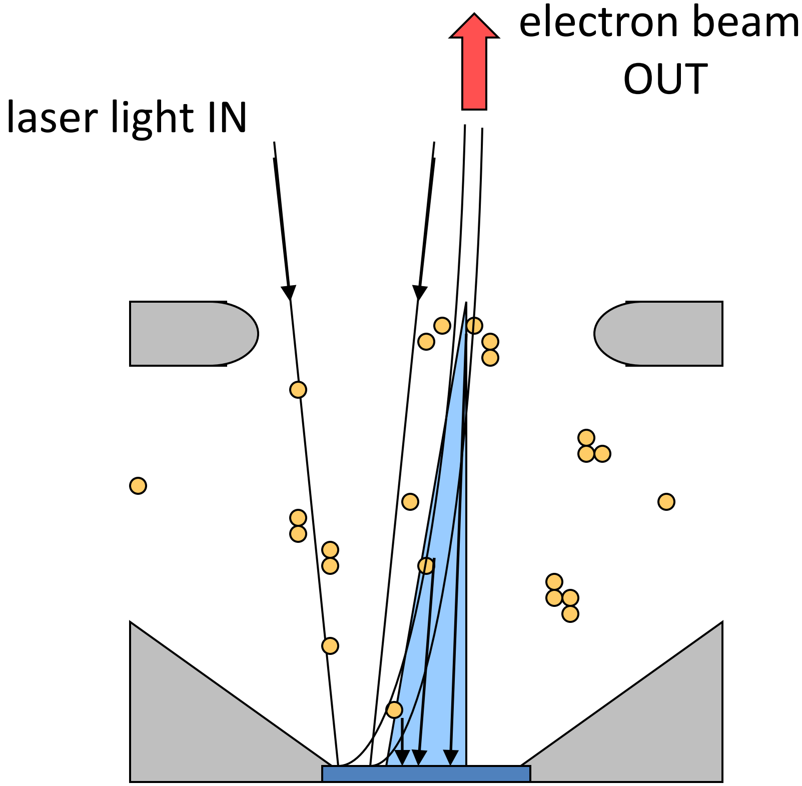
QE scan of photocathode

Electron beam makes ions, that are attracted to the EC of the photocathode

I mentioned other factors can limit lifetime: Field emission, photocathode material, laser wavelength, laser radial position on photocathode, beam optics, gun voltage

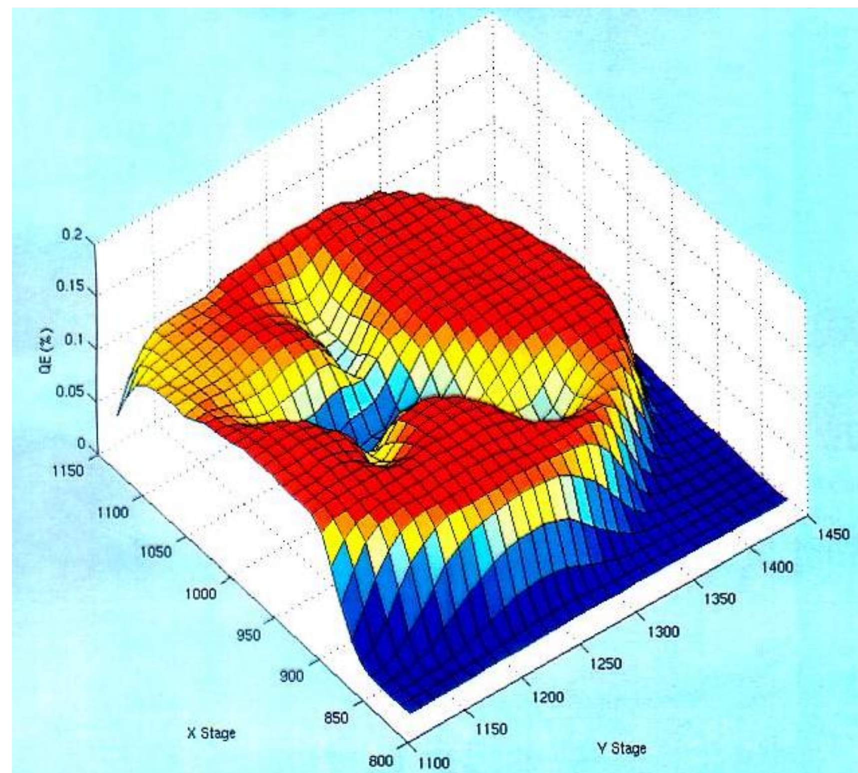
Avoid the Electrostatic Center (EC)

We don't run beam from electrostatic center



Ions create QE trough to electrostatic center

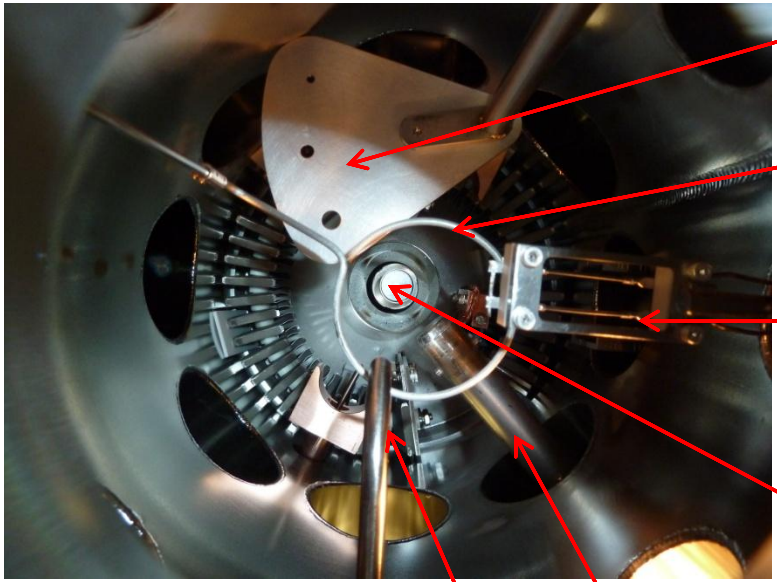
- characteristic QE "trench" from laser spot to EC. Ion are attracted to EC
- Laser spot size ~0.5 mm and can be moved to different locations on the photocathode.
- QE can be restored, but takes about 8 hours to heat and reactivate

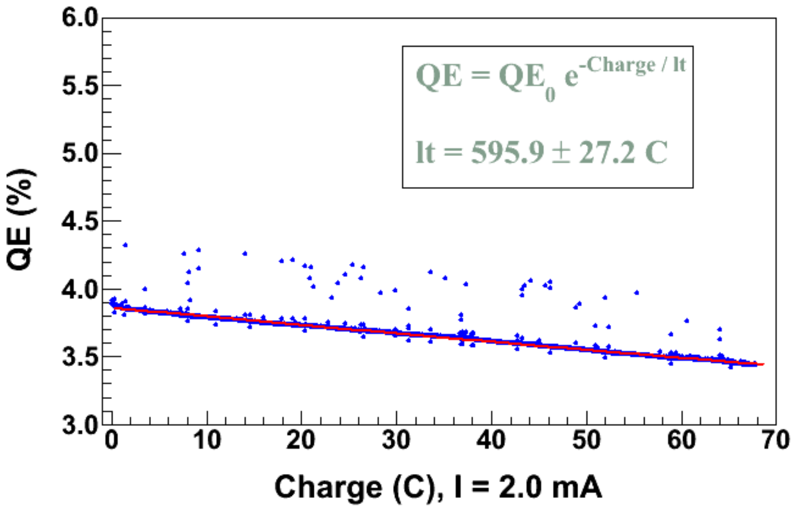


Lifetime vs. Laser Position and Active Area

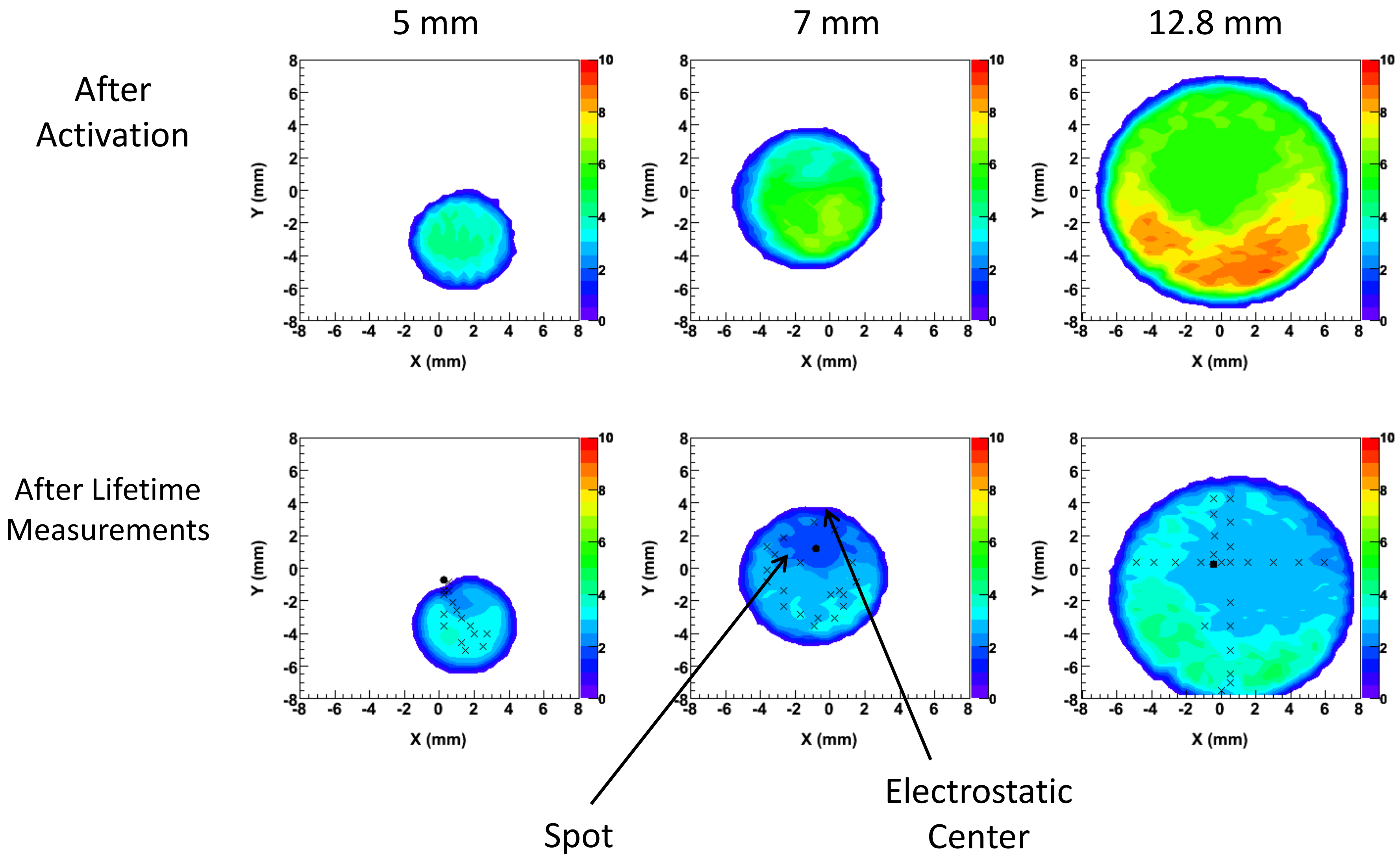
I. Activate with different Masks: 5 mm, 7 mm, and No Mask (12.8 mm)

II. Measure Lifetime from different spots on Bulk GaAs with 532 nm green laser





Lifetime vs. Laser Position and Active Area



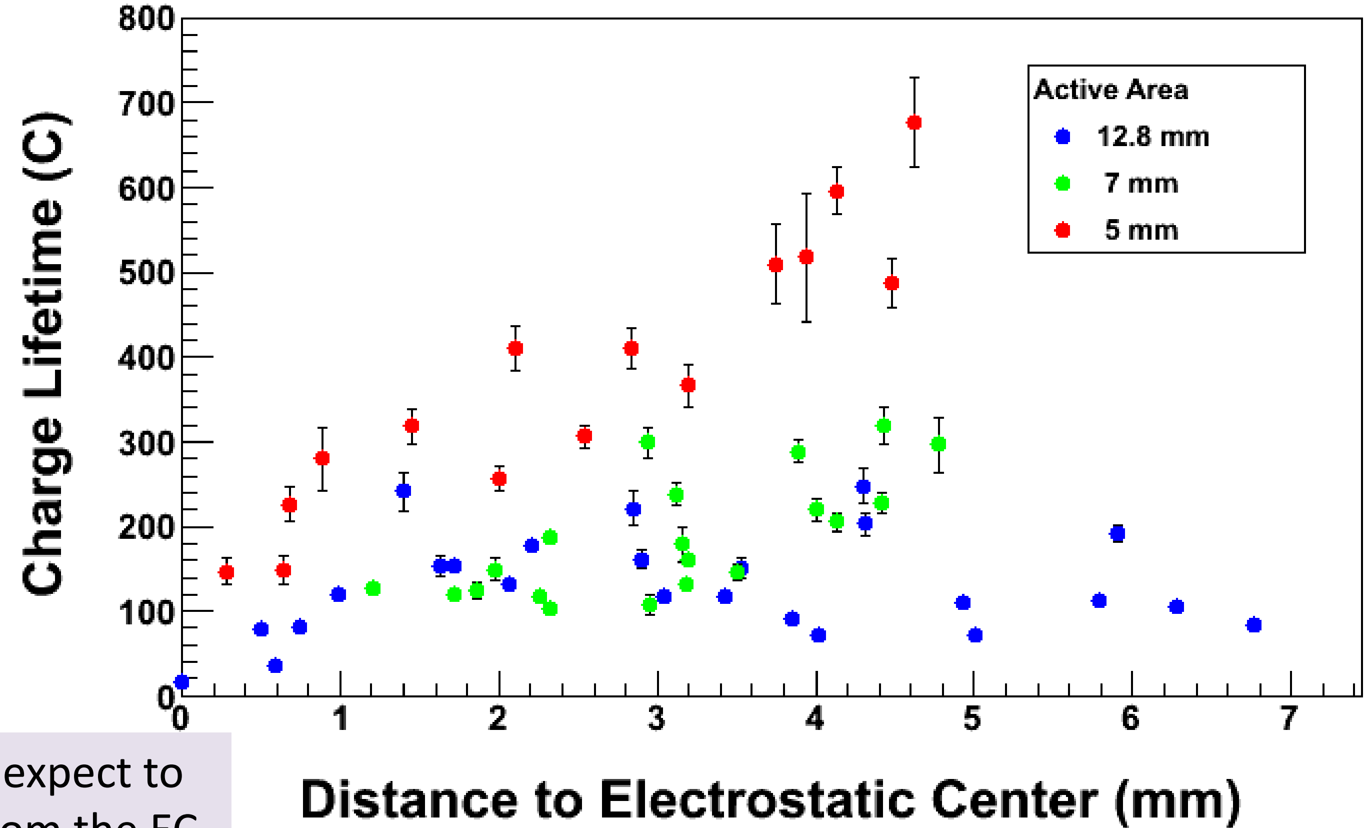
Lifetime vs. Laser Position and Active Area

Stray light, Spontaneous Emission from GaAs photocathode, and x-ray induced photoemission might be generating this "extra" beam

	I=0 (HV = 0, 100 kV)	I = 2 mA (Bulk GaAs, 532 nm, 350 μm Laser Spot) (HV = 100 kV)		
		5 mm Active Area	7 mm Active Area	12.8 mm Active Area
Anode Current (pA)	0.0 ± 0.3	0.0 ± 0.3	0.0 ± 0.3	-100 – -1000
X-ray Detector (E-2 mR/h)	0.6 ± 0.3	1.5 ± 0.5	1.8 ± 0.5	3 – 7
Gun Vacuum (pA)	0	0	0	0 – 30
Y-Chamber Vacuum (nA)	3.0	3.0	3.0	4 – 20

Lifetime vs. Laser Position and Active Area

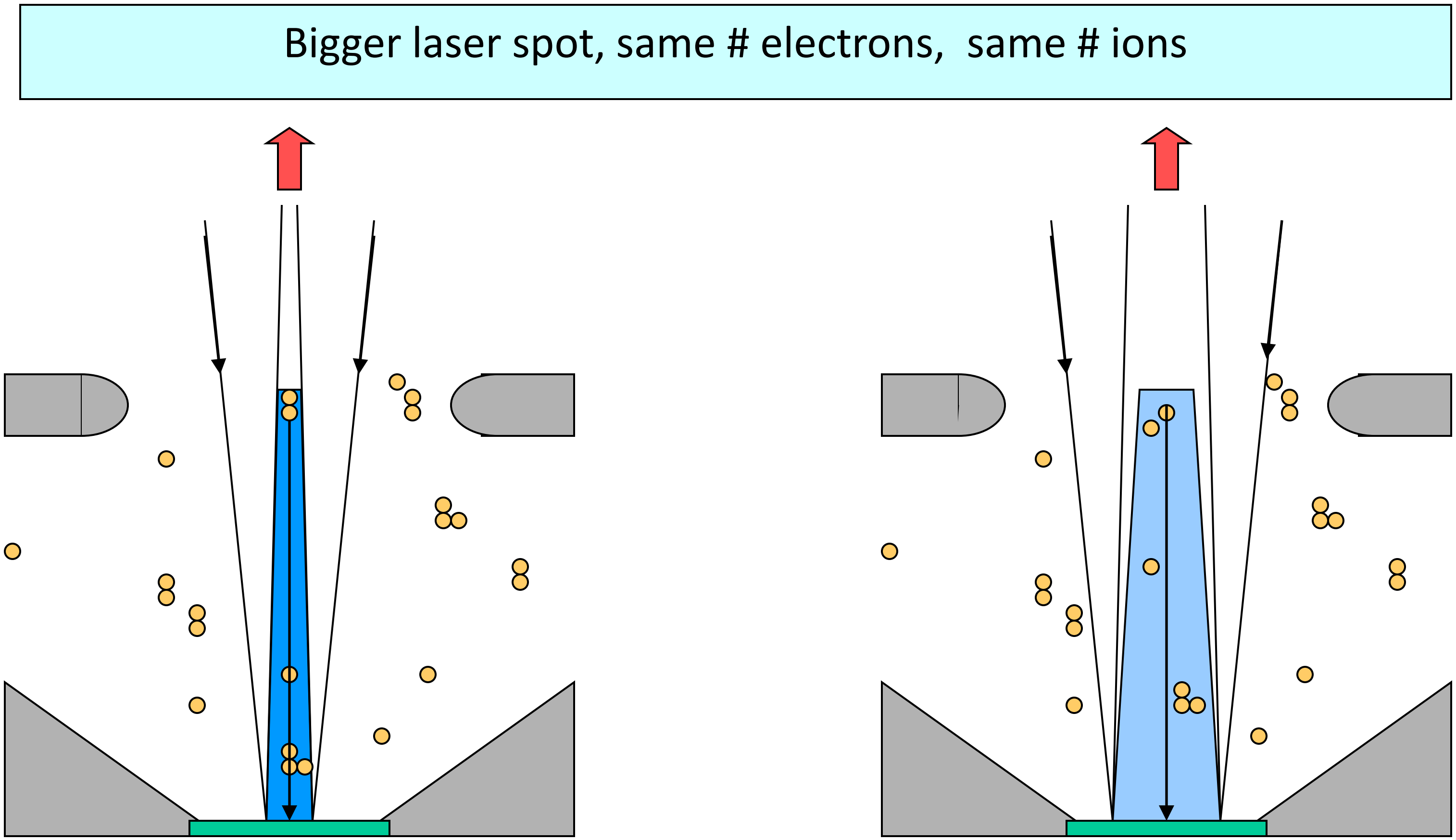
Lesson: electrons from the edge of the photocathode strike the anode and vacuum chamber walls, degrading vacuum and limiting lifetime.
Don’t make beam from the edge of the photocathode!!!



Also, don’t expect to run beam from the EC

Improve Lifetime with Larger Laser Spot?

(Best Solution – Improve Vacuum, but not easy)

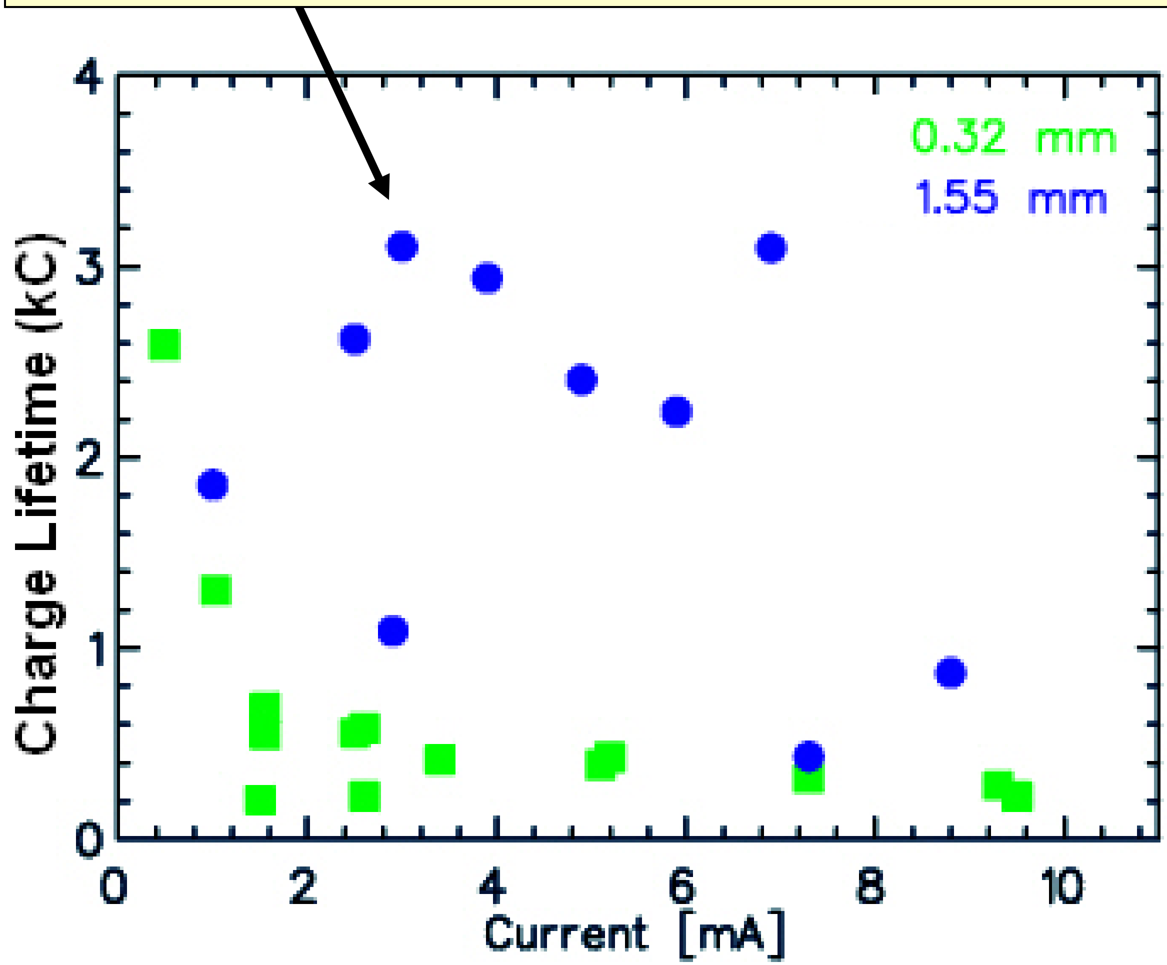


Ionized residual gas strikes photocathode

Ion damage distributed over larger area

Lifetime with Large/Small Laser Spots

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



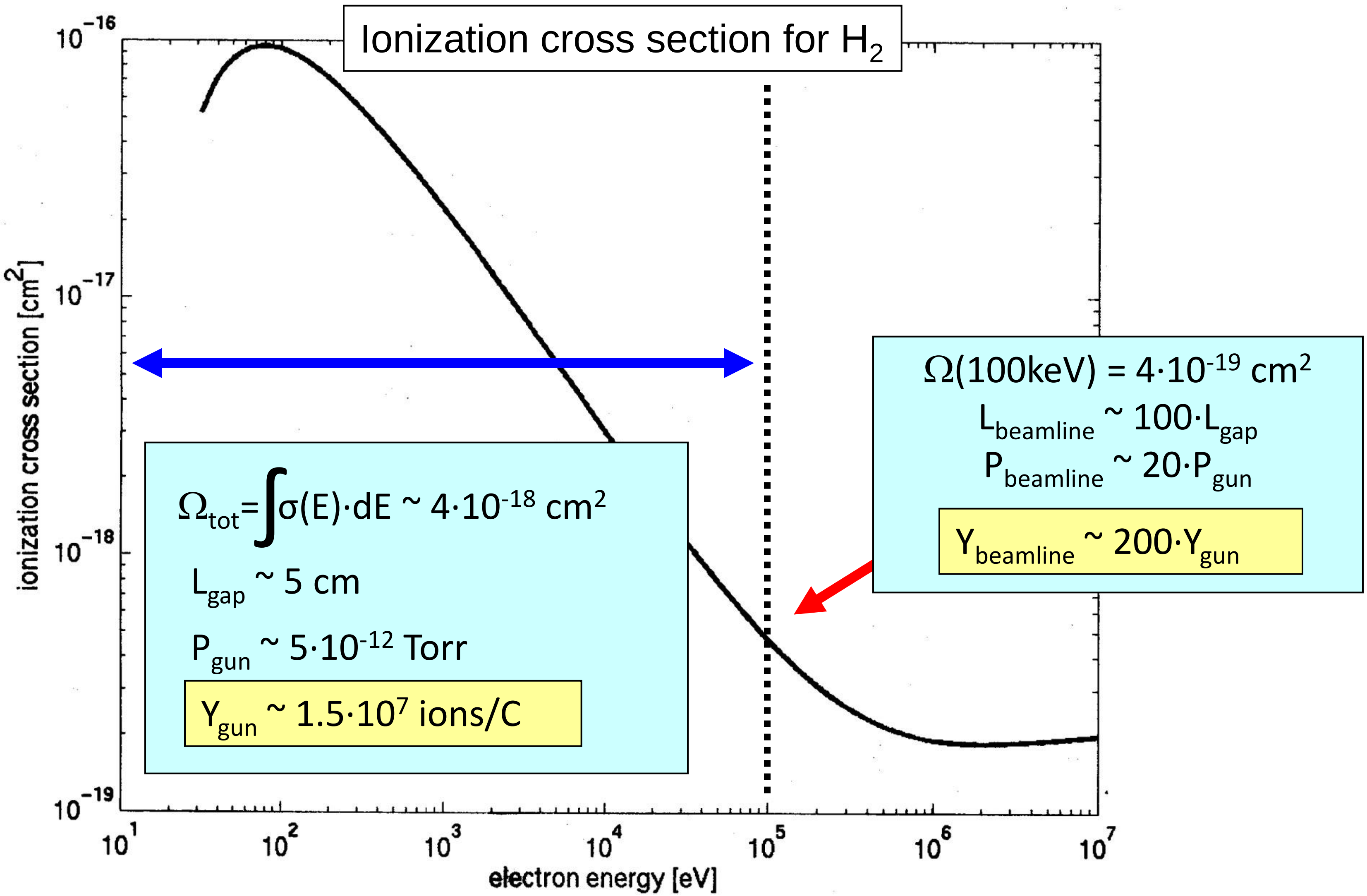
Factor of 5 to 10 improvement with larger laser spot size

Expectation:

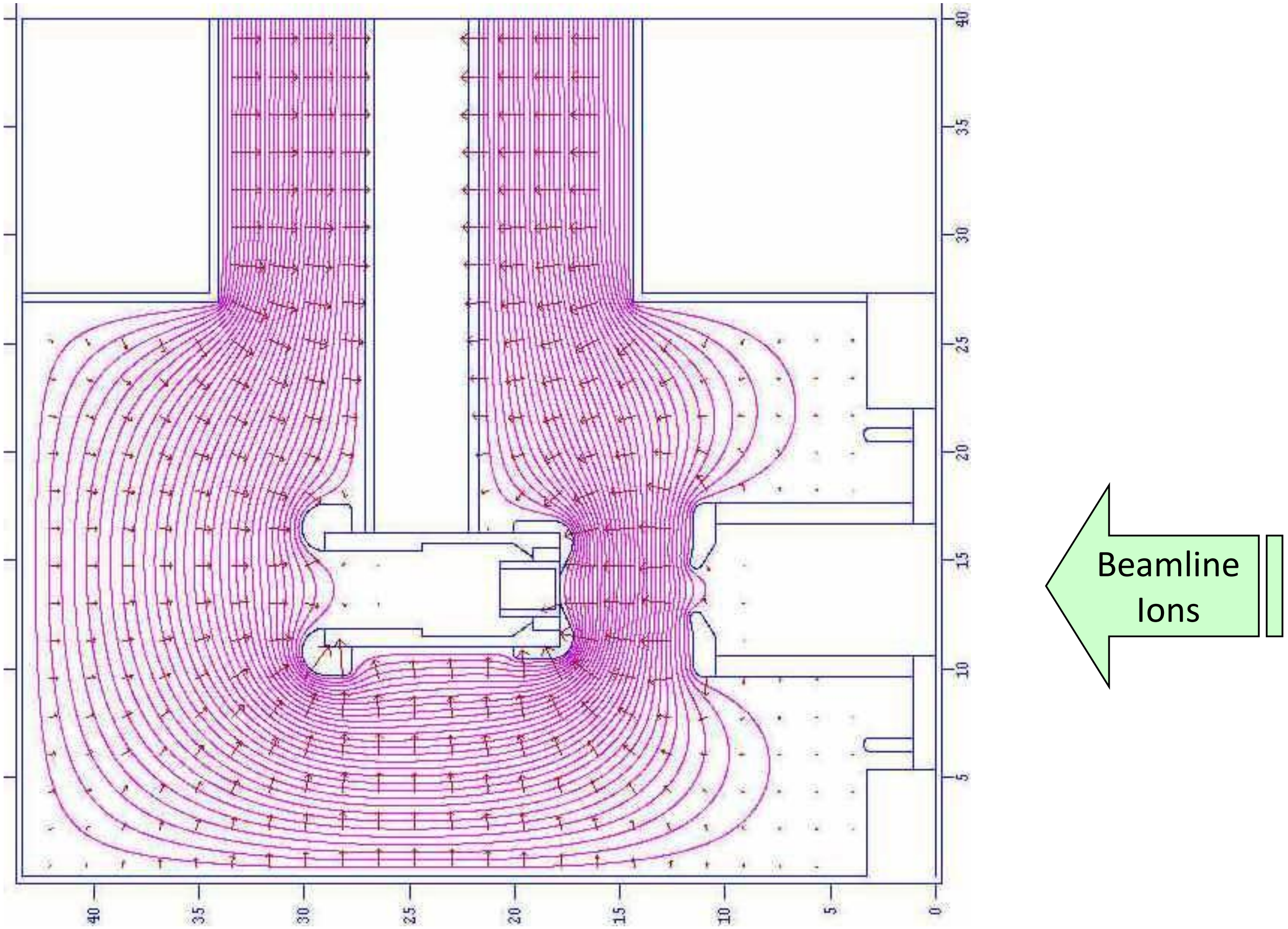
$$\left(\frac{1500}{350}\right)^2 \approx 18$$

"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

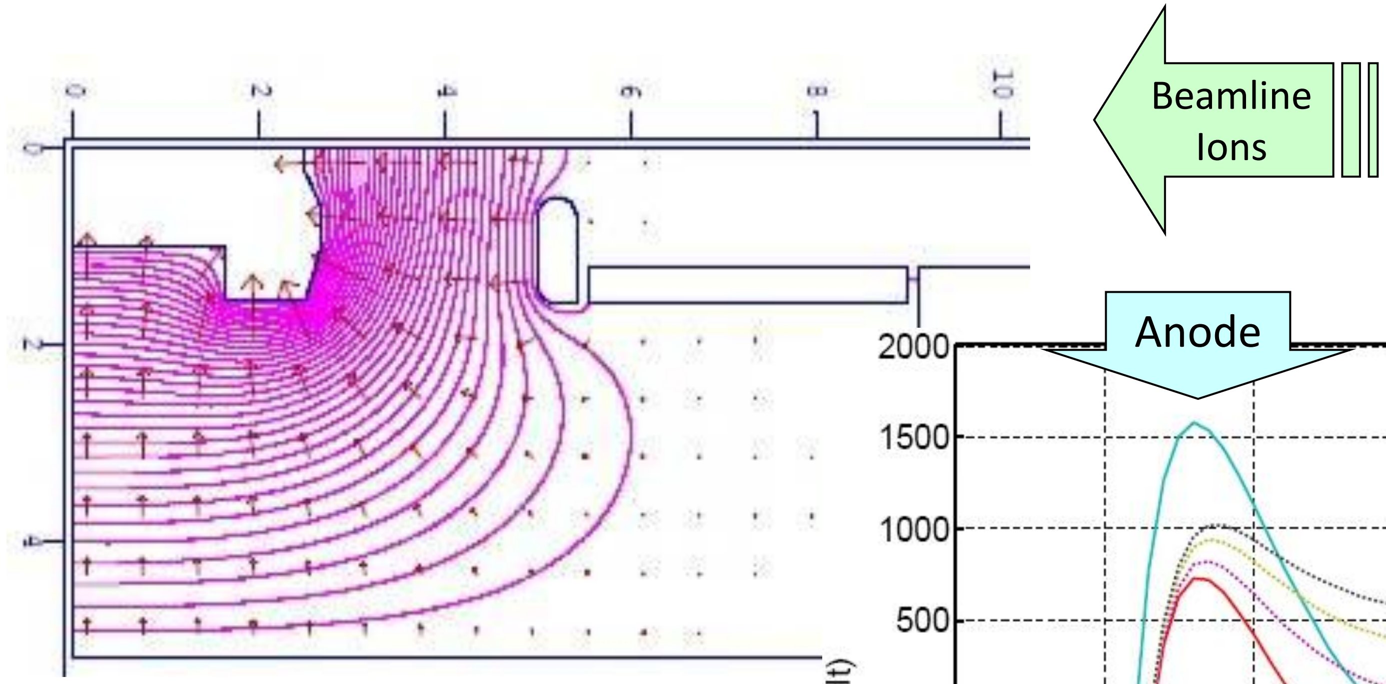
What about Ions Created Downstream of Anode?

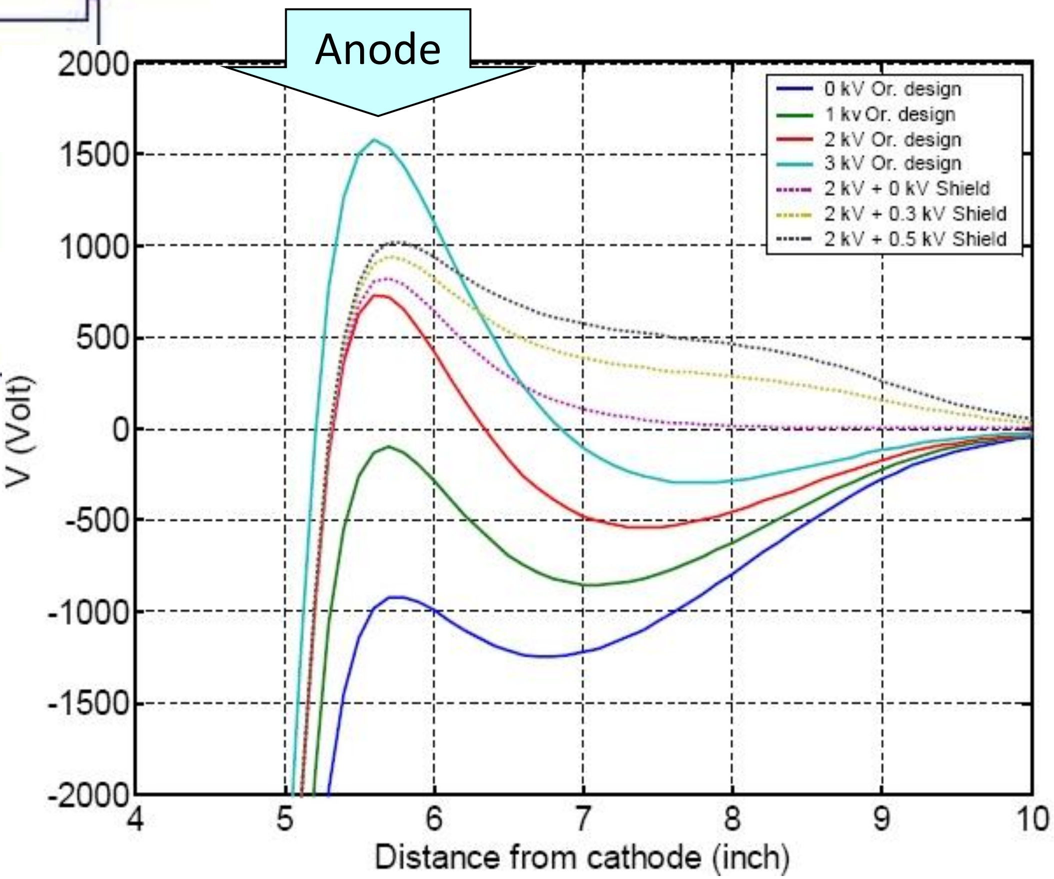


Modifying the HV Chamber Anode Structure



Limiting Ionized Gas from HV Chamber

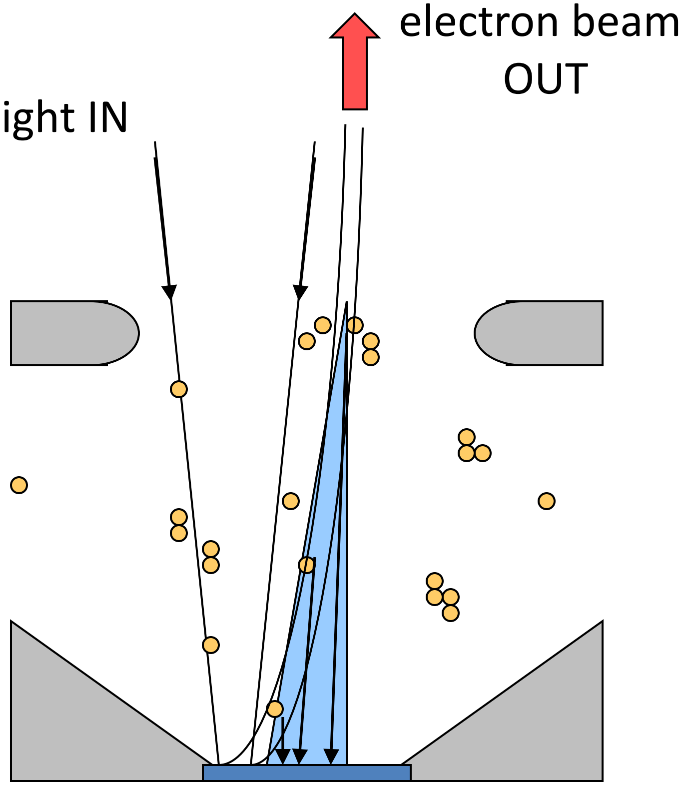




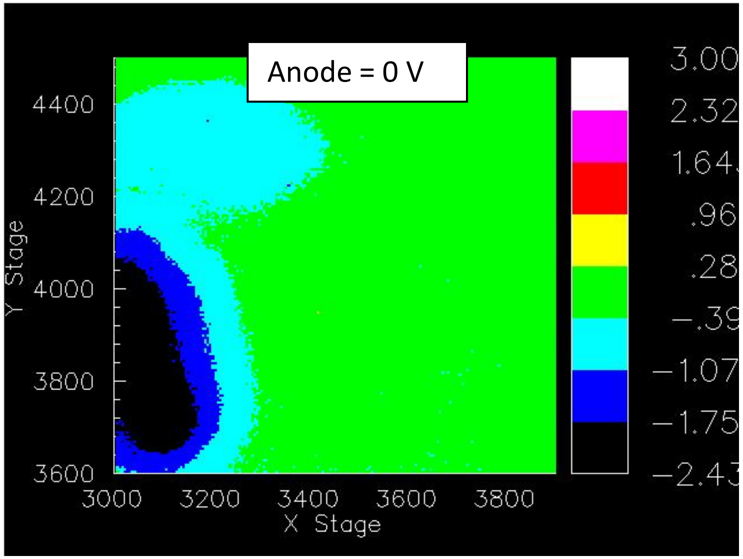
E. Pozdeyev,

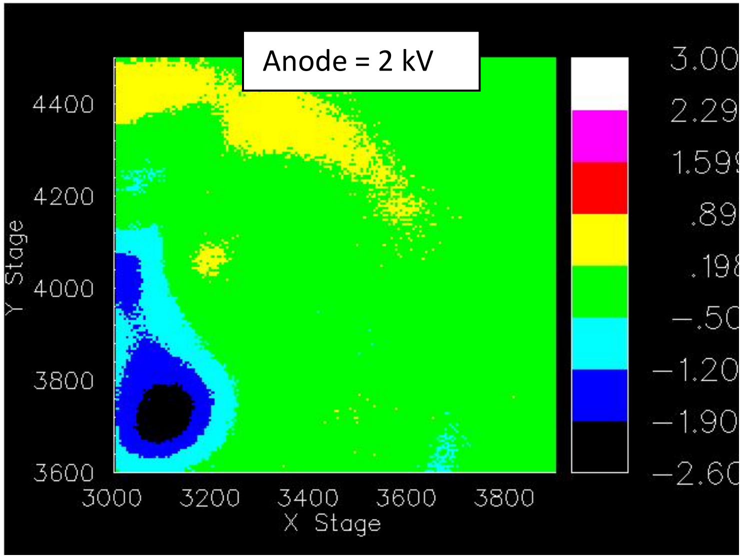
Phys. Rev. ST Accel. Beams 10, 083501 (2007)

Unbiased vs. Biased Running at 5mA

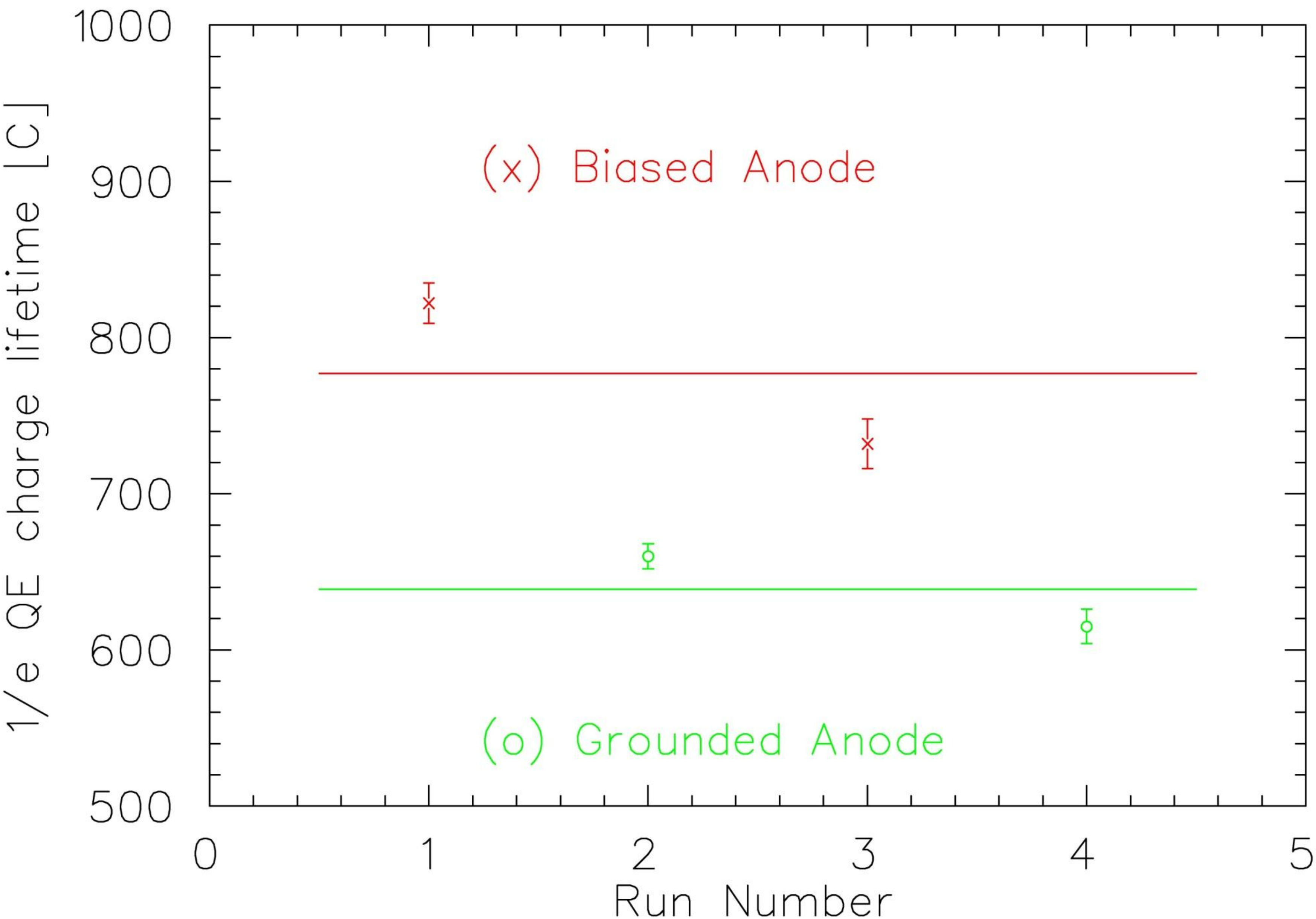


Ions create QE trough to electrostatic center



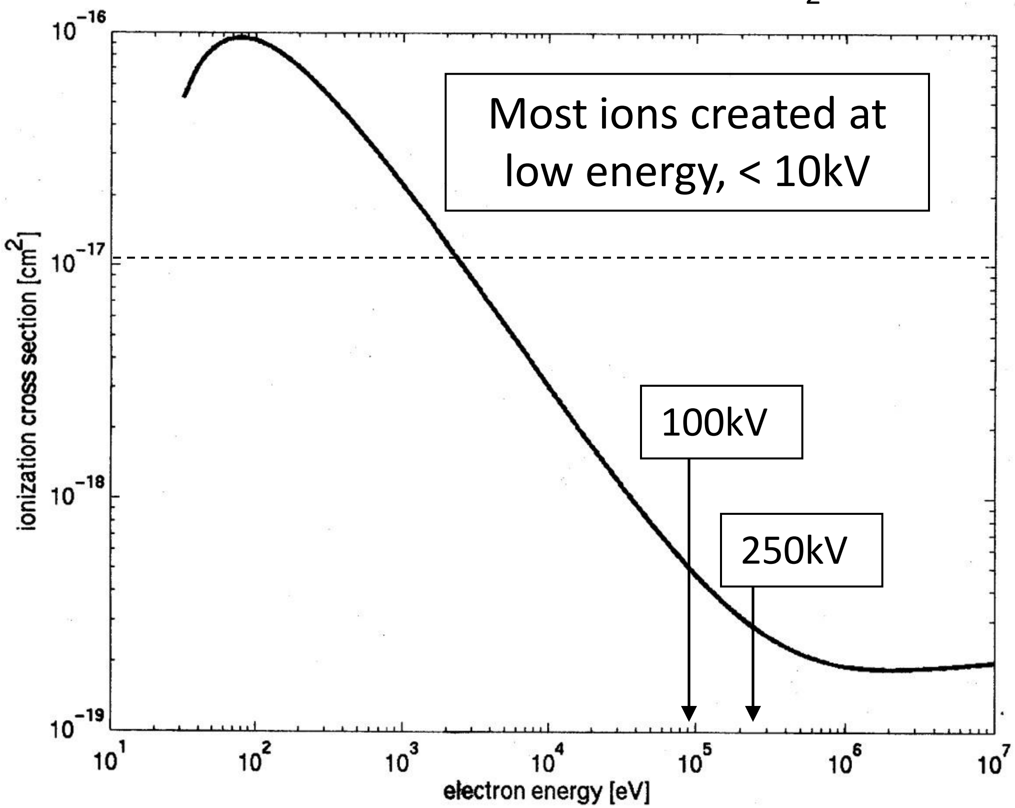


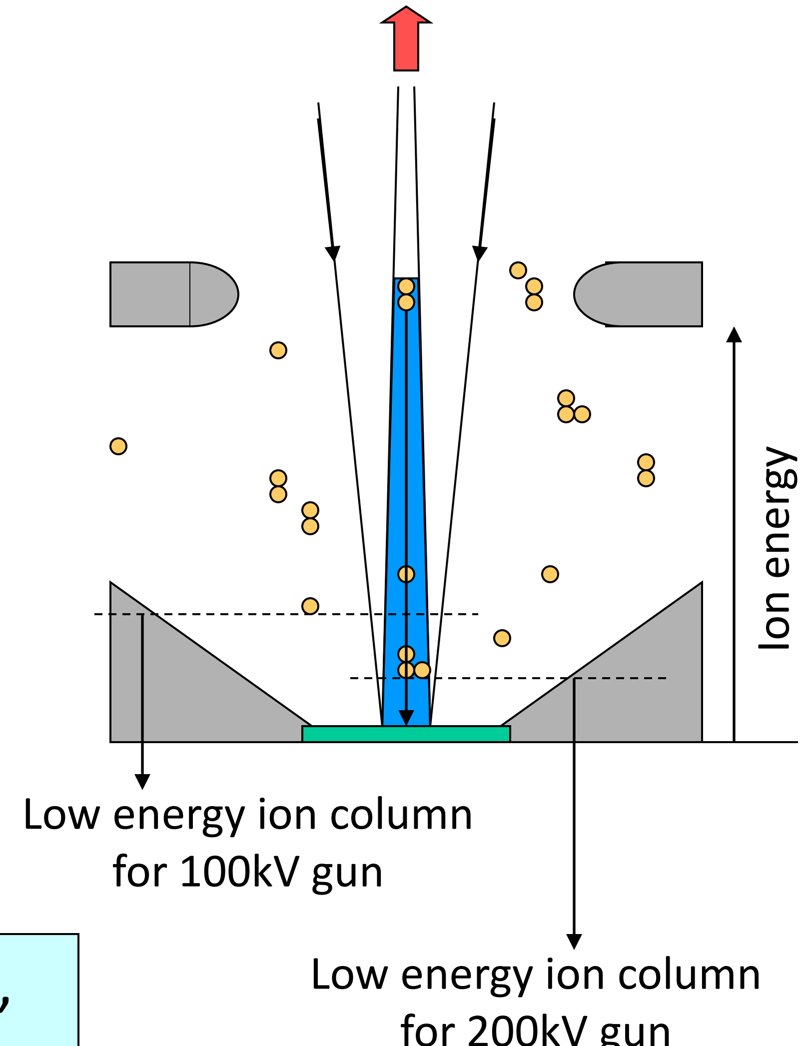
Photocathode Lifetime at “EC” at 2mA



Improve Lifetime with Higher Bias Voltage?

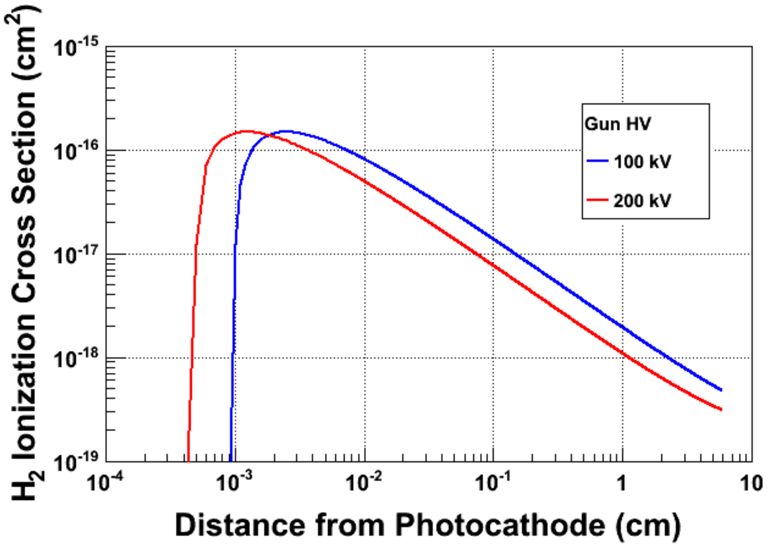
Ionization cross section for H_2

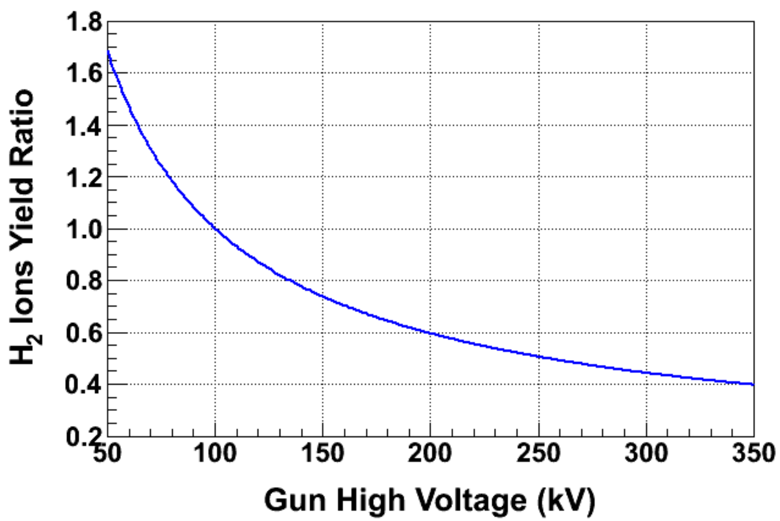


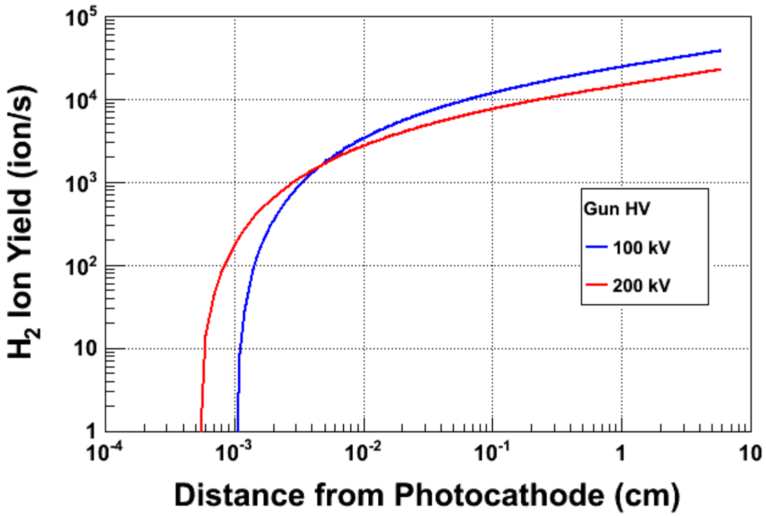


Hypothesis: Double the gun voltage, halve the # of "bad" ions, improve lifetime by 2

Prolong Photocathode Charge Lifetime





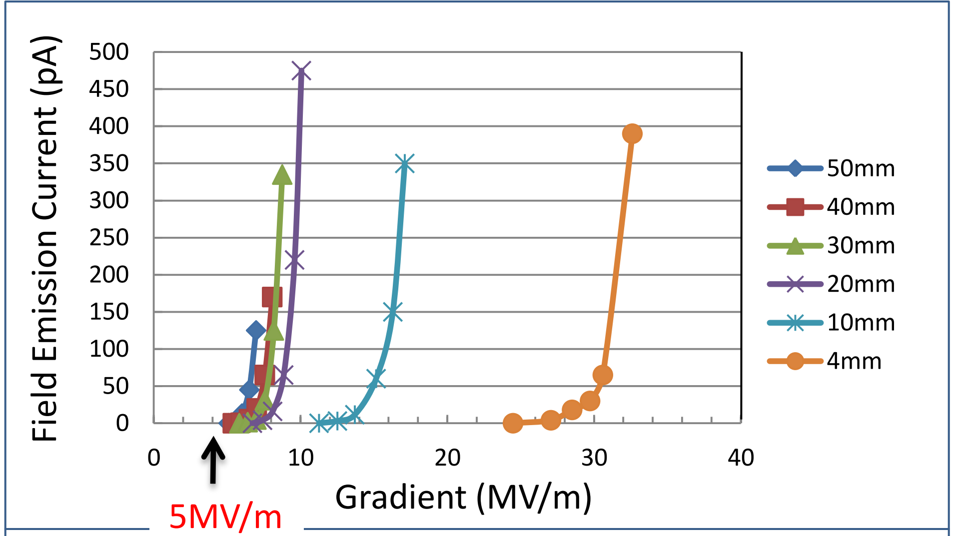


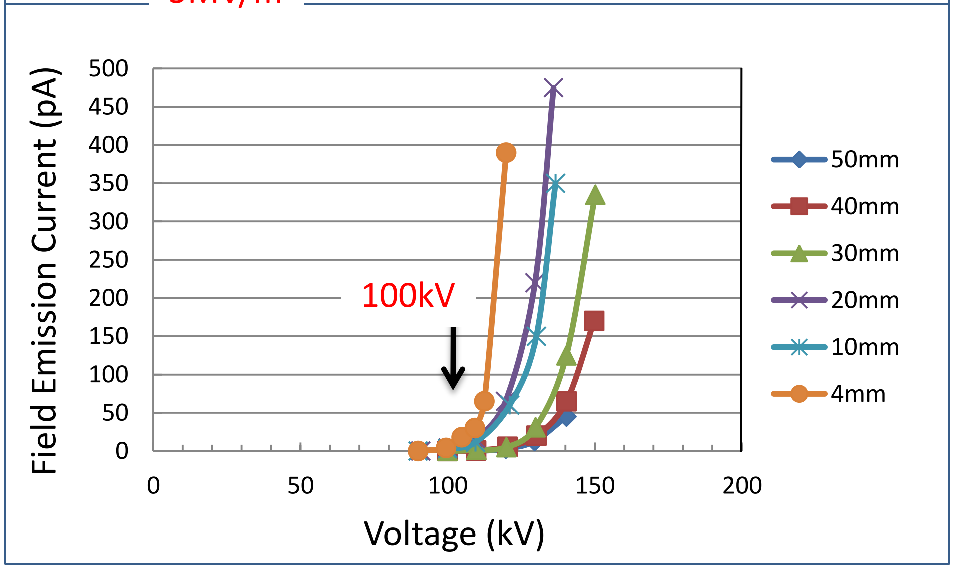
At 200 kV, only 60% of ions are created compared to 100 kV, longer lifetime

Beam Current: 2.0 mA
Vacuum: 8.0×10^{-12} Torr

Field Emission – A Very Important Issue

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



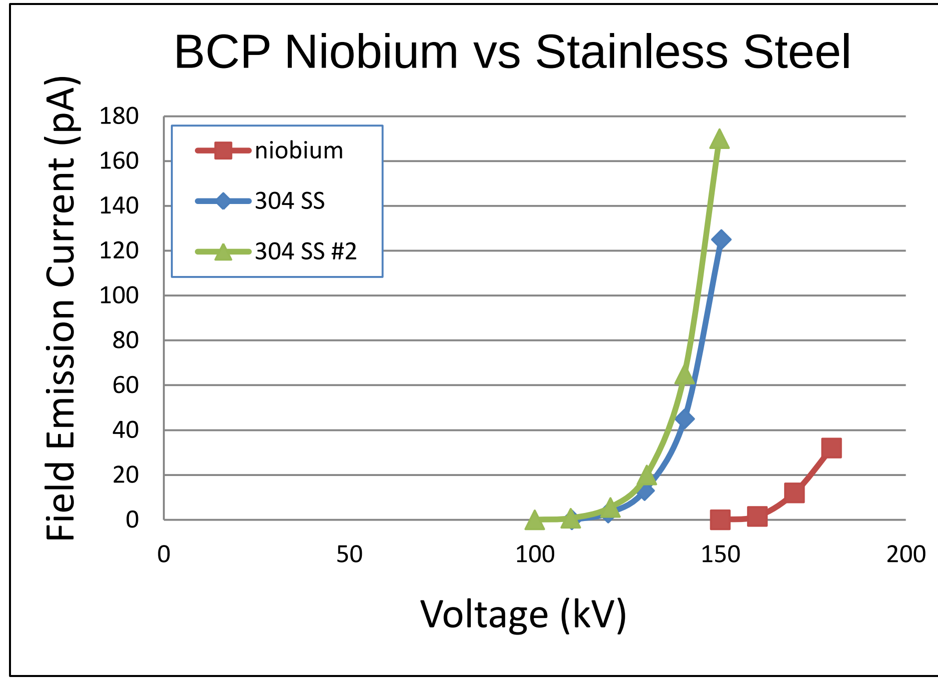


- Previous measurements with flat electrodes, small gaps and low voltage - not very useful
- Want to keep gun dimensions about the same – suggests our 200kV gun needs "quiet" electrodes to 10MV/m

Work of Ken Surles-Law, Jefferson Lab

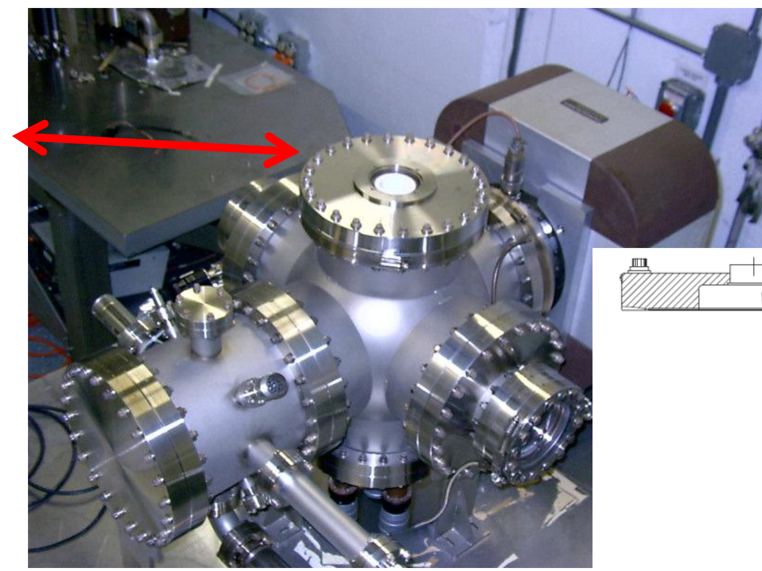
Single Crystal Niobium:

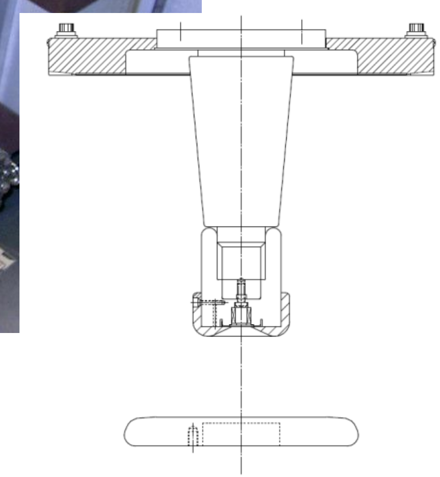
- Capable of operation at higher voltage and gradient?
- Buffer chemical polish (BCP) much easier than diamond-paste-polish



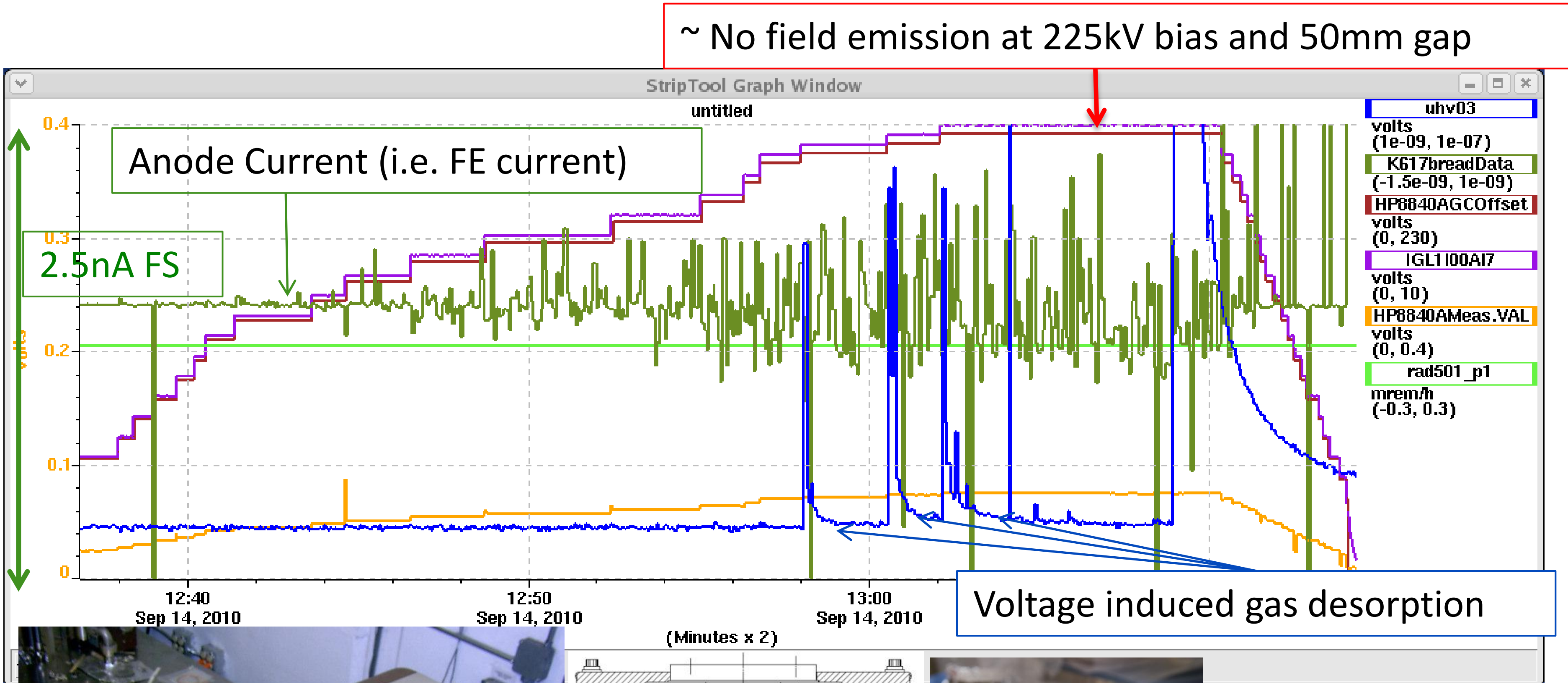
Conventional geometry: cathode electrode mounted on metal support structure

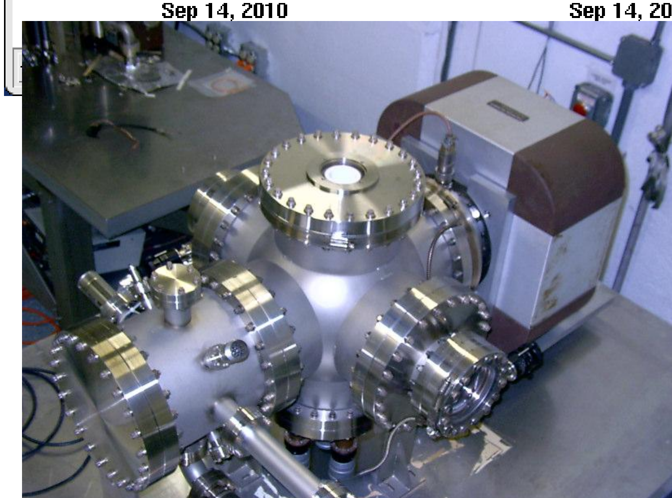
Replace conventional ceramic insulator with "Inverted" insulator: no SF6 and no HV breakdown outside chamber

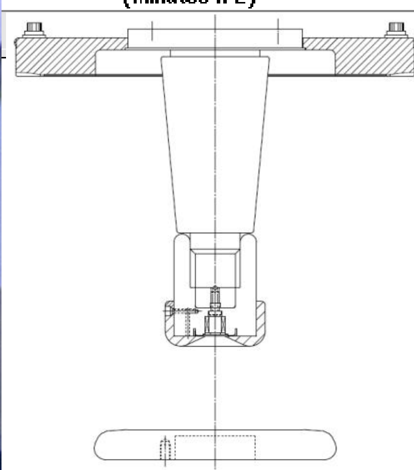




Single Crystal Nb: Good Cathode Electrode Material

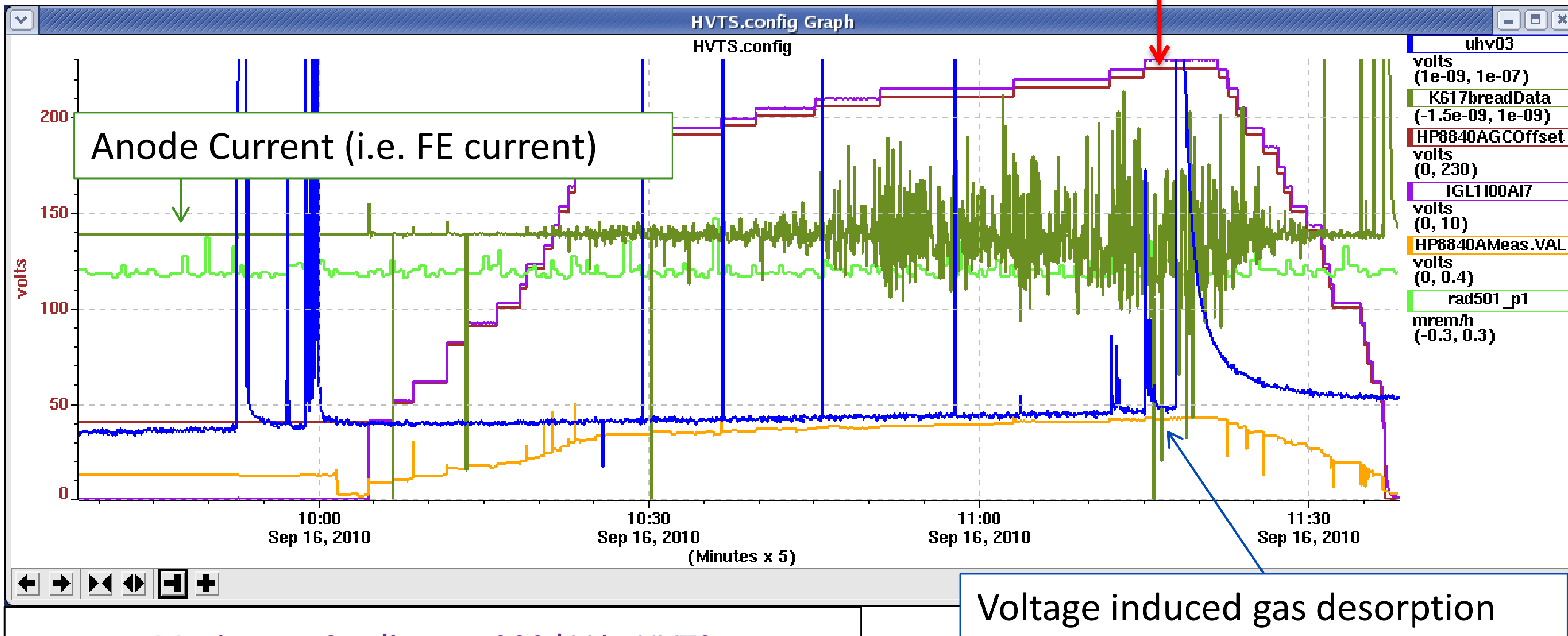


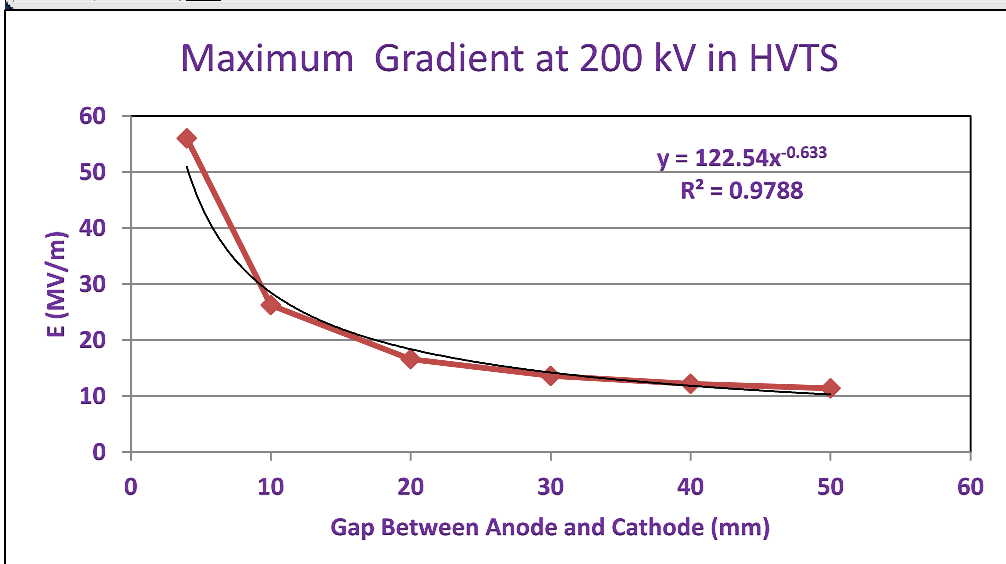




Work of M. BastaniNejad

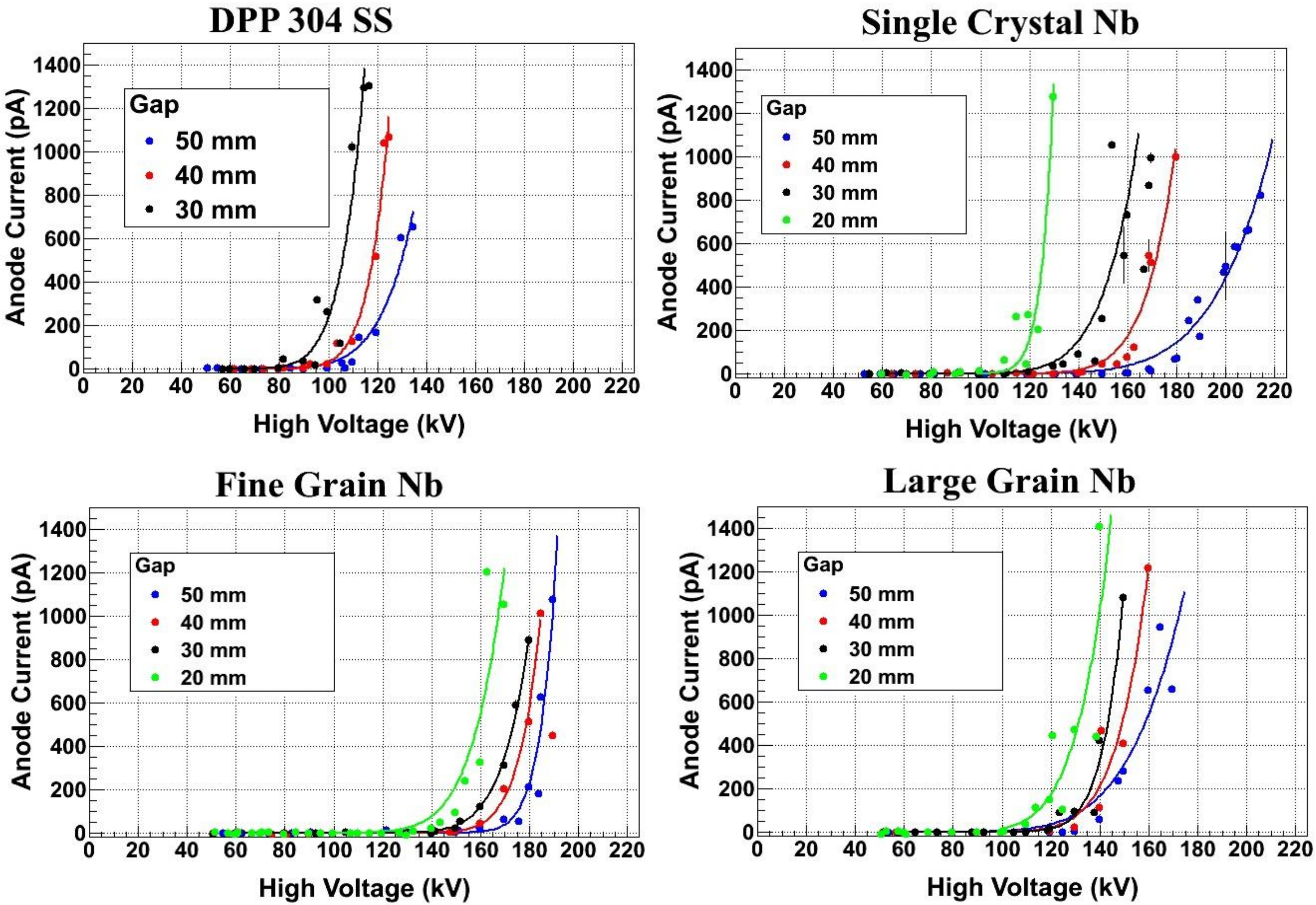
No field emission at 225kV bias and 20mm gap



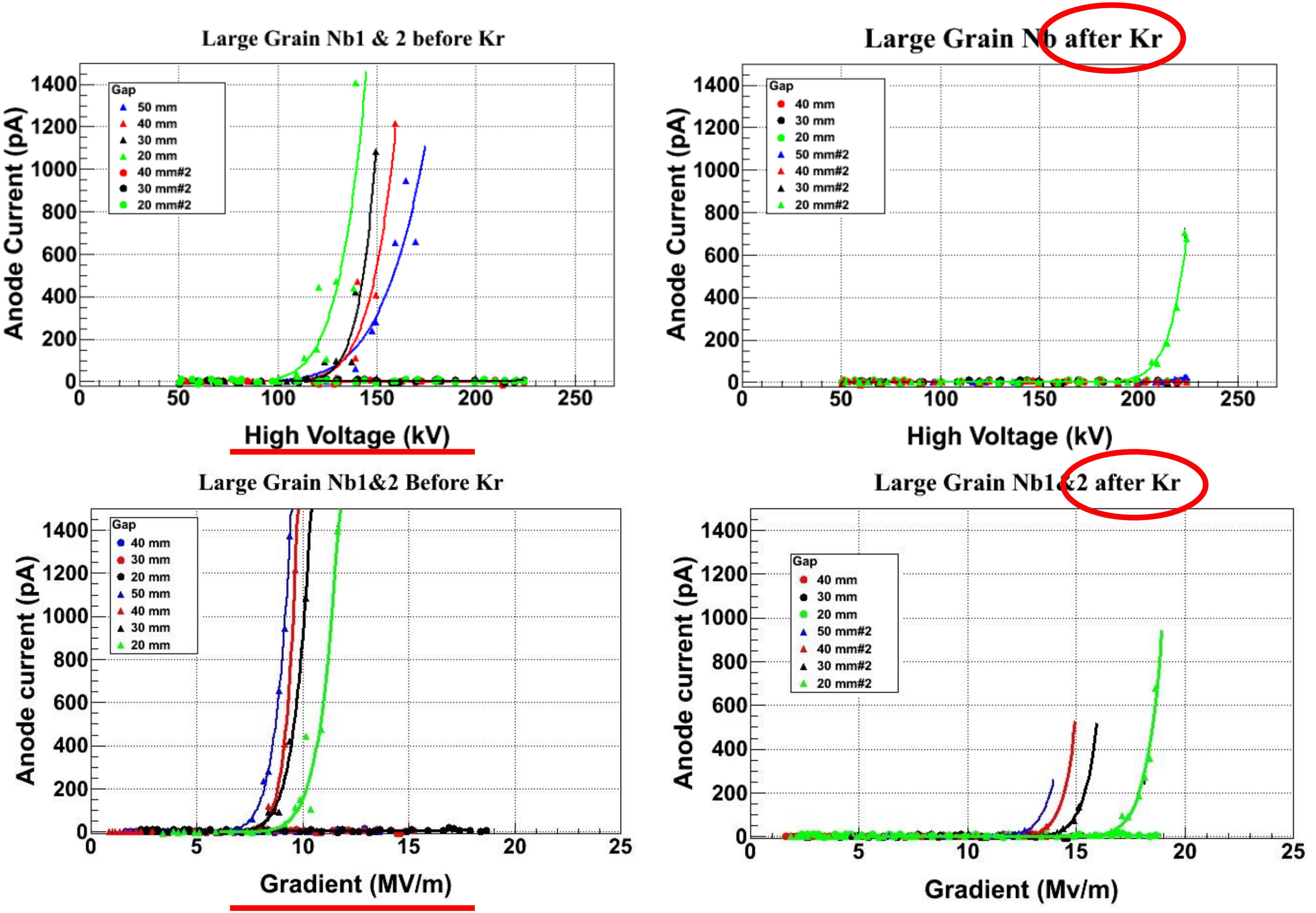


- But Niobium can be pushed too far, producing (many?) field emission sites. Avoid small gaps.
- These field emission sites can be difficult to process out
- Krypton processing works
- Sometimes, electrode needs to be re-BCP-ed.

Why a Niobium Cathode Electrode?

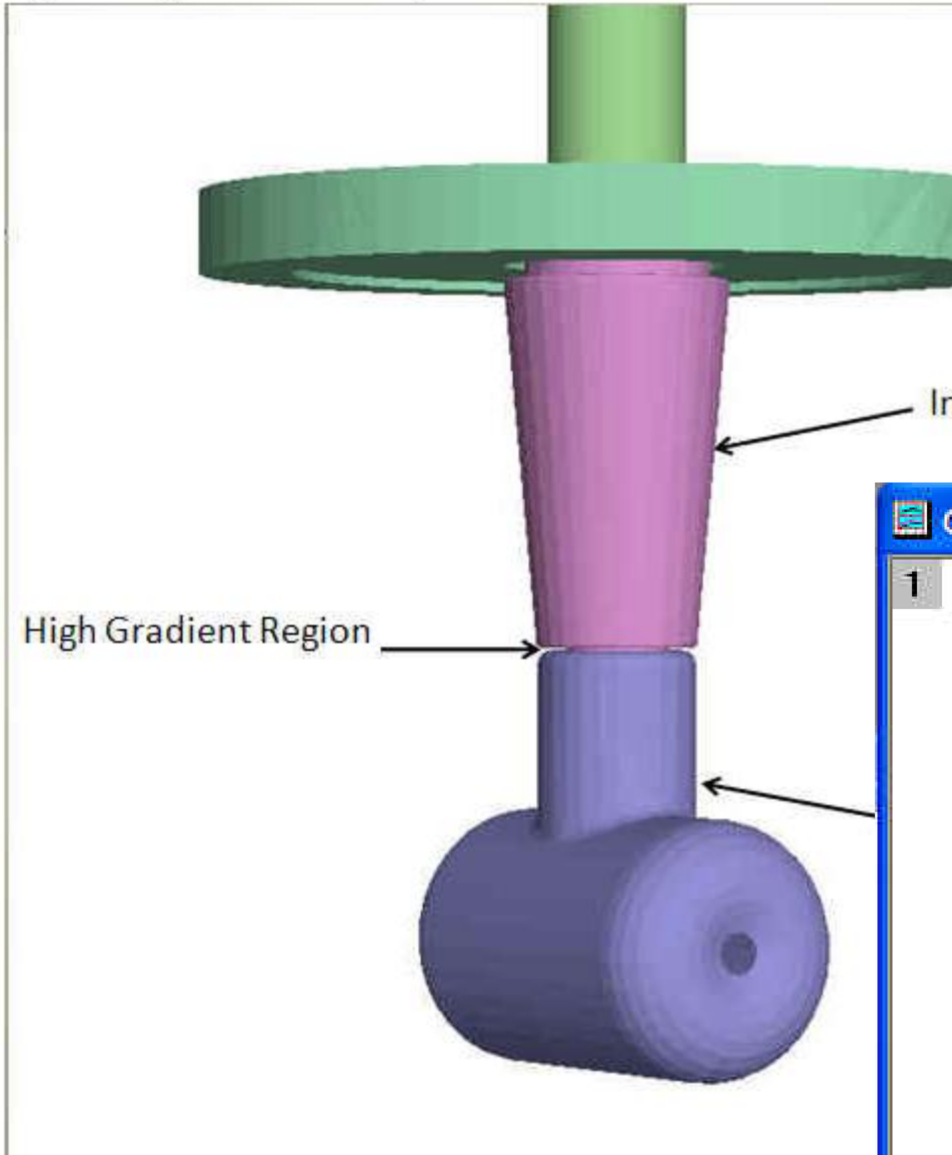


Krypton Processing to Eliminate FE



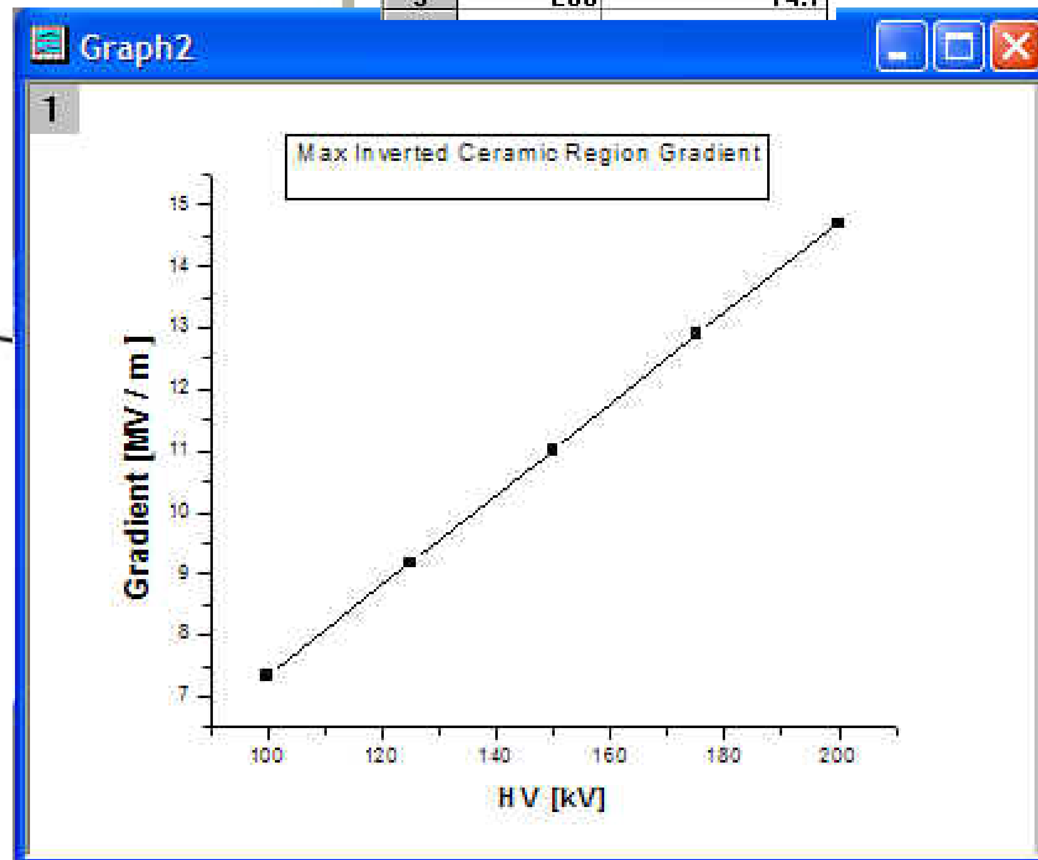
Our design has one region of "unintended" high gradient – could be problematic…..exploring new designs via electrostatic modeling

Figure 1: Highest Gradient Region



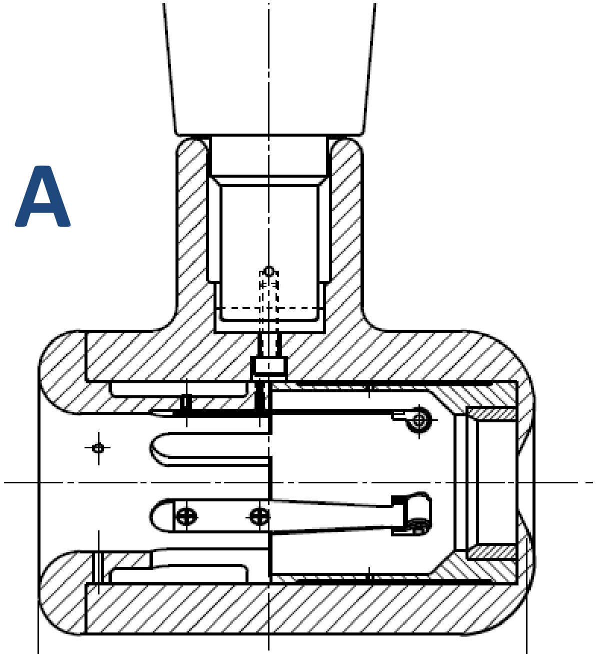
Data2 - InvCeramic Region Max ...

	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

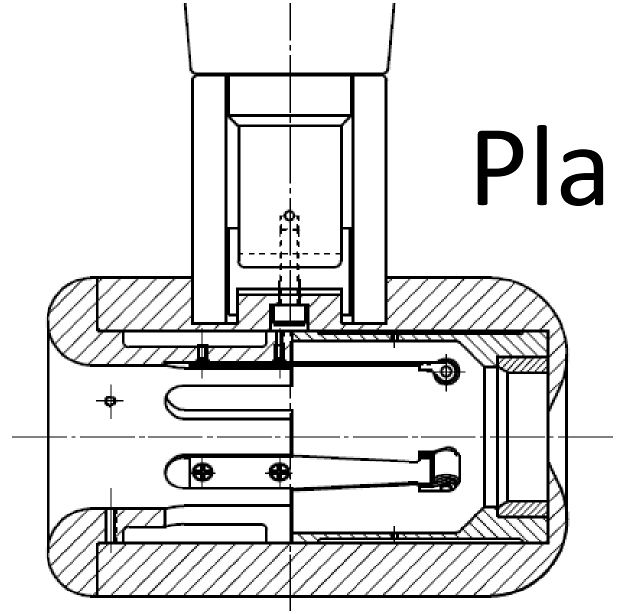


Work of Ken Surles-Law

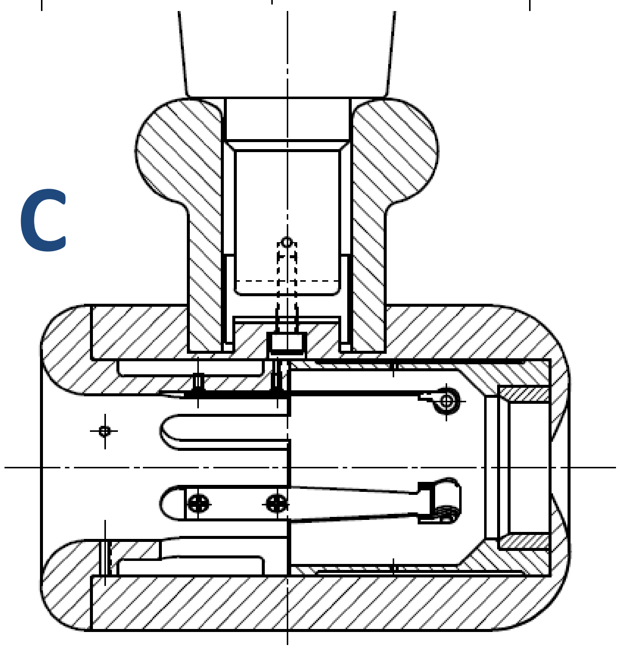
Plan A



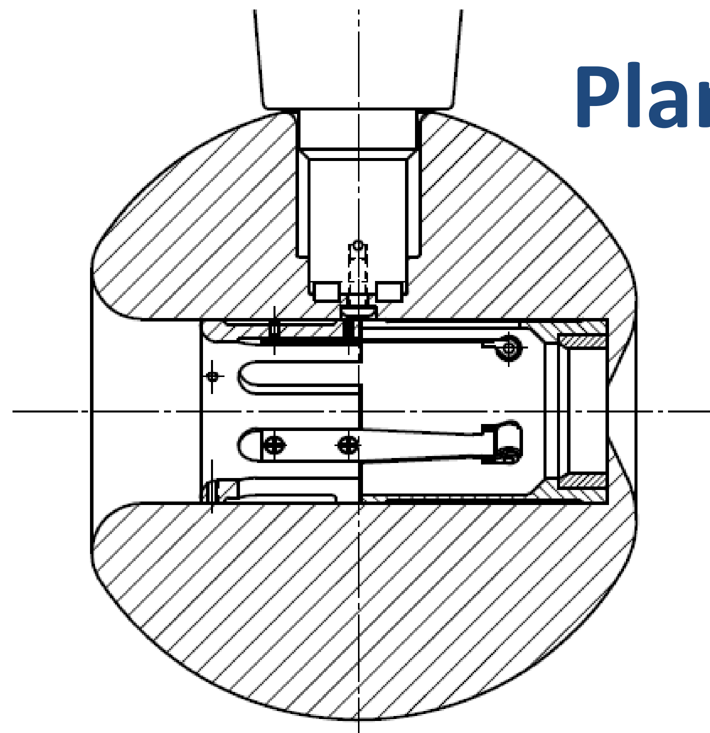
Plan B



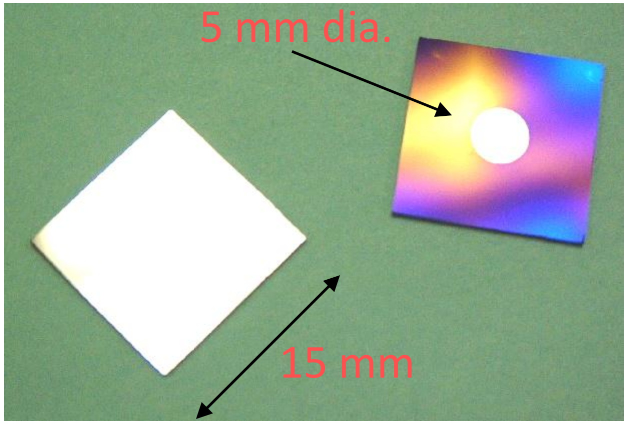
Plan C



Plan D



Limiting the Active Area via Anodization



Anodized photocathode

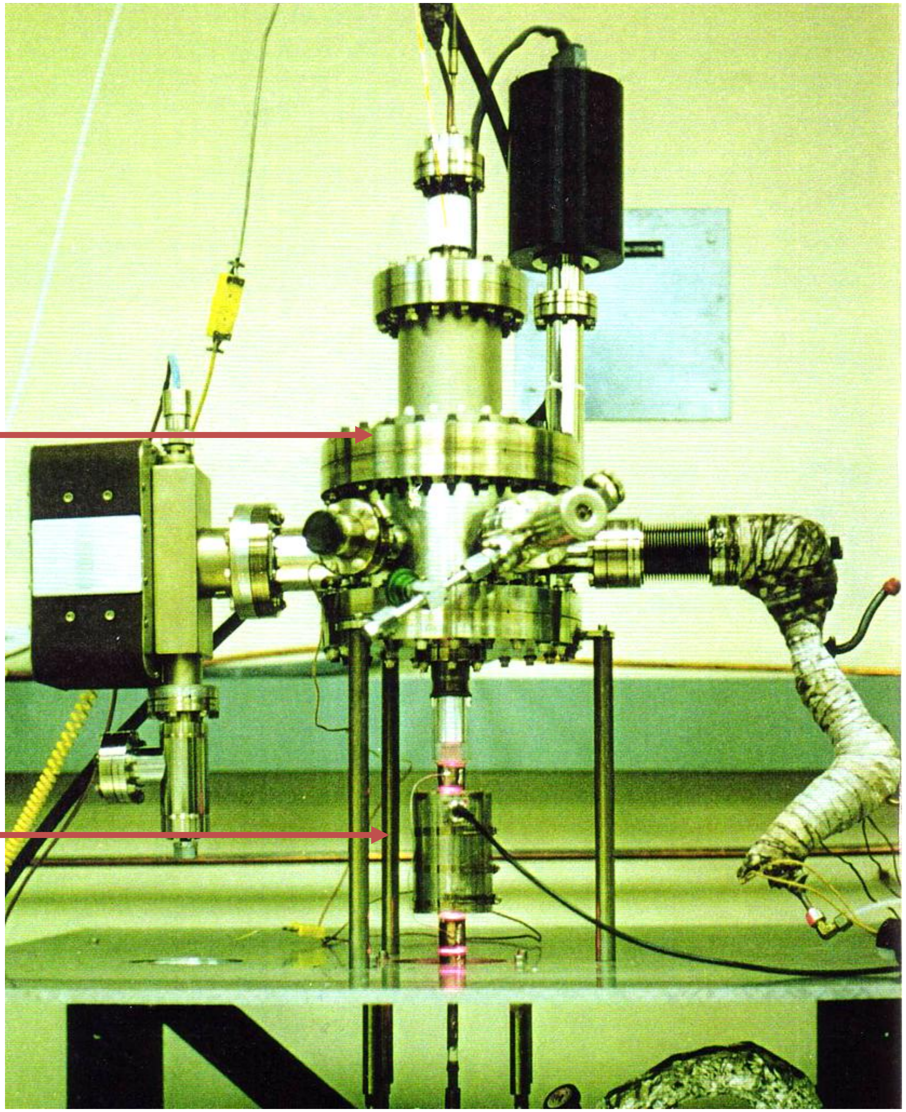
Normal photocathode; "out of box"

- Electrons emitted from edge of wafer hit vacuum chamber walls. This is bad for vacuum.
- Anodization eliminates inadvertent photoemission from locations not intentionally illuminated with laser light
- Anodizing process dirties the photocathode surface, bad for QE

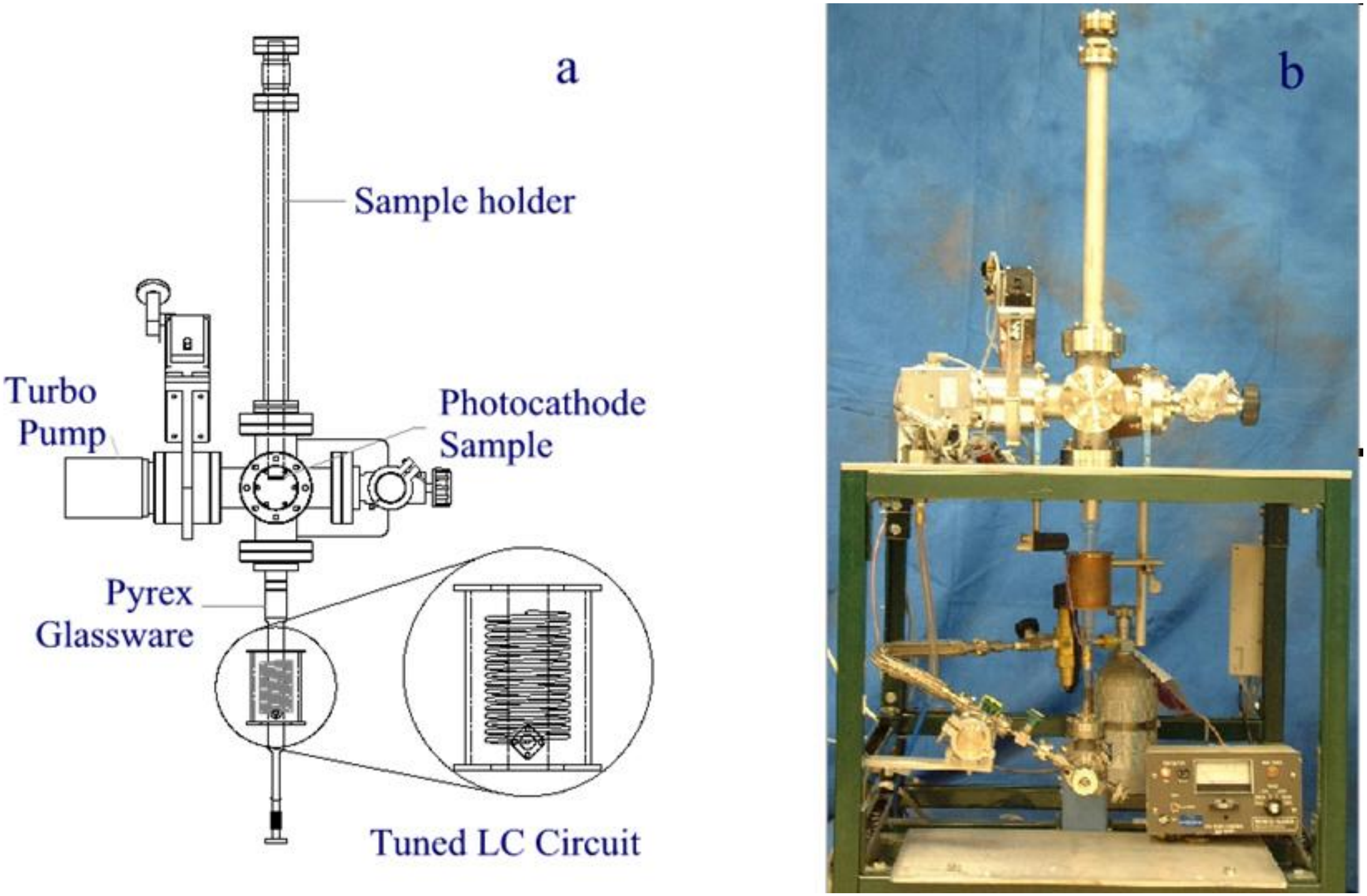
Atomic Hydrogen Cleaning

Photocathode sits here, inside vacuum chamber

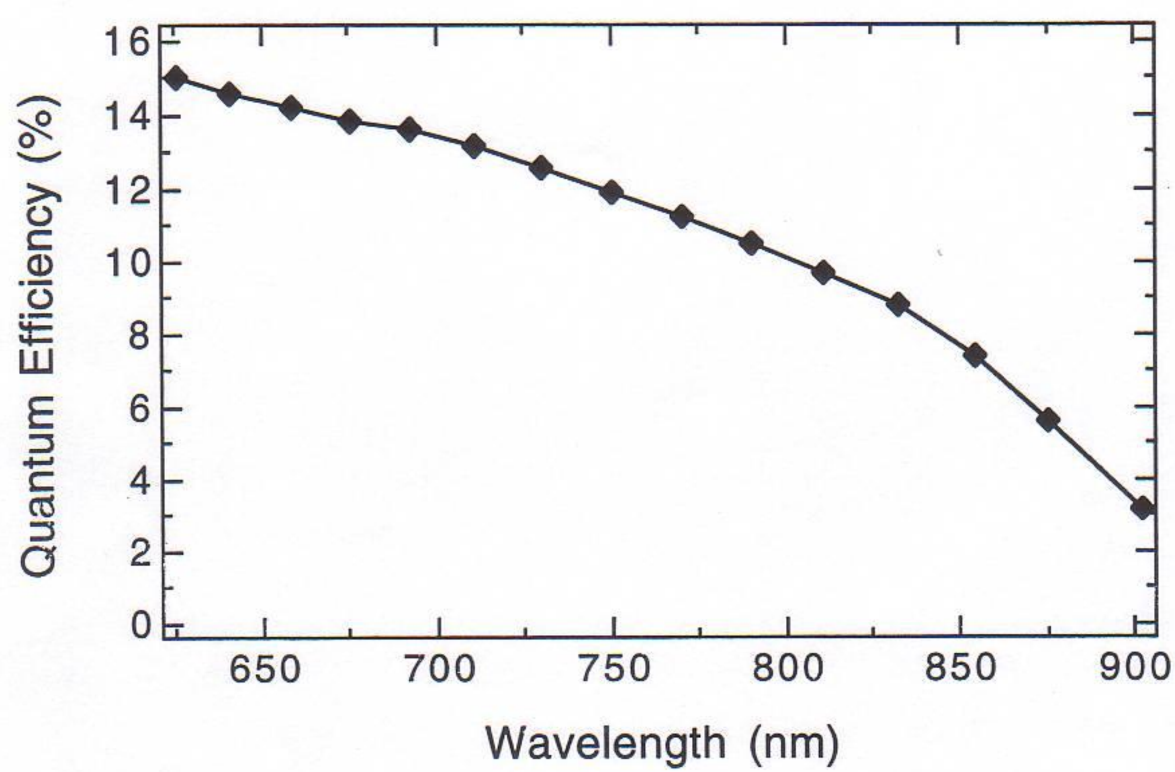
Molecular hydrogen dissociated with RF inductive discharge



“Portable-H”

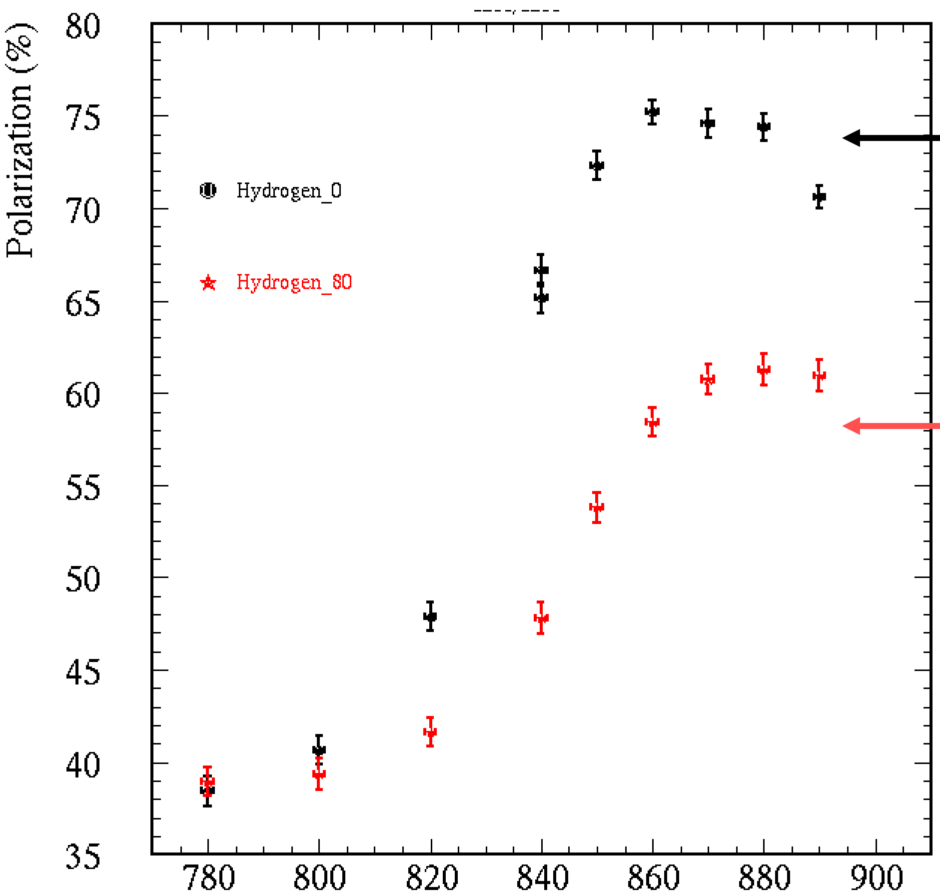

a
Sample holder
Turbo
Pump
Photocathode
Sample
Pyrex
Glassware
Tuned LC Circuit
b

Atomic Hydrogen Cleaning



- Extremely high QE from bulk GaAs
- Reliable cleaning method
- No wet chemicals
- *In situ* cleaning an option (i.e., put it on the gun or in prep chamber)

But not for High Polarization Photocathodes



Wavelength

Polarization w/o Hydrogen cleaning

Polarization w/ Hydrogen cleaning

Solution: Arsenic Capping and Masking

Deep UHV gauges
Theory and Practice

Marcy Stutzman Jefferson Lab

Bruce Kendall Elvac Laboratories

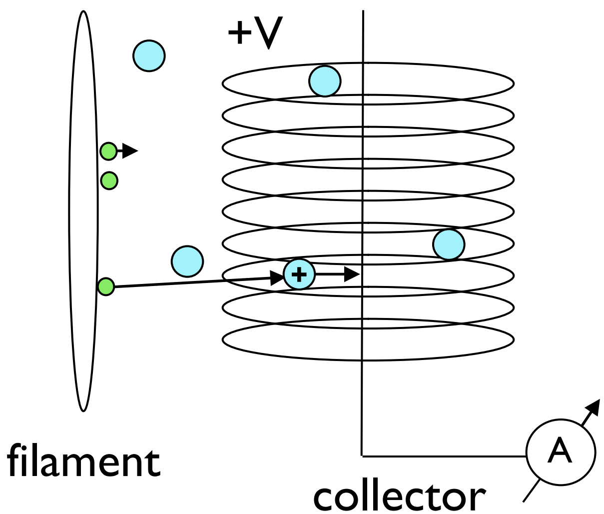
Pressure ranges

- Deep ultra high vacuum: below $1x10^{-10}$ Torr
  - Commercially available gauges exist
  - Care must be taken in using gauges properly
- Extreme high vacuum: below $1x10^{-12}$ Torr
  - Few room temperature systems obtain XHV
    - Electron sources for accelerators would benefit
    - Particle collider interaction regions
    - Reactive surface science applications
    - Nano-electronics
- Ionization gauges required to measure deep UHV
  - Hot filament gauges
  - Cold cathode gauges

HOT FILAMENT GAUGES

Bayard-Alpert
Modulated Bayard-Alpert
Extractor
Bessel Box
Bent Beam

Hot filament gauges



$$P = nkT$$

- Electrons produced by hot filament
- Electrons accelerated toward biased grid
- Gas molecules ionized by electron impact
- Ionized molecules collected on wire
- Collector current proportional to gas density

HOT FILAMENT GAUGE ERRORS

X-ray limit

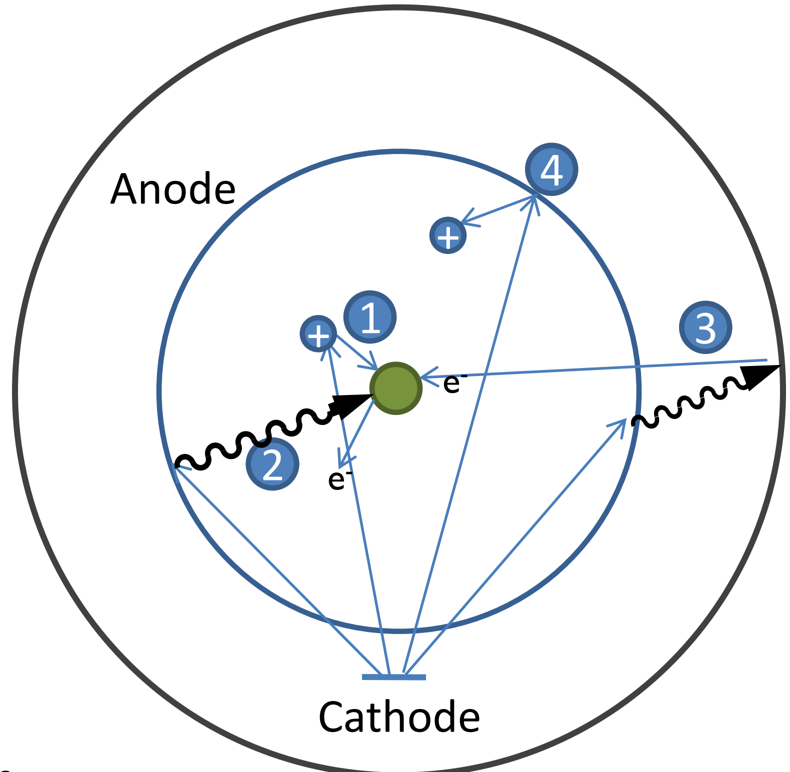
Inverse X-ray effect

Electron Stimulated Desorption

Outgassing from heated surfaces

Hot cathode gauge operation and errors

1. True gas ionization
    - Positive current
2. X-ray effect
    - e- on anode -> photons emitted
    - Photons on collector -> electrons emitted
    - Extra positive current
3. Inverse X-ray effect
    - e- on anode -> photons
    - Photons on walls -> electrons
    - Electrons to collector
    - Extra negative current
4. Electron stimulated desorption
    - e- strike gas molecules on anode
    - Gas ionized and reaches collector
        - can be distinguished with energy analysis
    - Neutral atom desorbed
        - Ionized within grid
        - Indistinguishable from real gas
        - Must eliminate souce

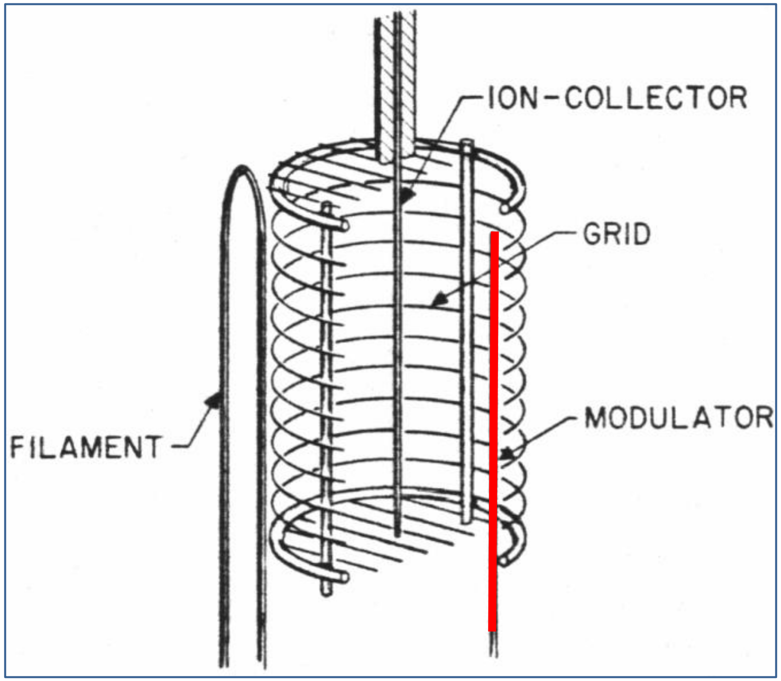


$$I^{+} = I_{real} + I^{-}_{x-ray} - I^{-}_{inv.x-ray} + I_{ESD}$$

Reduction of x-ray and ESD errors

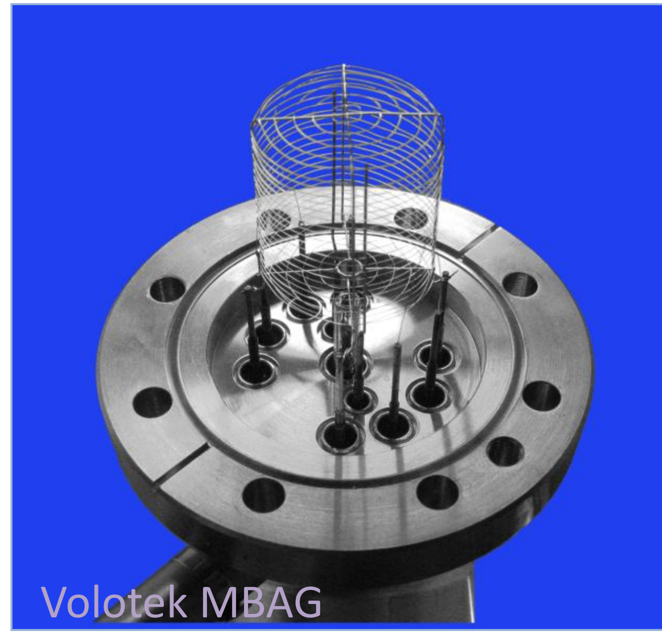
- Modulation
- Geometry

- Extends BA gauge below 10^{-9} Torr
- Redhead modulated gauges 1960s
  - ETI / Teledyne sold commercial version
- Modulator varied between potentials near grid and collector voltages
  - Careful selection of potentials required to avoid changing ESD and x-ray currents
  - Real signal modulates, background constant
  - High pressure (10^{-8} Torr) determination of modulation constant
- MBAG benefits
  - Retrofit existing BAG with external modulation unit
  - Unaffected by electrometer drift
  - Read pressure near/better? extractor gauge



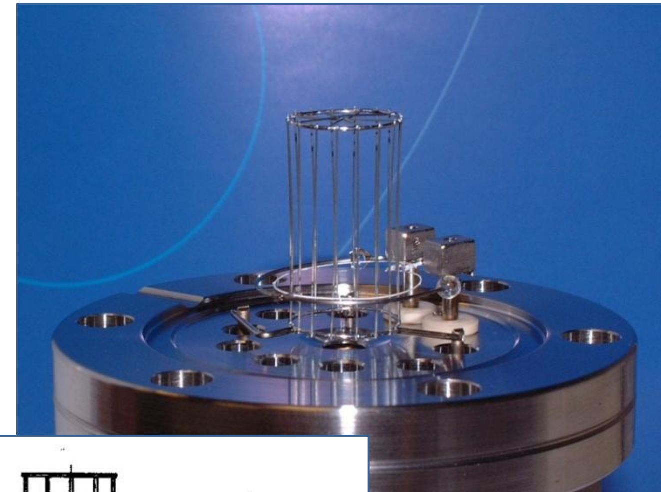
Reduction of x-ray and ESD errors

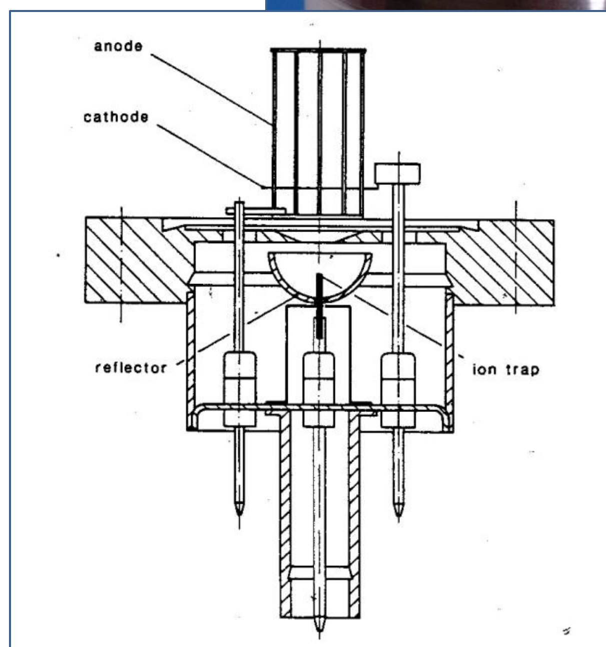
- CERN style commerical MBAG coming from Volotek
  - CERN vendor for MBAG controllers
  - Finishing prototyping
  - Commercial manufacturing run soon
  - Hope to exceed extractor capabilities
  - XHV vacuum work
    - heat treat flanges
    - ceramic feedthroughs (previously glass)
    - 4.5” flange – less wall interference
    - CERN working on qualification
- Televac/ETI have produced metal MBAG as special order – Kendall, custom electronics


Volotek MBAG

Reduction of x-ray and ESD errors

- Geometry
  - Reduce collector solid angle (thin wire BA)
  - Shield the collector from line of sight to the grid
    - Extractor
    - Bent Beam
      - Helmer
      - Ion Spectroscopy
    - Bessel Box
      - AxTran
  - Energy discrimination
    - Repeller in extractor
    - Bent beam gauges





Oerlikon Leybold Extractor gauge

X-ray limit measurements

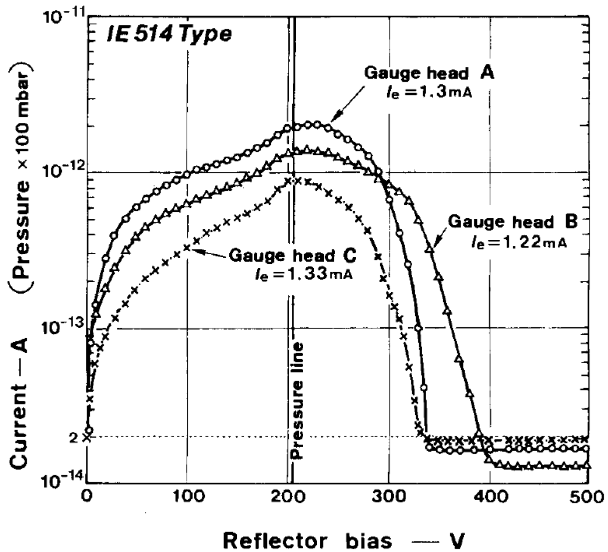
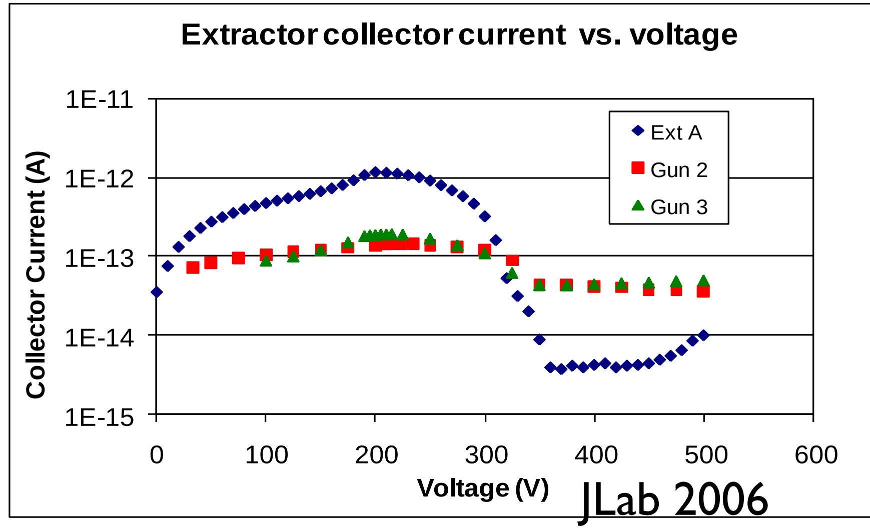


FIG. 3. Reflector bias effect for various IE514 gauge heads.



Fumio Watanabe JVSTA 9 (1991).

Determines x-ray limit for certain setup

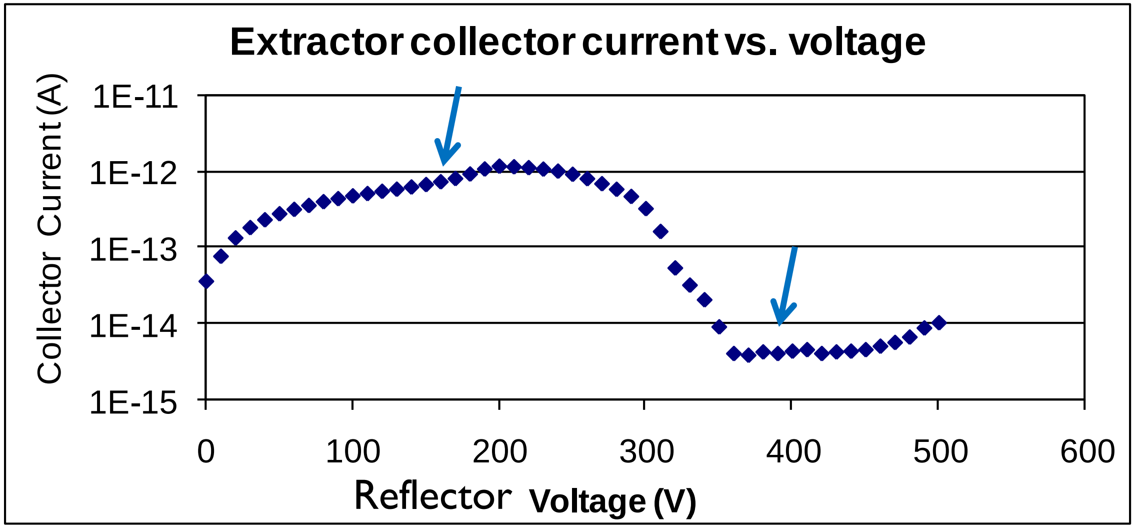
- Current at reflector > grid
- Current with voltages off

Gauge	X-ray Limit (Torr)
Watanabe A	2.1×10^{-12}
Watanabe B	1.6×10^{-12}
Watanabe C	1.9×10^{-12}
JLab A	0.63×10^{-12}
JLab Gun 2	$>2 \times 10^{-12}$
JLab Gun 3	$>2 \times 10^{-12}$

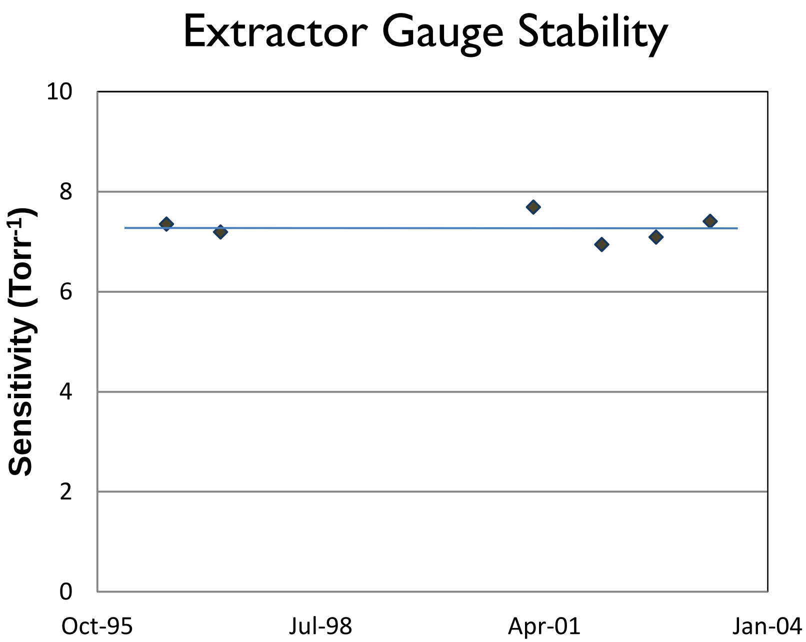
Modulated extractor gauge

- Cornell vacuum group with Charlie Sinclair (retired)
  - Modulate reflector potential with AC voltage
  - Read signal using Lock-in amplifier system
  - Measure field-off current (often negative) and account for this
  - Real time measurement with compensation for x-ray limit

- Student project that requires follow-up
- Redhead 1966 modulated extractor with filament in grid – revisit?



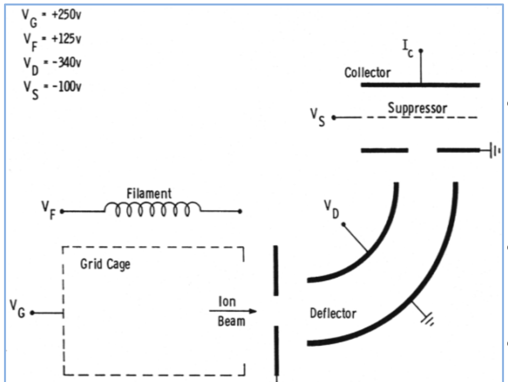
Extractor gauge long-term stability data



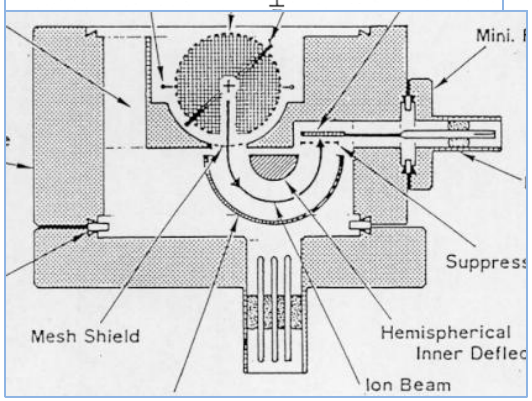
- Excellent stability with near continuous operation for more than a decade
- Venting 3-4 times per year
- Largest sensitivity changes follow system bakeouts
- Factors affecting stability
  - Excessive heating - deformation
  - Contamination
  - Mechanical damage
  - Nude gauge mounting geometry
  - Degas protocol

Energy analysis for ESD ions

- Bent Beam Gauges



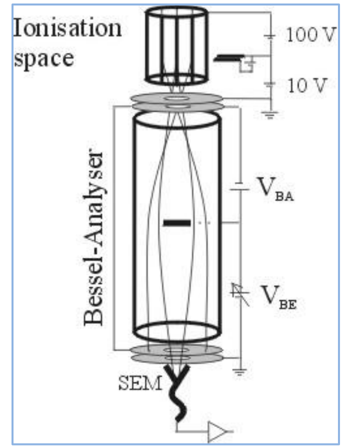
Helmer/Improved Helmer
•90° bend
  •Distinguish against ions at grid potential
•<10^{-13} Torr measured CERN ISR interaction region
•Volotek: available next year?



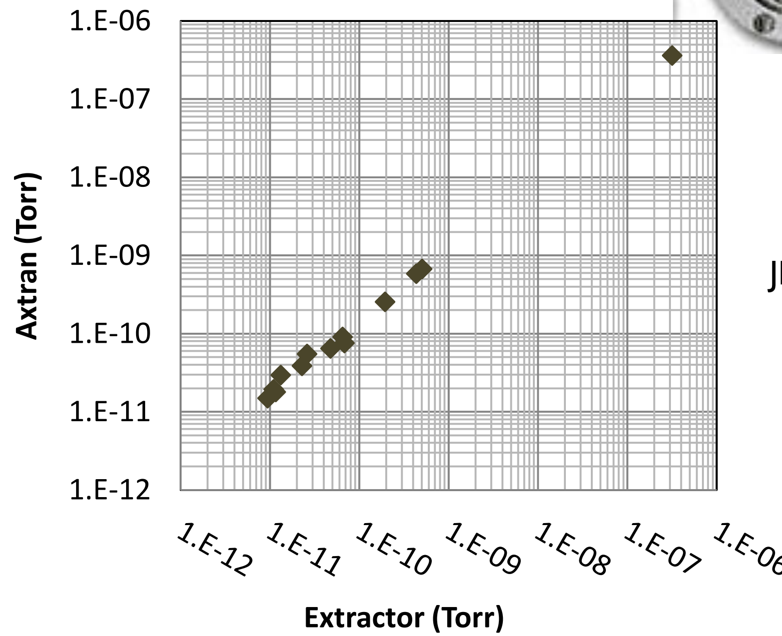
Redhead:
For scientists energy analyzer gauges ideally have tunable energy for analysis

Watanabe Ion Spectroscopy Gauge
•180° bend – hemispherical energy analyzer
•Spherical Grid - more uniform ion energy
•Not commercially available

- Bessel Box



Bend ions
•High energy ESD ions blocked
•Sold as AxTran by ULVAC
• Good agreement with extractor
•Electron multiplier



JLab 2004

Application notes

- Hot filament gauges will heat walls
  - Reduce heat of gauge (1 mA instead of 10 mA)
    - Outgassing from walls reduced
    - More gas adsorbed on grid, walls -> ESD increased
  - Use better wall materials
    - BeCu – Watanabe
    - Silco-steel™ – Kendall
  - Heat walls until molecules don't stick
    - Kendall: operation 700-800K eliminates adsorbed molecules on walls and grid
      - Eliminates ESD neutrals
    - Watanabe: heated grid / cold cathode gauge
- Electronics issues
  - Cable leakage
    - Replace coax cables with twin-ax or tri-ax
  - Electrometer stability
    - Always use same head/control unit combination
- Calibrate each gauge (vs. spinning rotor gauge) regularly for optimal performance

COLD CATHODE GAUGES

Magnetron

Inverted Magnetron

Double Inverted Magnetron

Ion pump?

Cold Cathode Gauge Operation

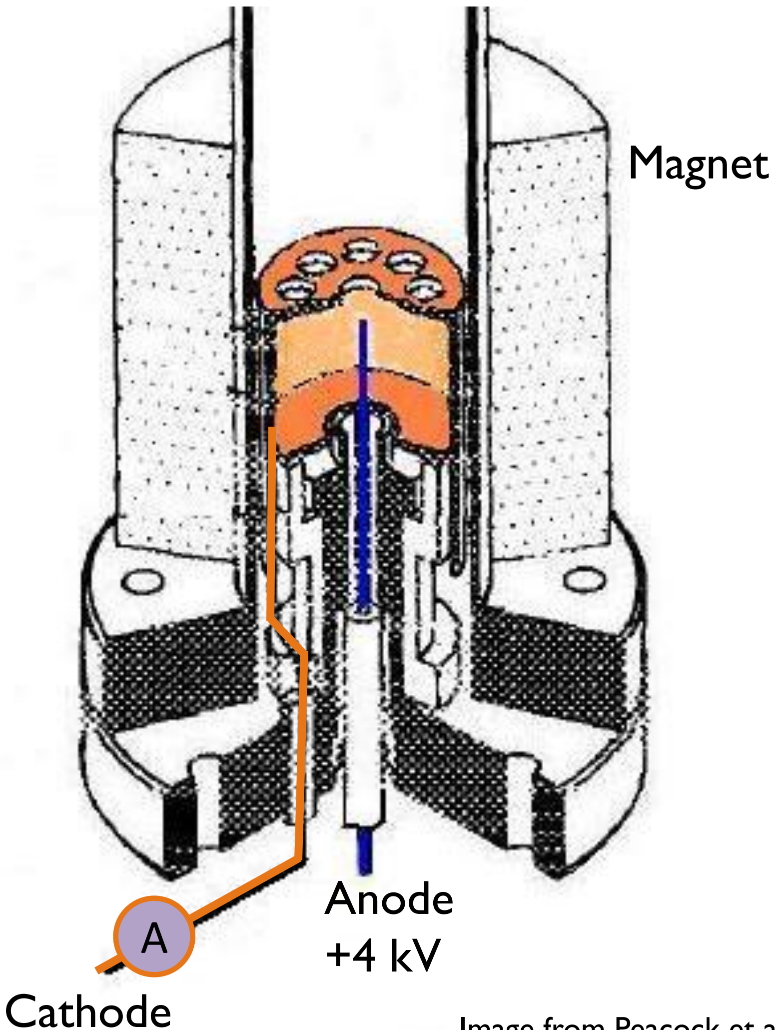
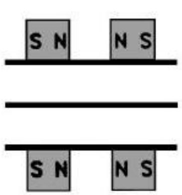


Image from Peacock et al.
JVSTA 9 1977 (1991)

- Electron cloud trapped in crossed electric and magnetic fields
  - Spontaneously starts in presence of electric field at HV pressures
  - Electron cloud density limited by space charge effects
- Ionized gas collected at cathode
  - UHV starting element
    - Radioactive
    - Thermal
    - UV

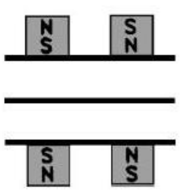
Modern Cold Cathode Gauge

- No gauge heating
- Very rugged, low power consumption
  - Lunar missions, space applications
- Change in power law behavior at "magnetron knee" ~10^{-9} Torr
- Stray magnetic fields minimized in modern designs
- Accuracy for ELVAC modification of Televac CCG
  - Stronger magnets
  - Smaller volume
  - Precision alignment mounting jig
  - Controller improvements

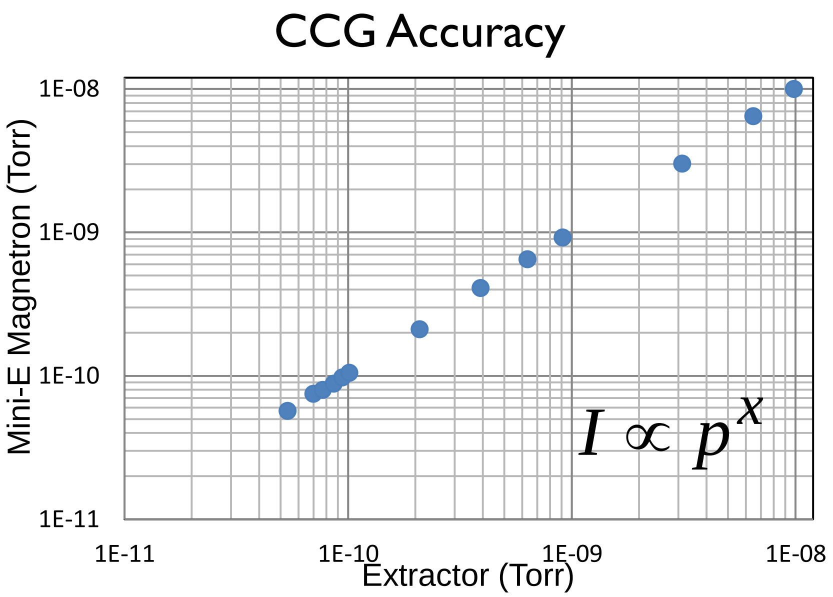


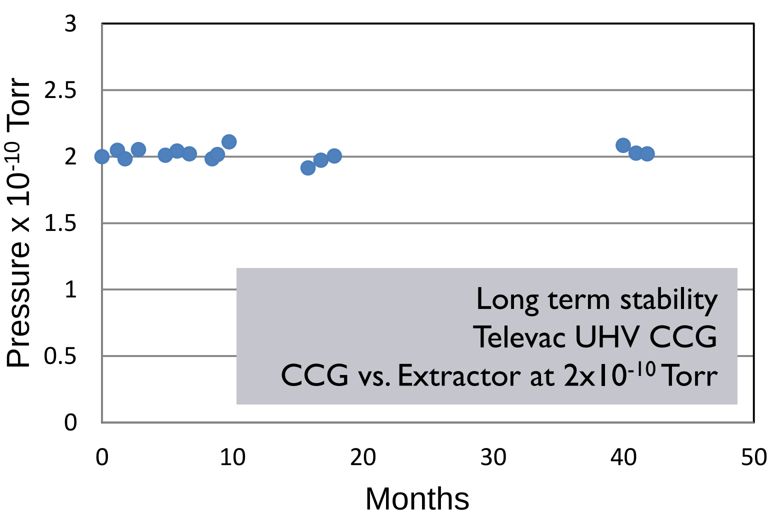
Televac Double Inverted design

Kendall JVSTA **18** 1724 (2000).

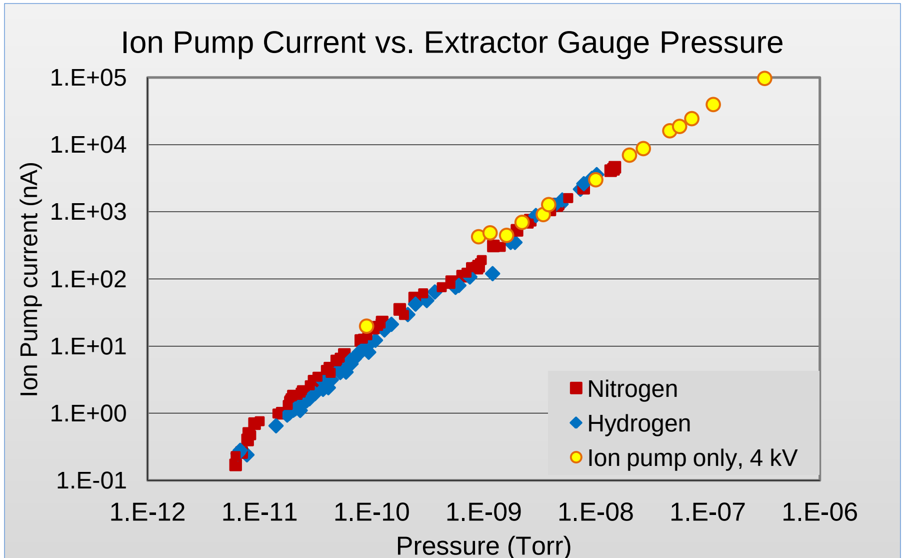


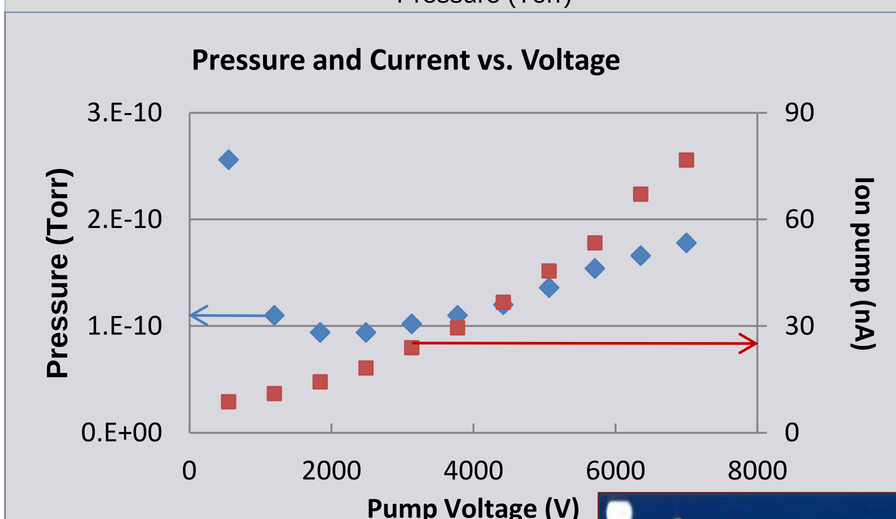
Edwards low field magnet design

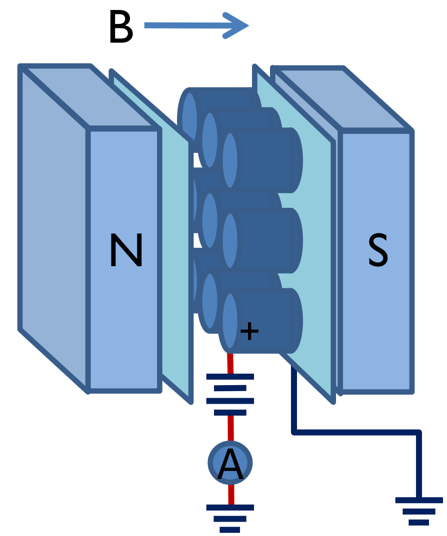




Ion pump as a pressure gauge







- PE sputter DI pumps
- Penning cell
- Power supply with Electrometer

- Current linear vs. extractor gauge
- Minimum voltage to sustain discharge
- Does not work with all ion pump designs (Noble ion configuration)

Conclusions

Hot filament gauges

- X-ray limit, ESD ions
  - Geometry
  - Modulation
- ESD neutrals
  - Heated grid gauges
  - Novel materials
- Sensitive to abuse, contamination
- Lowest pressure measured with Helmer gauge

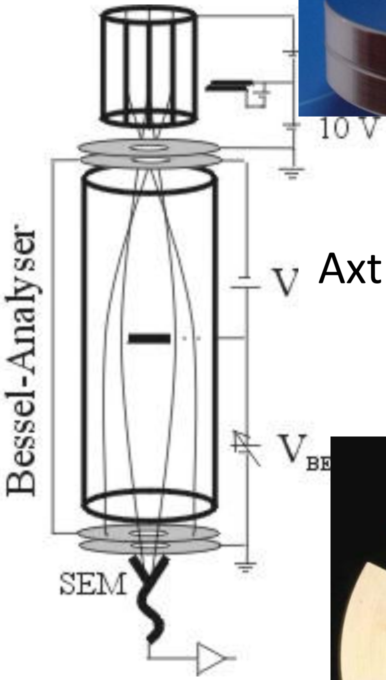
Cold cathode gauges

- Rugged, low energy consumption
  - Lunar, space applications
- Compensation for "knee" in electronics
- Ion pumps with sensitive current monitor shown to work as a relative pressure gauge
- Extension of conventional gauges toward XHV requires more work

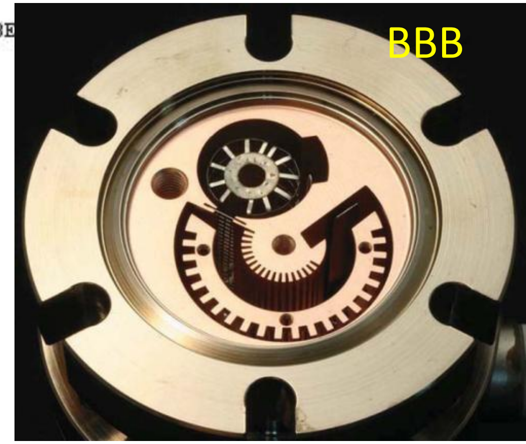
Small market – few commercially available gauges
Careful selection, utilization essential for accurate readings
Deep UHV gauges essential for improvements toward XHV

Deep UHV/XHV gauges

- Extractor gauge
  - available for decades
  - x-ray limit reduced through geometry
  - x-ray limit quote: 7.5×10^{-13} Torr
- Axtran gauge
  - Bessel box energy discrimination
  - electron multiplier to assist in low current measurements
  - Purchased, not yet installed
  - Measurement limit quote: <7.5e-15 Torr
- Watanabe BBB (Bent Belt Beam) gauge
  - Newly designed (JVSTA **28** (2010) p. 486)
  - Operates with Leybold IE540 controller
  - 230° degree deflector (similar to Helmer)
  - BeCu housing to reduce $I_{heating}$
  - Manufacturer's lower limit: 4×10^{-14} Torr



Axtran



Pressure Measurement = Current Measurement

Ionization gauge current contributions

$$I_{measured} = I_{real} + I_{x-ray} + I_{heating} + I_{ESD} + \left(I_{inv.x-ray} + I_{ESDneut.} \right)$$

I_{real}: pressure dependent gas phase ions – species sensitive

I_{x-ray}: x-ray induced electron desorption from collector

- reduce by geometry

I_{ESD}: ions arriving at collector from electron stimulated desorption (ESD) of molecules on the grid

- reduce by degassing grid

$I_{heating}$: pressure rise due to filament heating – species sensitive

- reduce by material selection, geometry, long duration

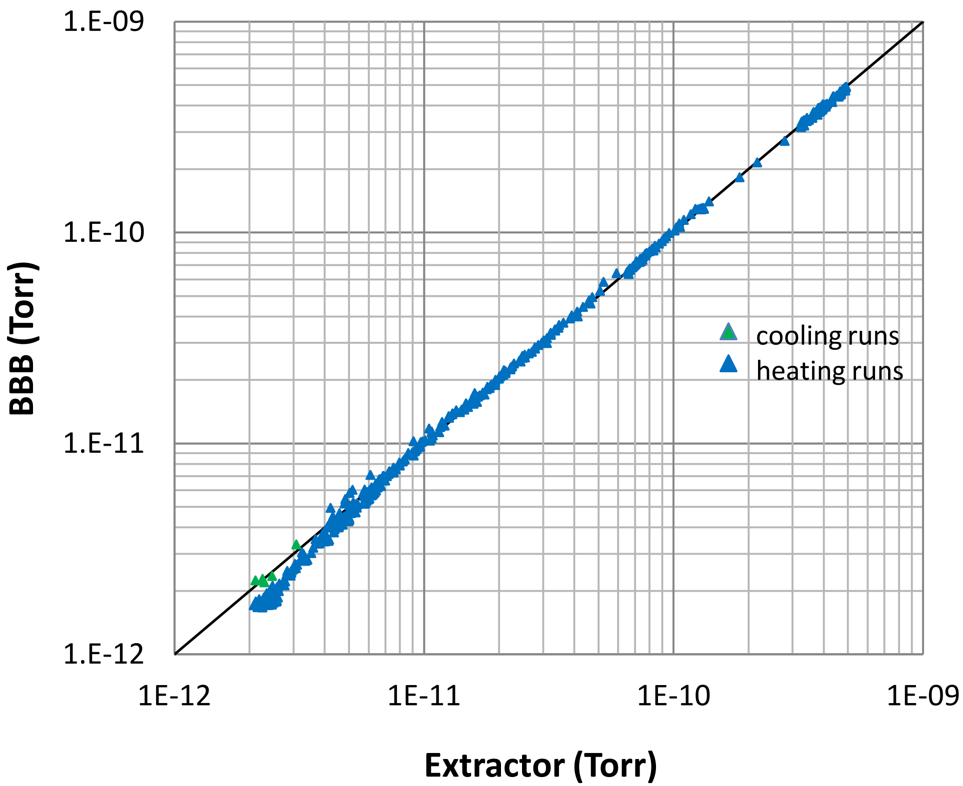
Gauge characterization chamber

- Heat treated twice
  - 400°C 10 days
- Outgassing (Q)
  - $3x10^{-14}$ Torr·L/s·cm^2
- Q following 250°C bake
  - $6.3x10^{-14}$ Torr·L/s·cm^2
- 3800 cm^2, 12L
- Pumping
  - 4 WP1250 NEGs, 60% 1300 L/s
  - 40 L/s ion pump (behind right angle valve)

Predicted pressure $2x10^{-13}$ Torr

- Extractor Gauge
- BBB Gauge
- 2 Leybold IE540 controllers
- 2 Keithley electrometers
- UHV ion pump power supply
- Diagnostic cross with RGA and ion pump
- NEG activation flange

Linearity between gauges



BBB and Extractor compared vs. pressure

- Leybold IE 540 source
- Keithley Electrometer

Pressure varied in chamber by heating NEGs or chilling

Conversion to Torr using manufacturer calibration factor / sensitivity

- Depends on species
- Ionization energy
- Ionization current
- Geometry

Gauge responses linear response over decades, possible deviation at lowest pressures

Sensitivity

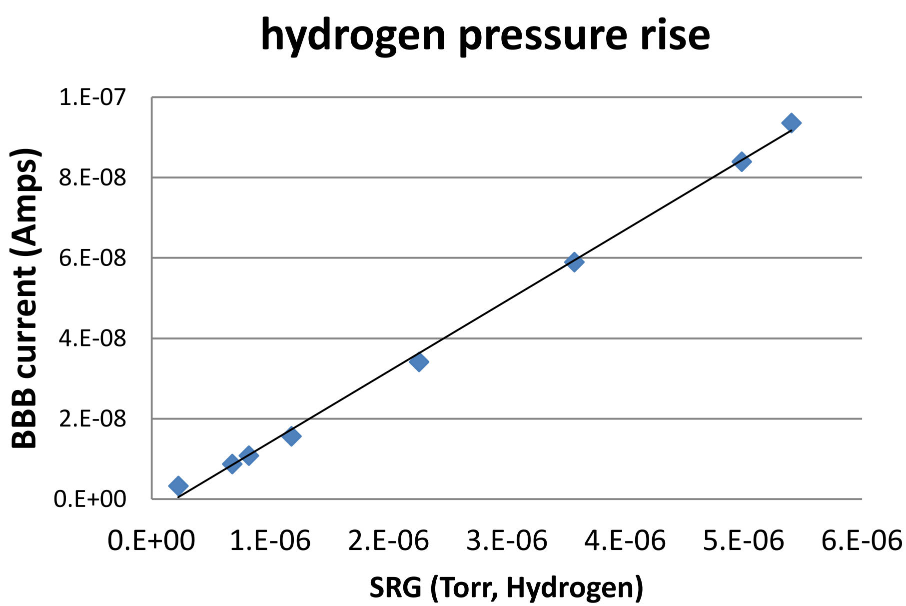
$$S = \frac{I_i}{P \times I_e}$$

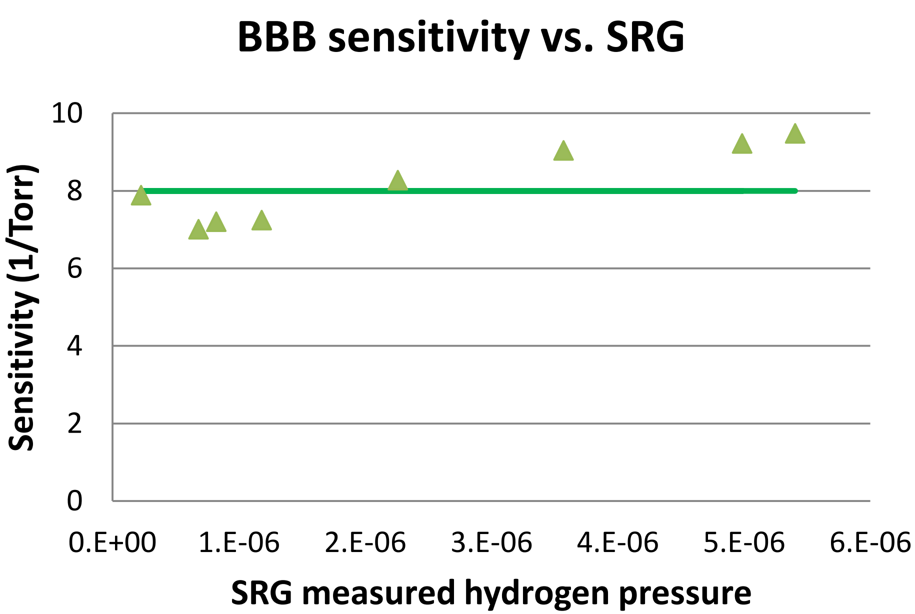
I_i ← Ion current

I_e ← Emission current

BBB and Extractor

- 120V electron energy
- 1.6 mA emission current
- geometry, collection efficiency vary

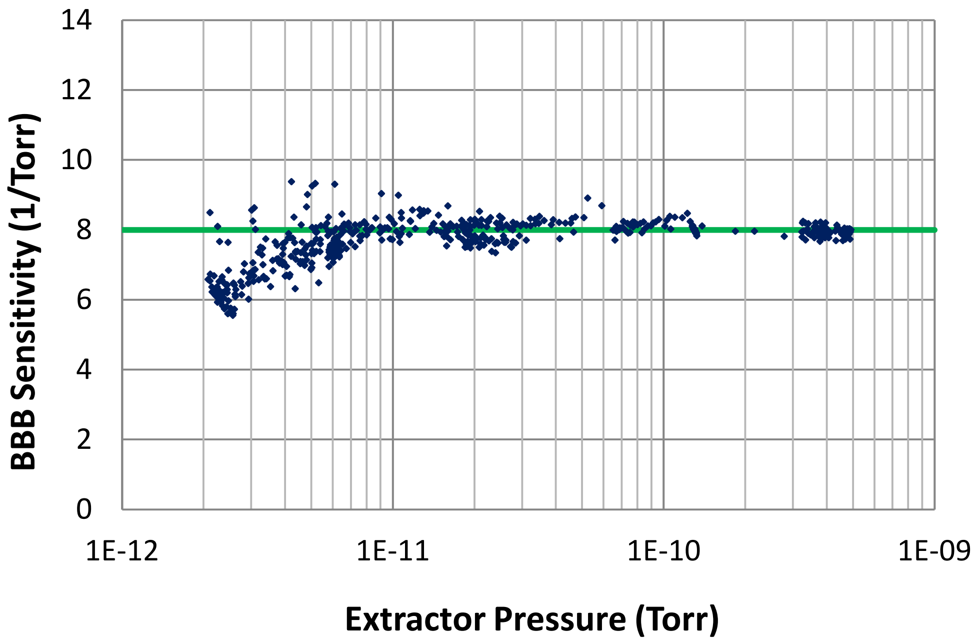




BBB vs. SRG data from previous setup

BBB sensitivity calculated using extractor

SRG Data: pressure 10^5 higher than our area of concern
Calculate BBB sensitivity from Extractor gauge pressure?



Calculated Extractor pressure relies on sensitivity of extractor gauge.

$$P = \frac{I_i}{S \times I_e}$$

Gauge sensitivity depends on

- Ionization energy
- Gas species
- Geometry
- Collection efficiency

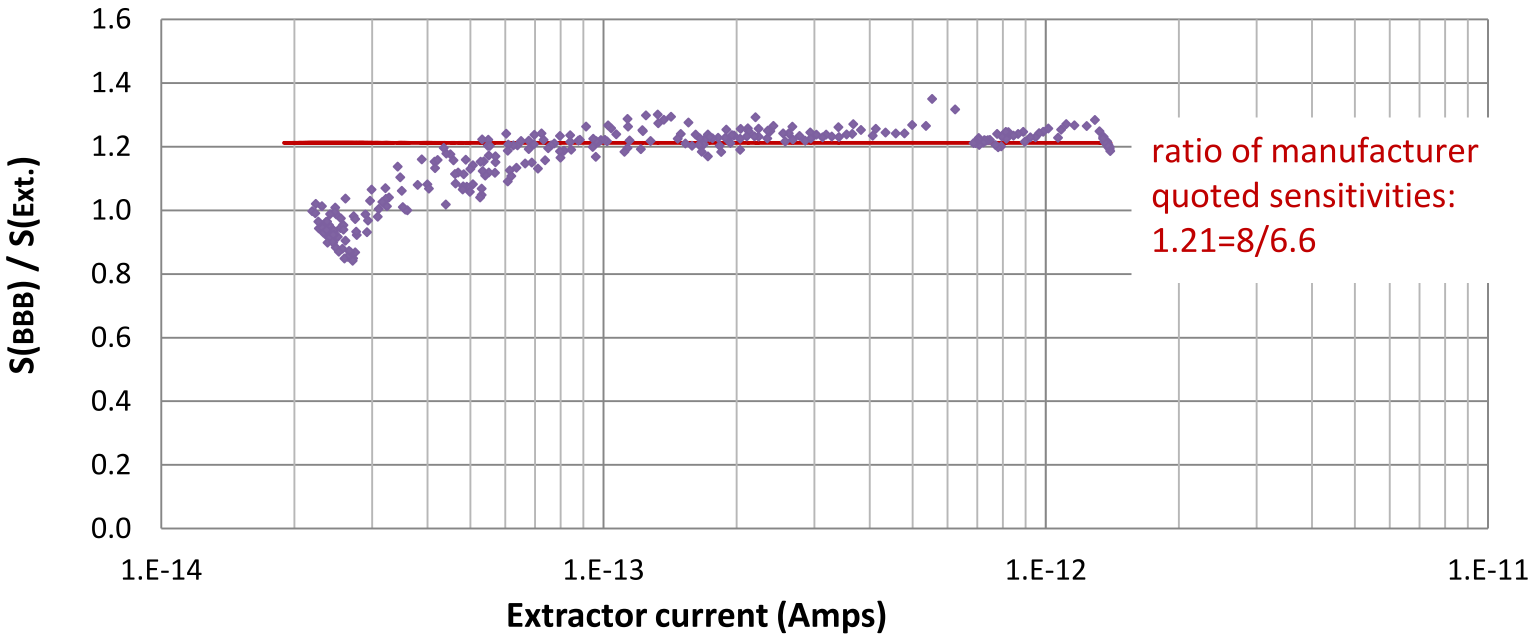
same (Ionization energy, Gas species)

constant (Geometry, Collection efficiency)

relative sensitivity

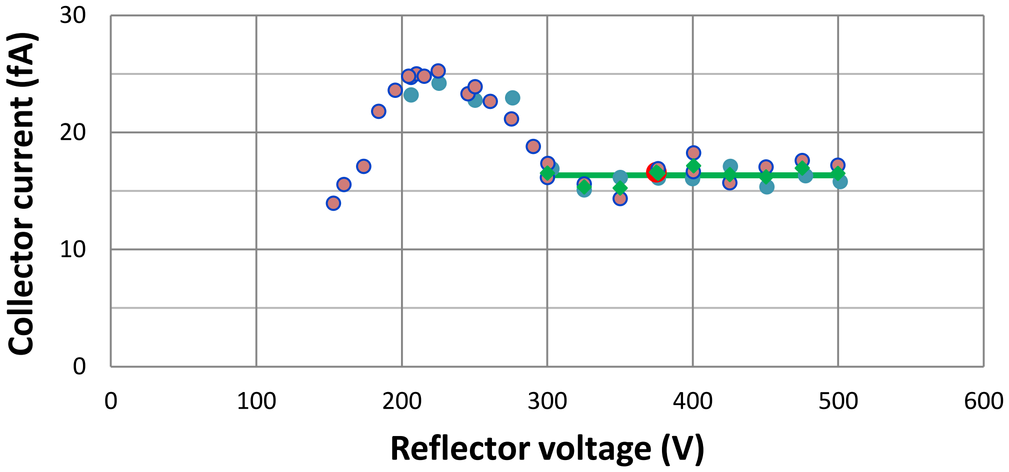
Define sensitivity ratio
- should be constant

$$\frac{S_{BBB}}{S_{EXT}} = \frac{I_{BBB}}{I_{EXT}}$$

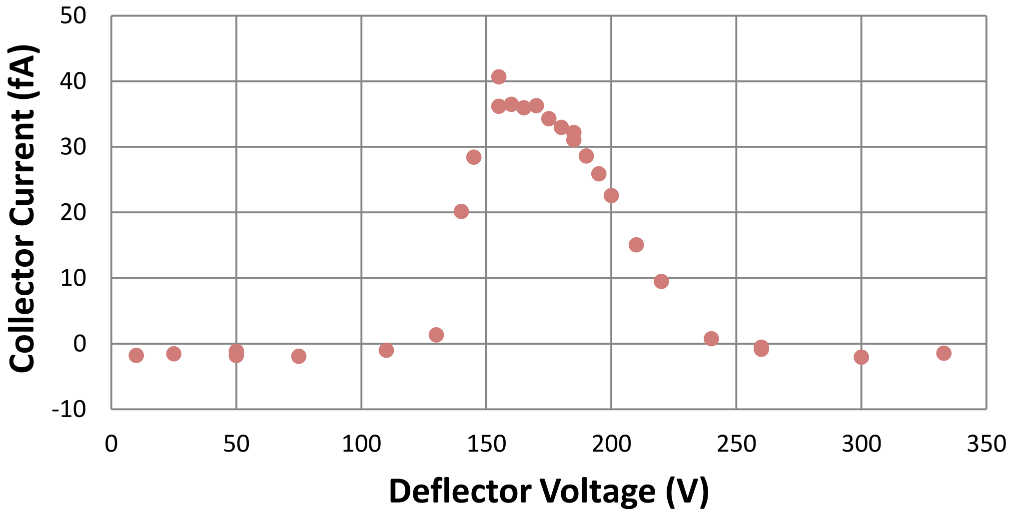


Can the deviation from constant behavior be explained by gauge backgrounds?

Background current measurements



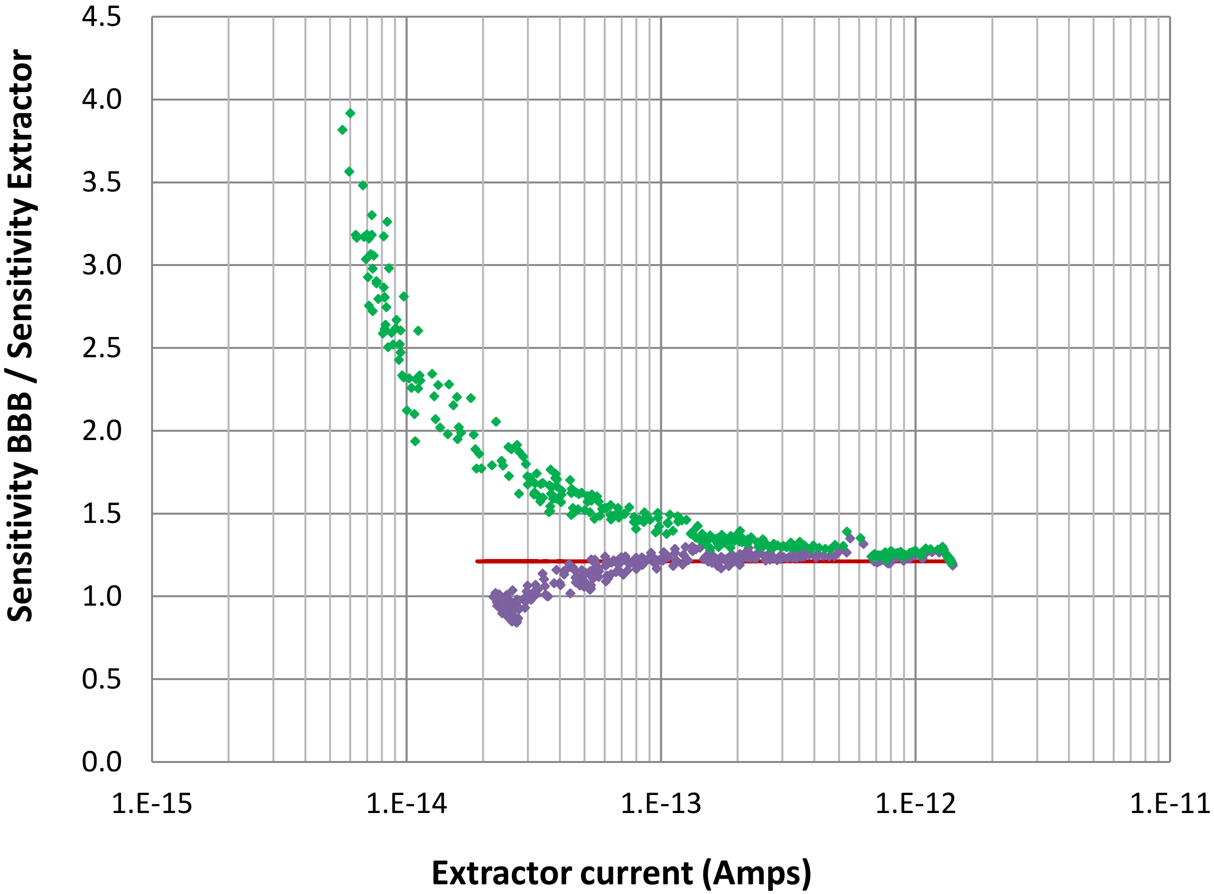
Extractor x-ray current accounts for
3/5 of total measured signal



BBB signal of 35 fA with background of -1 fA

Gauge backgrounds measured at different times, different pressures

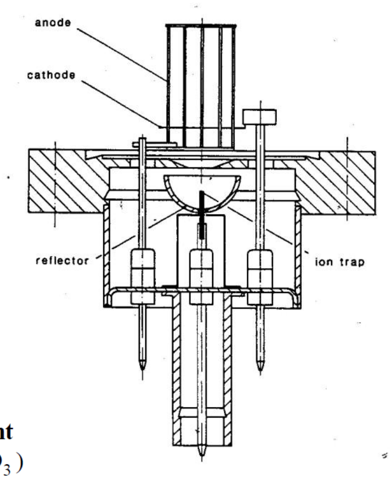
Sensitivity ratio: x-ray limit correction



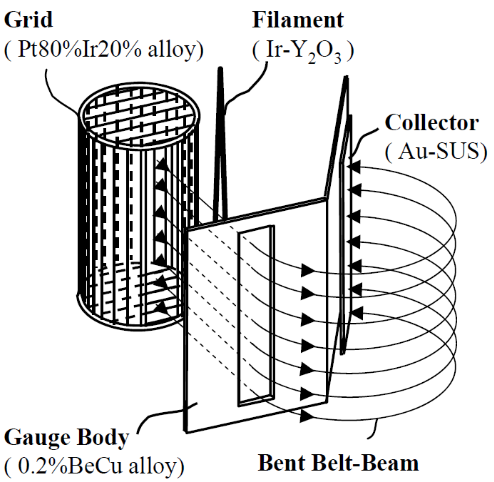
- Subtraction of x-ray background for extractor gauge overcorrects
- What else?
  - ESD limits
  - Load due to gauges
  - Small current measurement errors
  - nonlinearity in gauge response?

Electron stimulated desorption

$$I_{measured} = I_{real} + I_{x-ray} + I_{heating} + I_{ESD} + \ldots$$

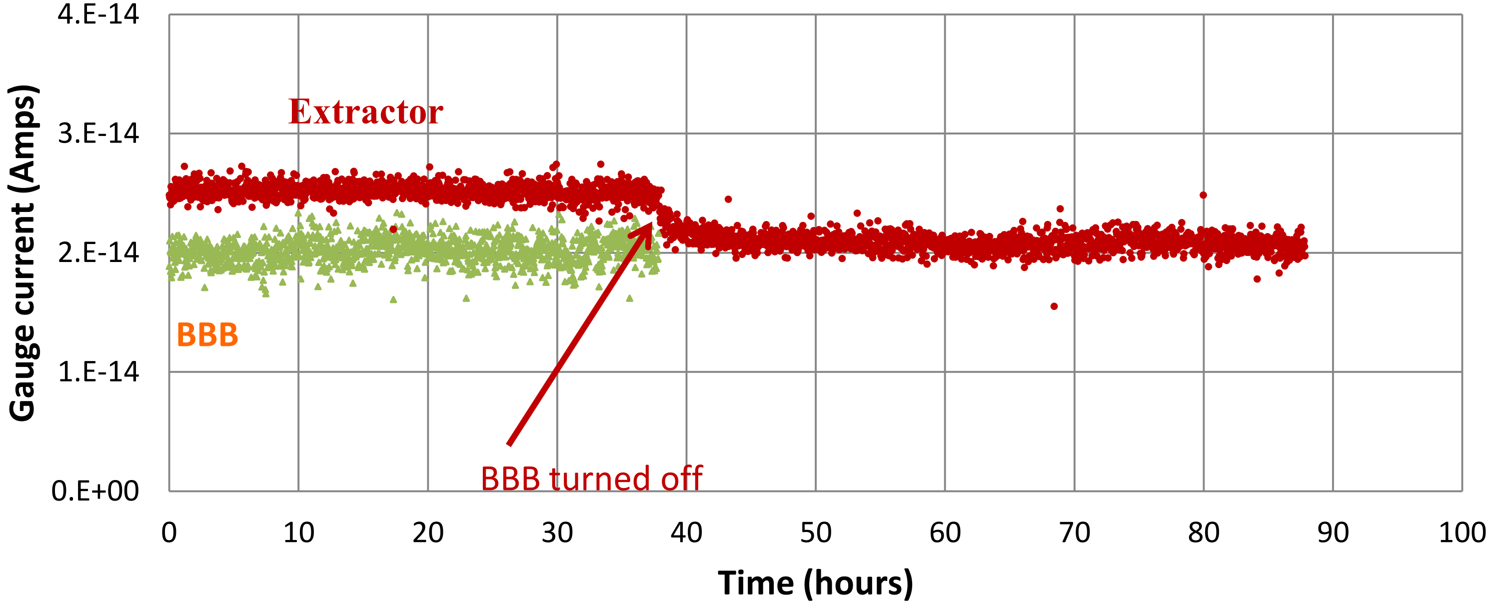


- Electrons can liberate elements adsorbed on the grid
- If grid - filament potential equal to electron energy, ESD difficult to separate
- Methods to reduce ESD
  - high energy electron bombardment (degas mode)
  - operate grid at elevated temperature
  - grid material optimization (BBB)
  - stabilize for months
  - Axtran: energy analysis since electron energy ≠ grid-filament potential



Current due to heating by filaments

$$I_{measured} = I_{real} + I_{x-ray} + I_{heating} + I_{ESD} + \ldots$$



Use one gauge to measure the additional current generated by other hot filament

ΔI (BBB) = 4.8 fA

ΔI (Extractor) = 5.6 fA

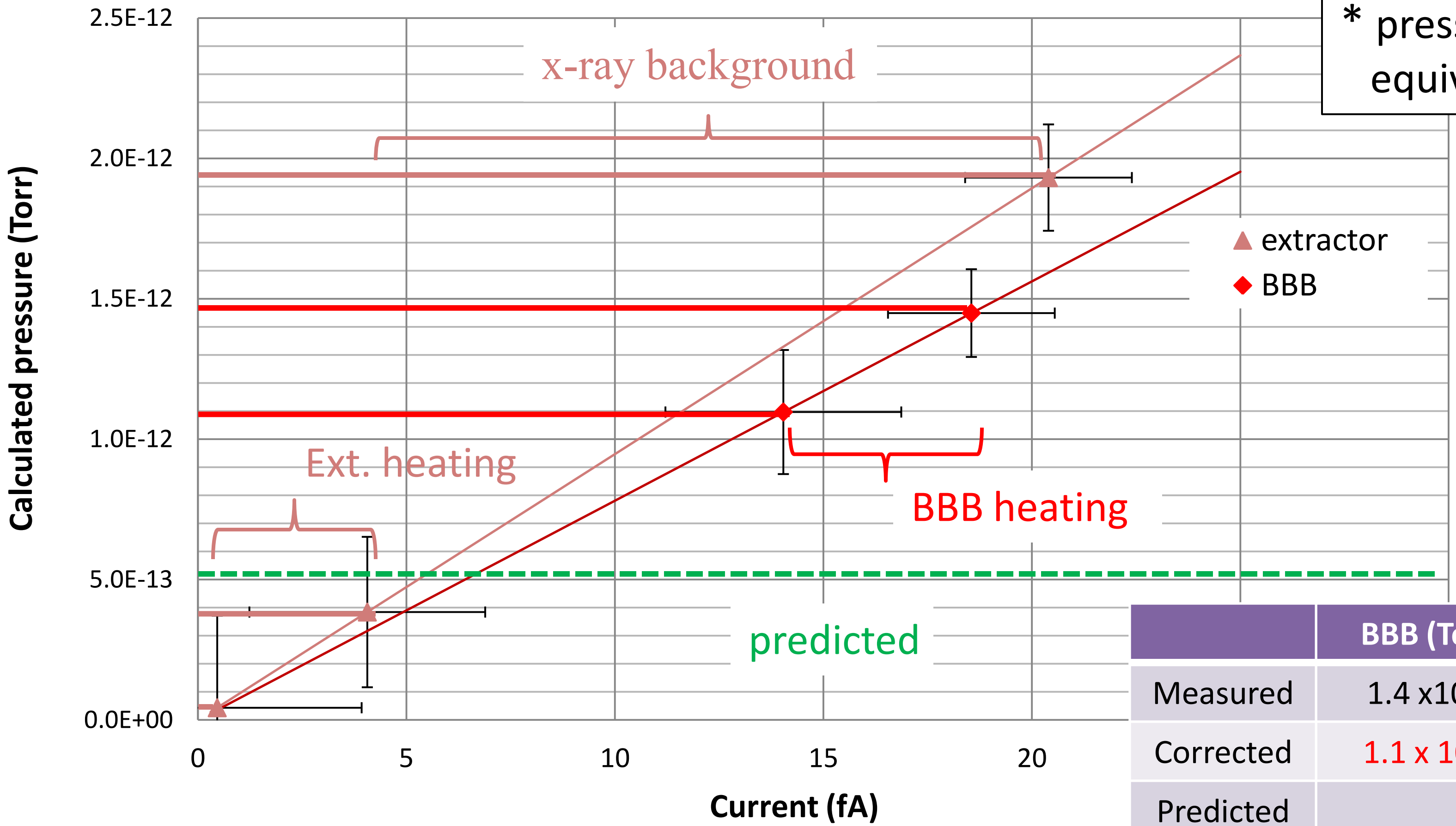
BeCu BBB housing should reduce effect

Difference minimized after 6 months?

So what is our pressure?

$$I_{measured} = I_{real} + I_{x-ray} + I_{heating} + I_{ESD} + \ldots$$

* pressures nitrogen equivalent, S_{vendor}



	BBB (Torr)	Extractor
Measured	1.4×10^{-12}	1.9×10^{-12}
Corrected	1.1×10^{-12}	5×10^{-14}
Predicted	6×10^{-13}	

Conclusions

- Pressure in our systems (nitrogen equivalent) corrected for gauge effects is near $1x10^{-12}$ Torr
- BBB signal to noise good: Noise < 10% signal
- Extractor gauge: measurements at lowest pressures dominated by background
- BBB and extractor agree very well above $1x10^{-11}$ Torr, diverge at lowest pressures
- The BBB gauge should be able to quantify pressure improvements in the bakable cryopump system.

Back up 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)

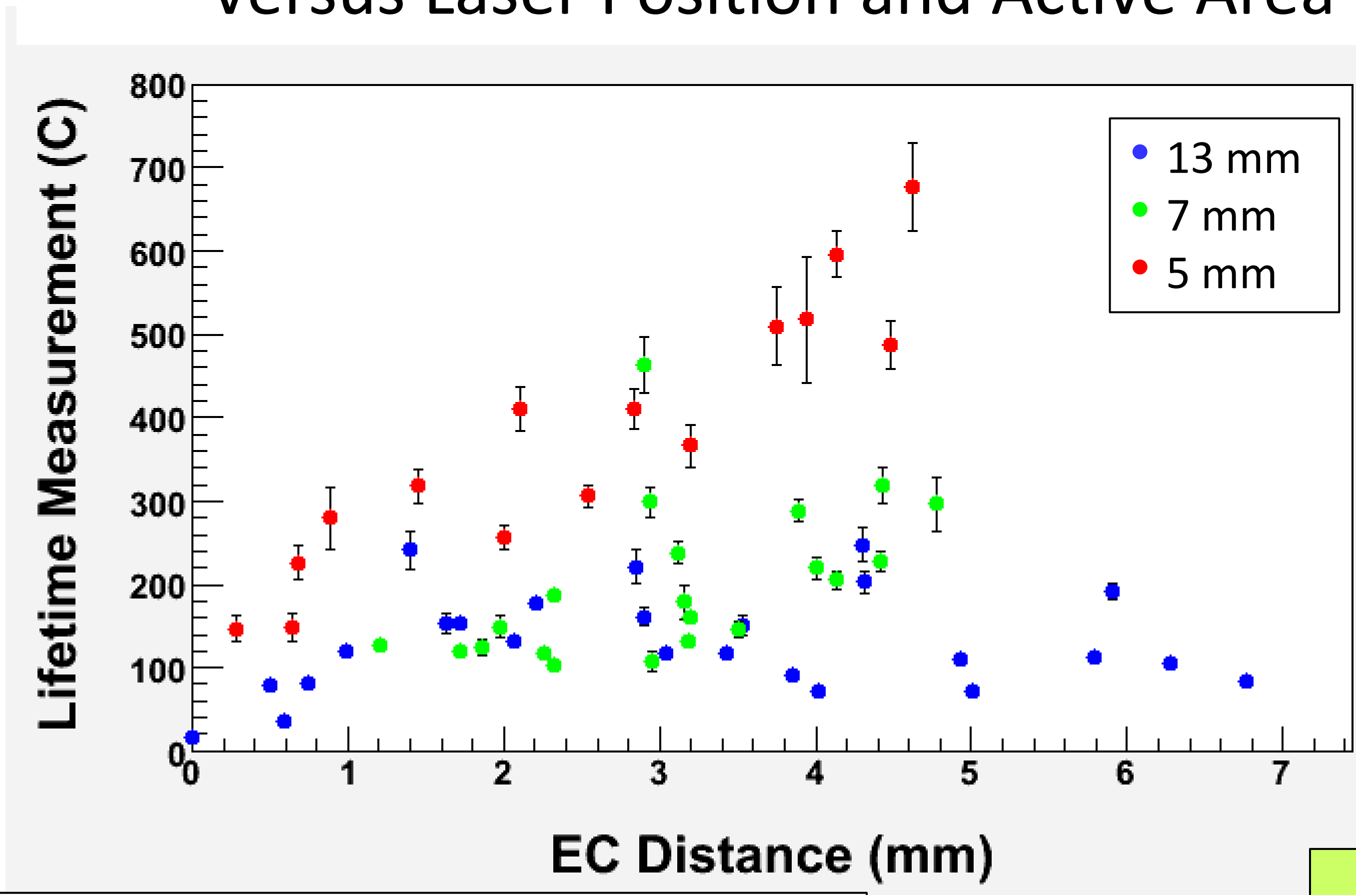
Gun HV (kV)	E_s (MV/m)	ε_n (μm)
100	2.0	0.011
140	2.8	0.009
200	4.0	0.008

- Normalized Brightness:

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

Brightness is proportional to Gun HV

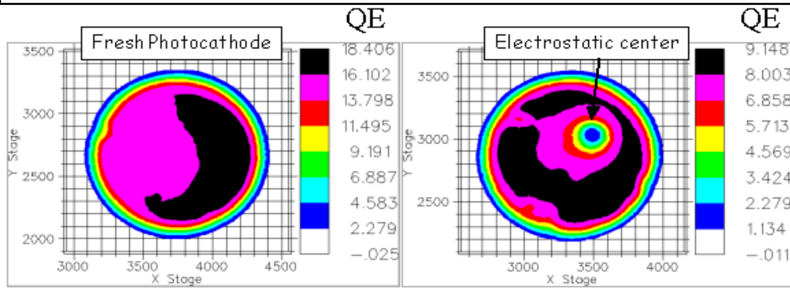
InvGun2 : Lifetime at 2mA and 100kV bias: Versus Laser Position and Active Area



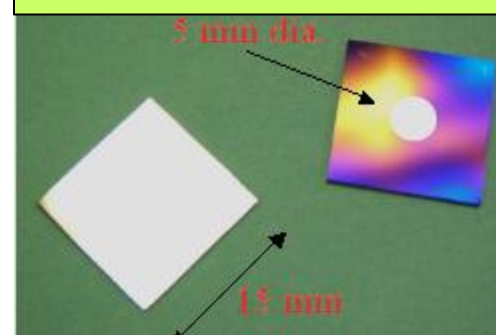
DC beam from bulk GaAs, green light and 350um spot.

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

Finite lifetime due to ion back-bombardment



Now we mask…



Work of Riad Suleiman