USPAS Course on Photocathode Physics

John Smedley, BNL and Matt Poelker, TJNAF

Lecture 4

Austin, TX January 16-20, 2011

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…..

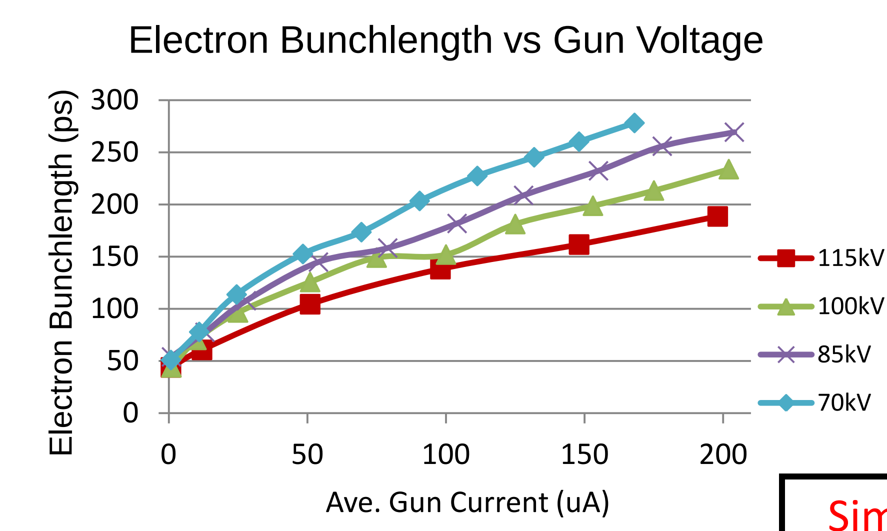
DC versus RF Gun

It’s mostly about bunch charge and duty factor…

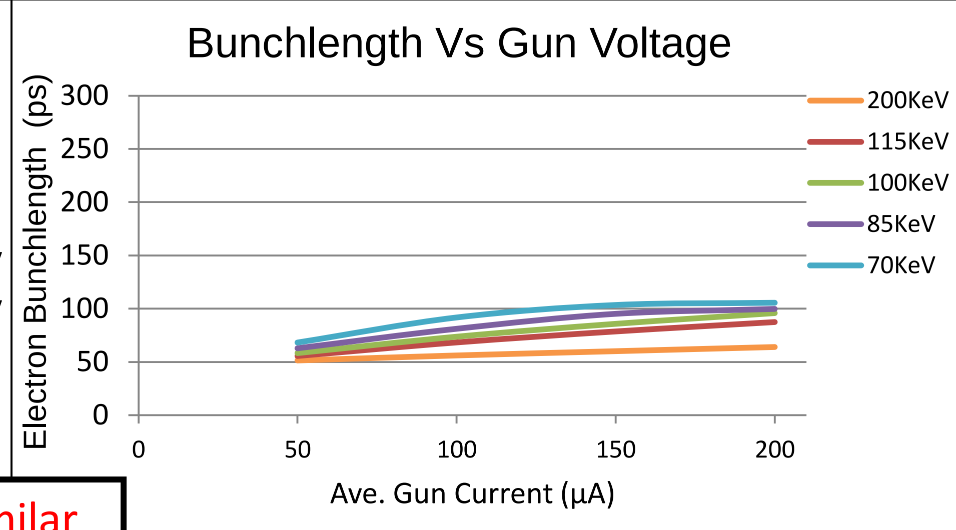
- Vacuum inside a warm (i.e., normal conducting) RF gun is not very good
  - So forget about using GaAs
- And warm RF guns get very hot when operating CW. Lots and lots of cooling required, presenting a complicated mechanical design. Most warm RF guns are pulsed, low duty factor devices
- SRF guns should 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

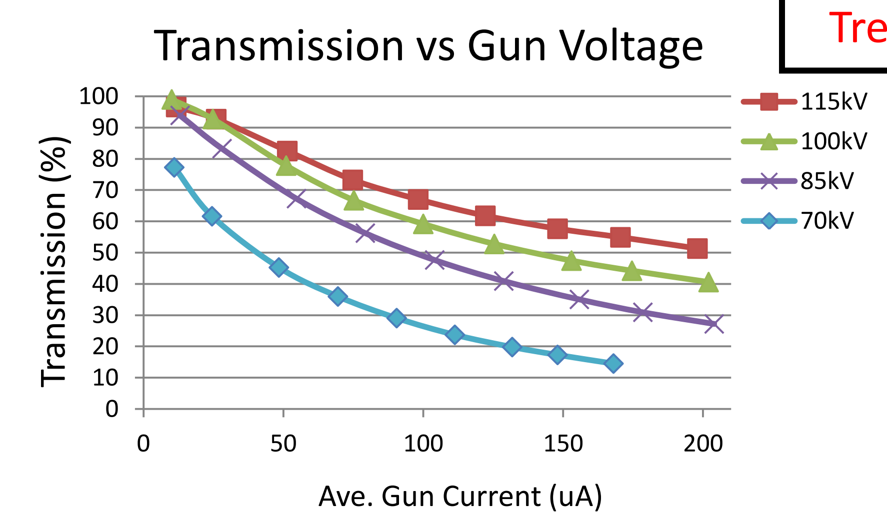
Measurements at CEBAF/JLab

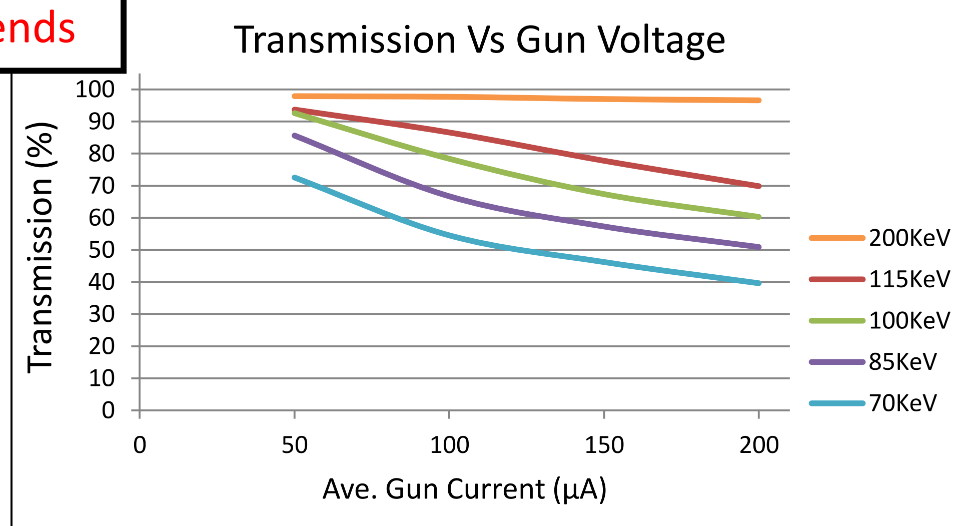


PARMELA Simulation Results



Similar Trends

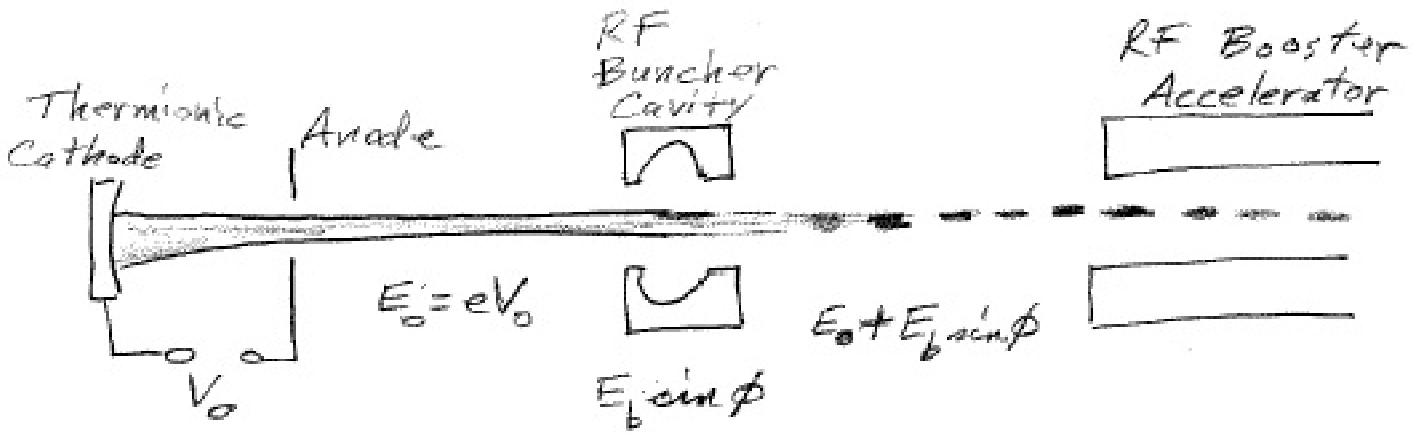




Message: Beam quality, including transmission, improves at higher gun voltage

A simple injector

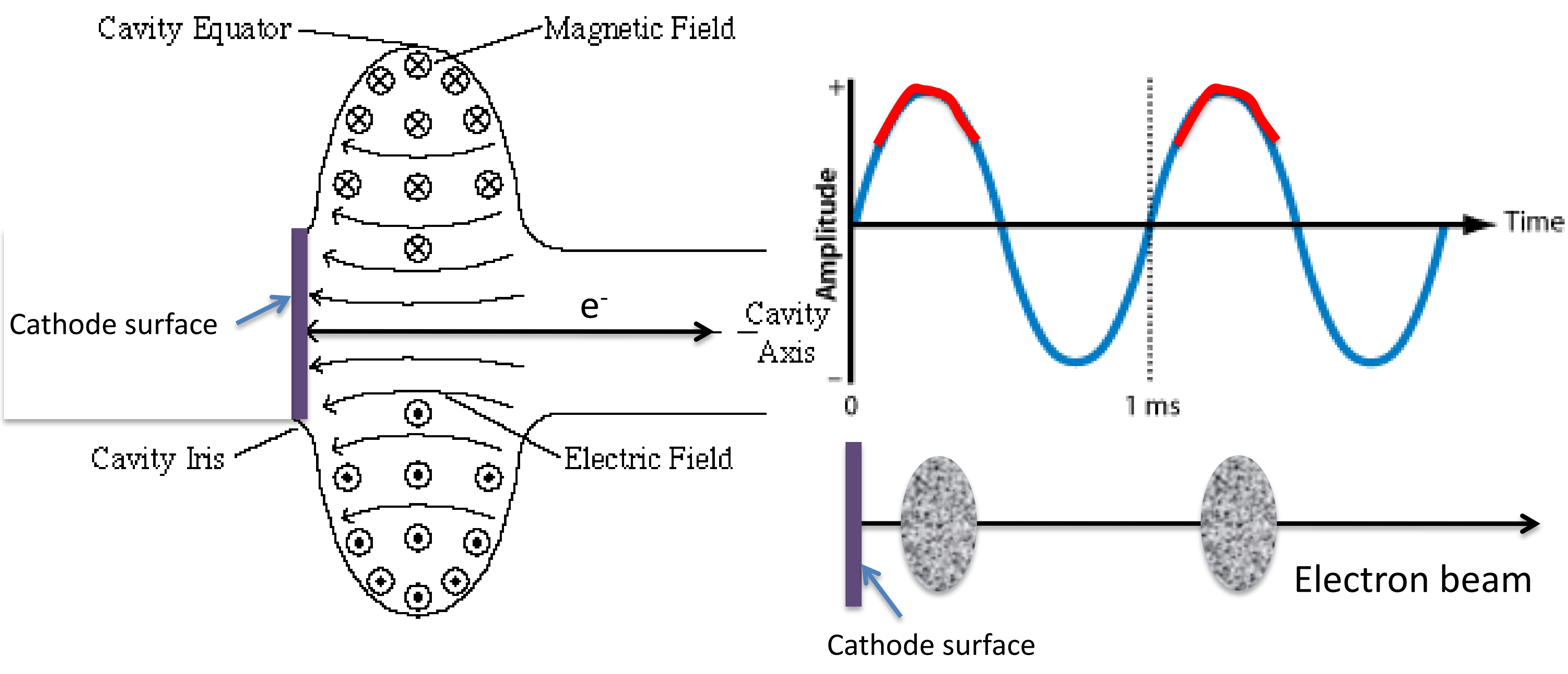
- DC thermionic gun followed by a buncher cavity which ballistically compresses electrons
- Thermal energy excites the electrons to overcome the cathode work function



Sketch courtesy of Dr. D. Dowell, SLAC.

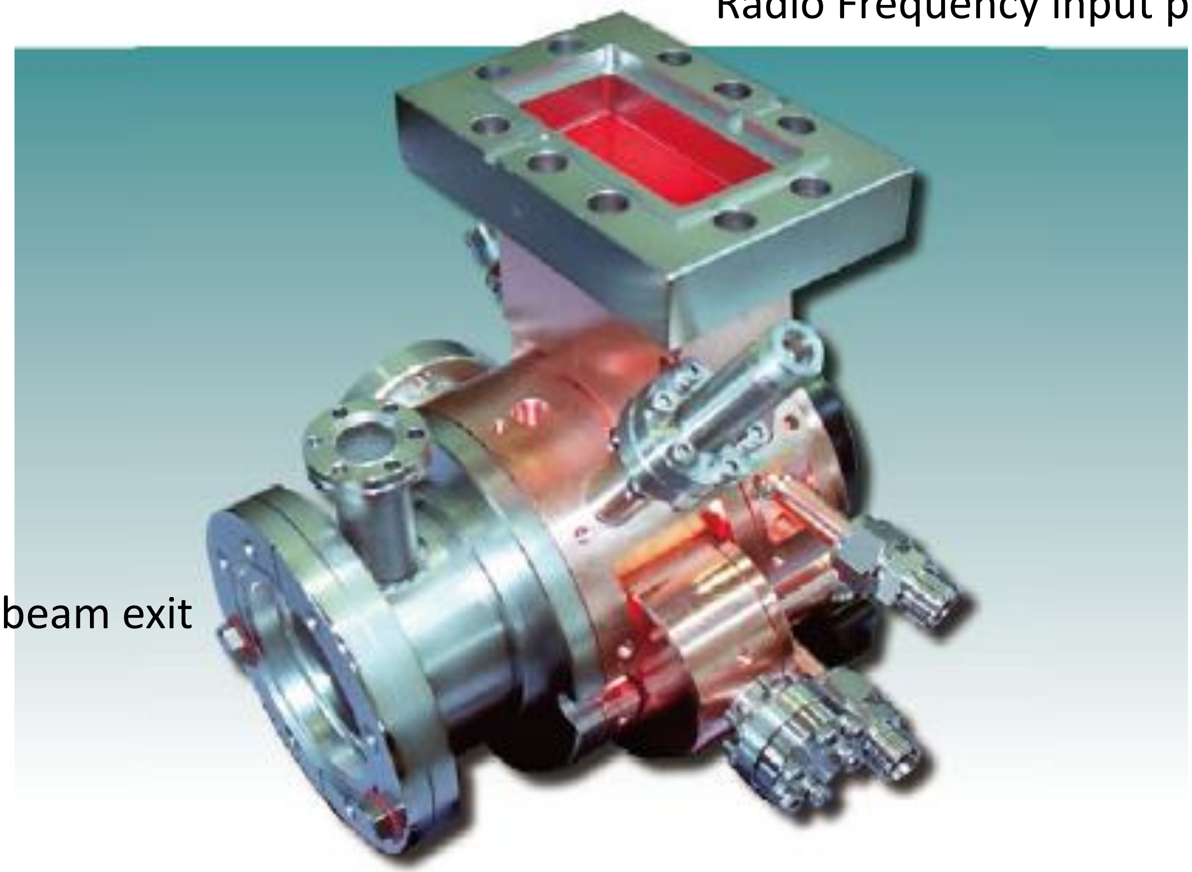
Thermionic cathode inside RF cavity

- 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 knows as thermionic radio-frequency guns.
- Thermal energy excites the electrons to overcome the cathode work function



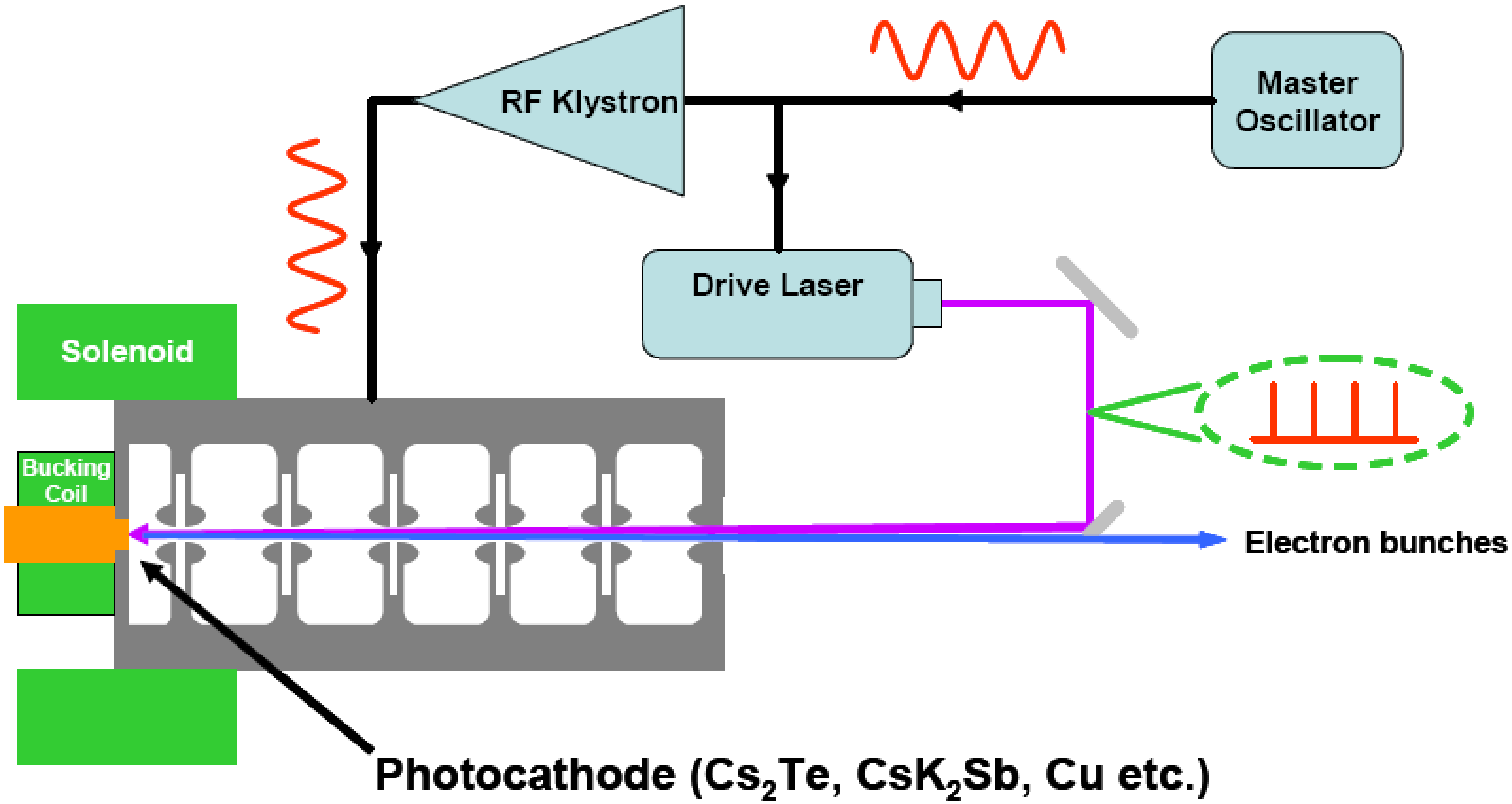
Thermionic Normal Conducting Radio Frequency electron gun

Radio Frequency input port



Electron beam exit

Photoinjector



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

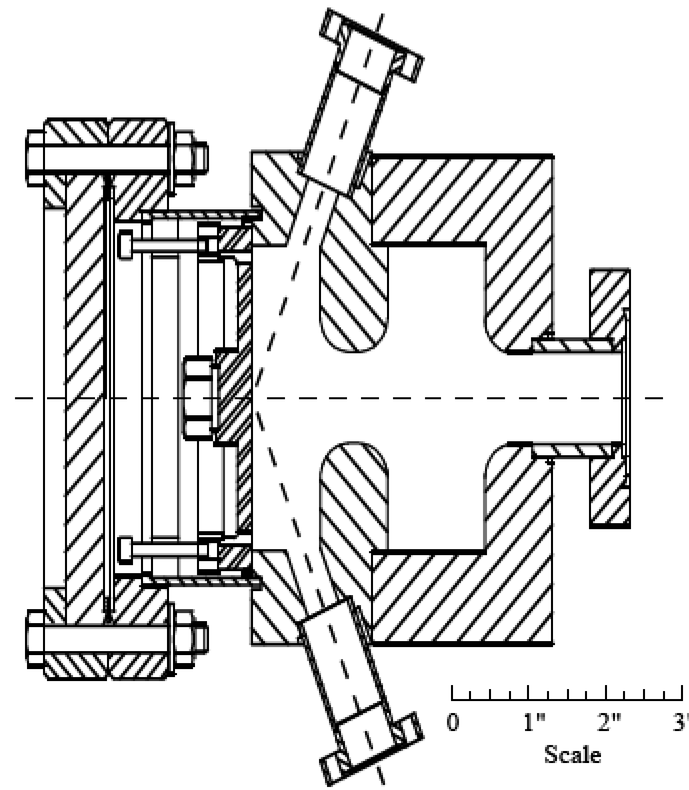
Good vacuum is challenging,

- typically >10^{-10} Torr

Good for high peak current, low average current applications

- High peak brightness X-ray FELs (LCLS, FLASH)

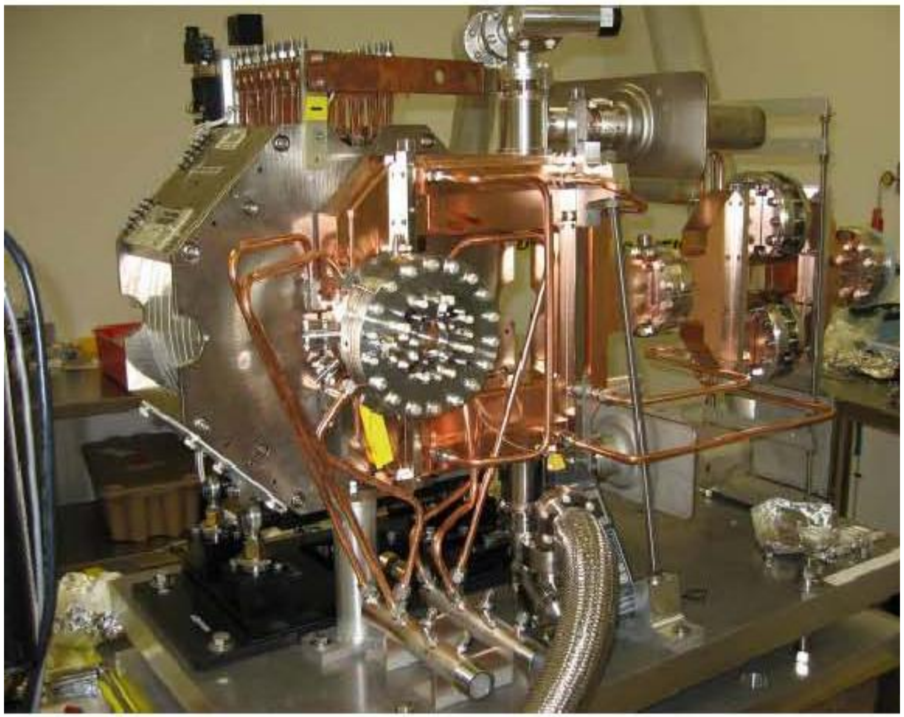
Chemical poisoning is the typical source of cathode degradation



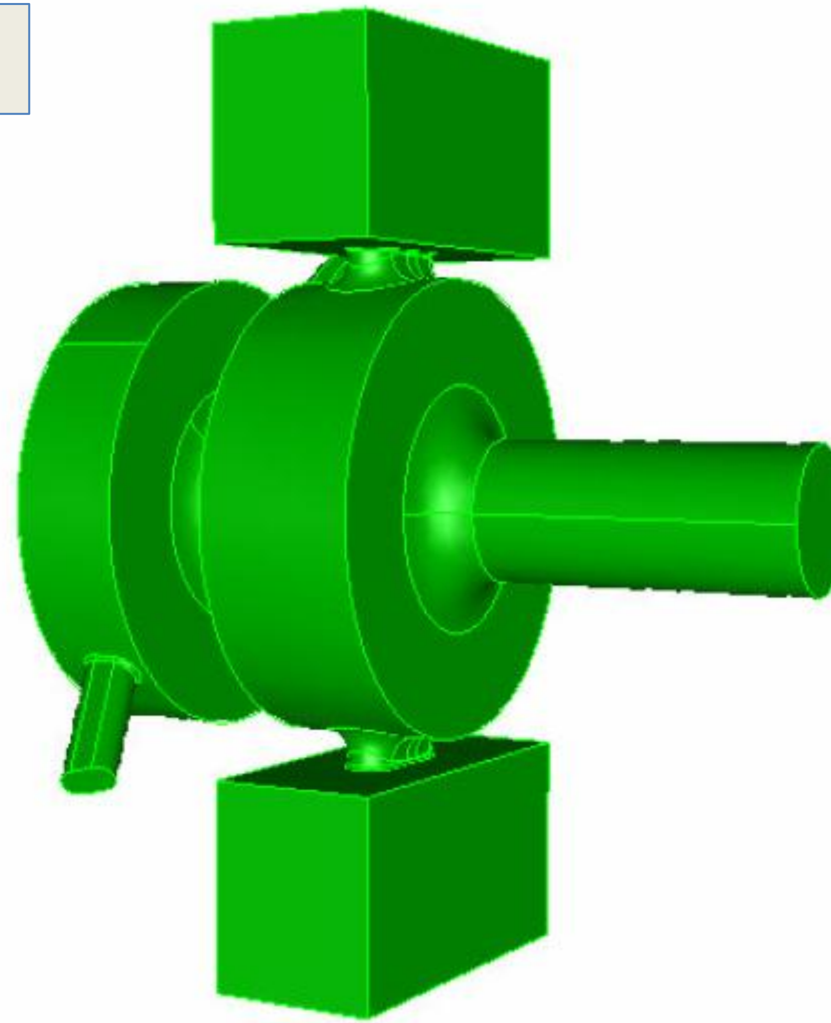
B. E. Carlsten, *Nucl. Instrum. and Meth.,* **A285,** 313 (1989)
D. H. Dowell *et al*., FEL2007

LCLS Warm RF PhotoGun

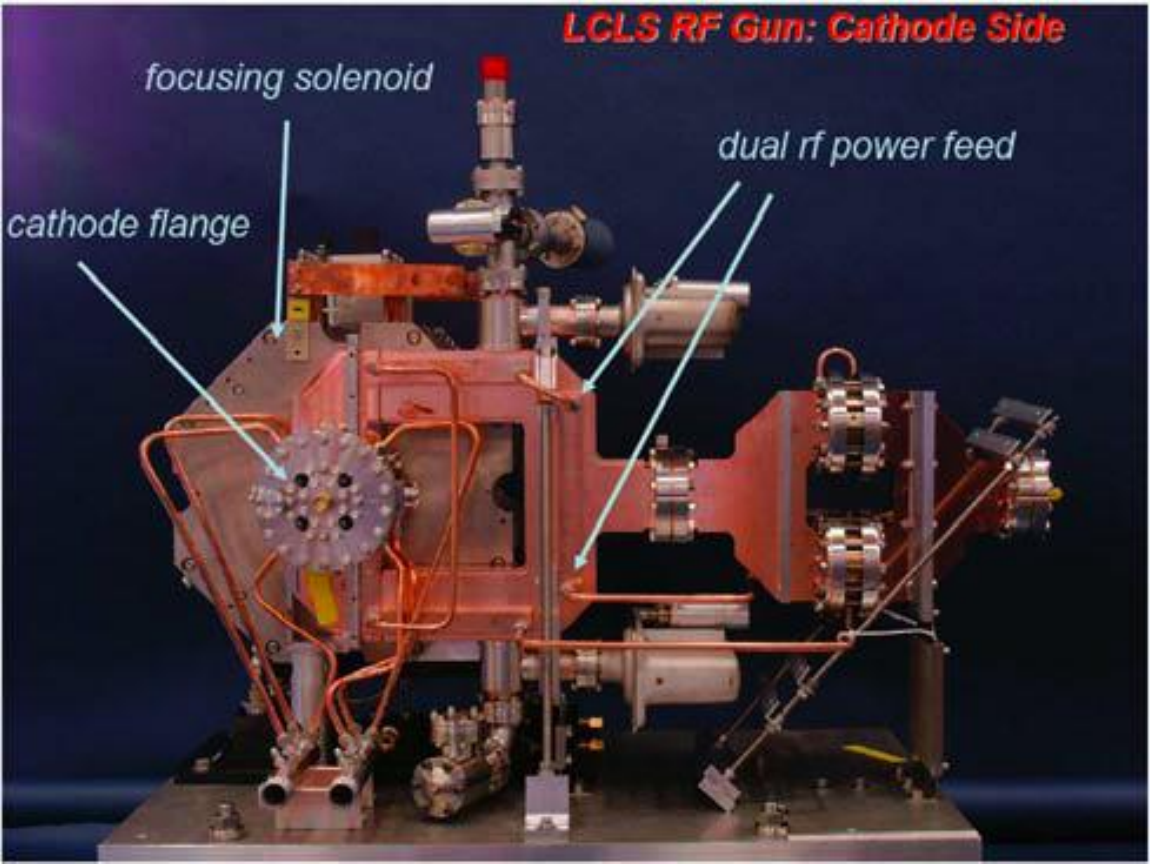
Metal photocathodes, pulsed-RF



https://slacportal.slac.stanford.edu/sites/ard_public/bpd/acd/Pages/acmod.aspx



Linac Coherent Light Source Photoemission NCRF gun at Stanford



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

COMMISSIONING THE *LCLS INJECTOR*

R. Akre, D. Dowell, P. Emma, J. Frisch, S. Gilevich, G. Hays, Ph. Hering, R. Iverson, C. Limborg-Deprey, H. Loos, A. Miahnahri, J. Schmerge, J. Turner, J. Welch, W. White, J. Wu

SLAC, Stanford, CA 94309, USA, SLAC-PUB-13014, November 2007

GaAs inside warm RF gun

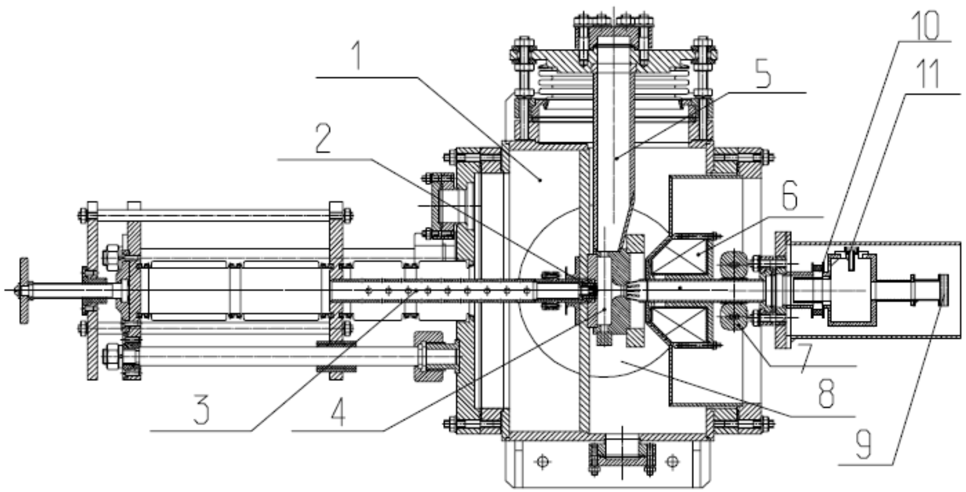


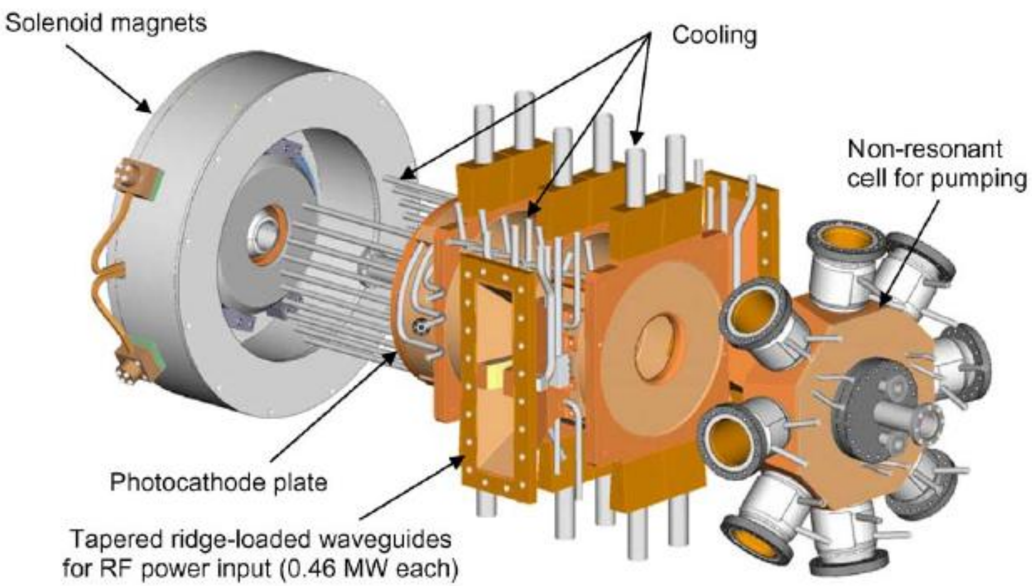
Figure 1: The scheme of RF gun prototype. 1 - activation chamber, 2 - photocathode assembly, 3 - manipulator, 4 - accelerating cavity, 5 - waveguide, 6 - focusing lens, 7 - transverse corrector, 8 - working chamber, 9 - vacuum window for laser beam, 10 - ceramic insulator, 11 - the cavity for bunch length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

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

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

A.V.Aleksandrov, M.S.Avilov, N.S.Dikansky, P.V.Logatchev,
L.A.Mironenko, A.V.Novokhatski, Yu.I. Semenov, S.V. Shiyankov.
Institute of Nuclear Physics, 630090 Novosibirsk, Russia.
L.Tecchio.
Dipartimento di Fisica Sperimentale dell’Universita and INFN, Torino, Italy.

CW Normal Conducting RF Guns



v of the $2\frac{1}{2}$—cell NCRF gun being fabricated by AES for LANL. The non-resonant cell provides additional vac

Key Issues:

- Managing the heat load
- Managing the vacuum
- Managing the field emission

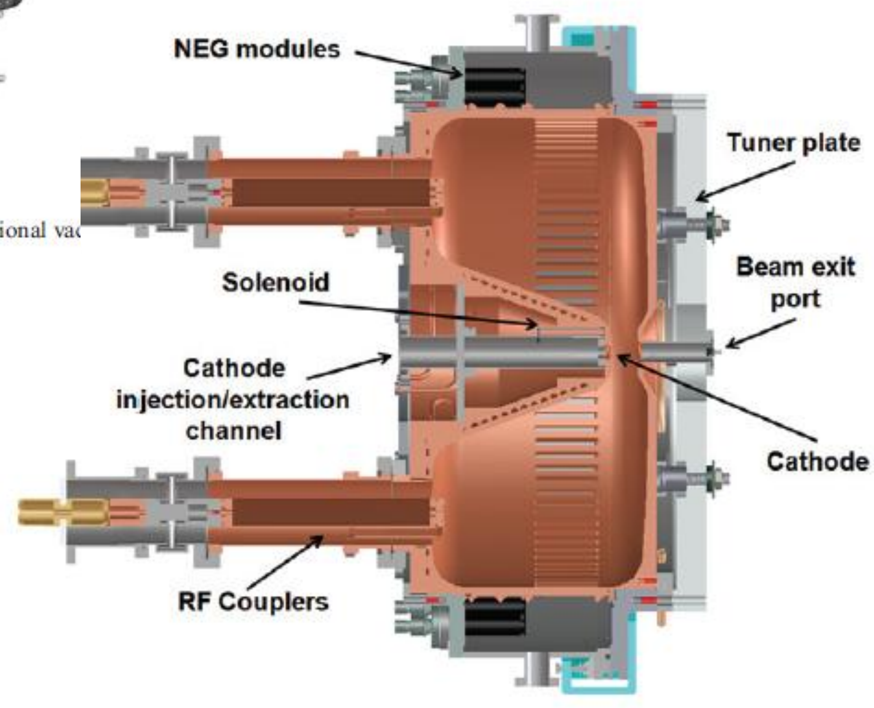
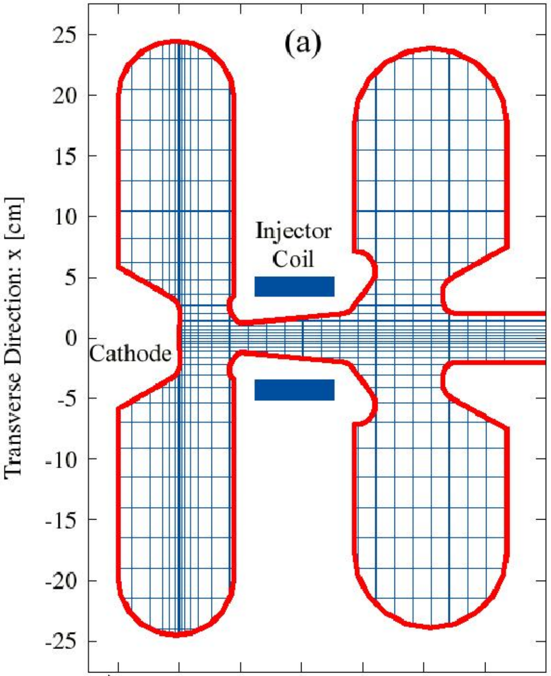
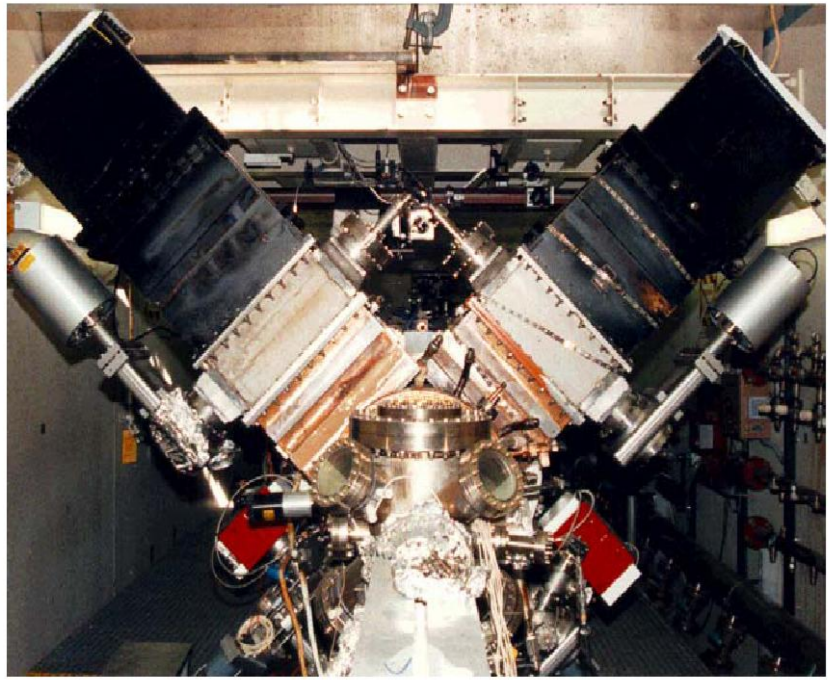


Figure 7: Low frequency, normal-conducting CW gun developed at LBNL [12, 13].

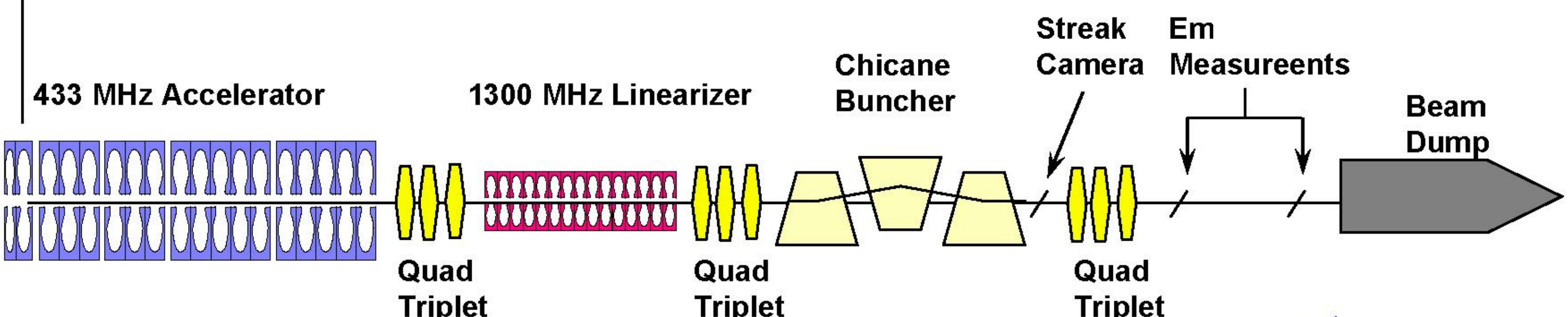
The Boeing Gun: Still the Demonstrated State-of-the Art





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

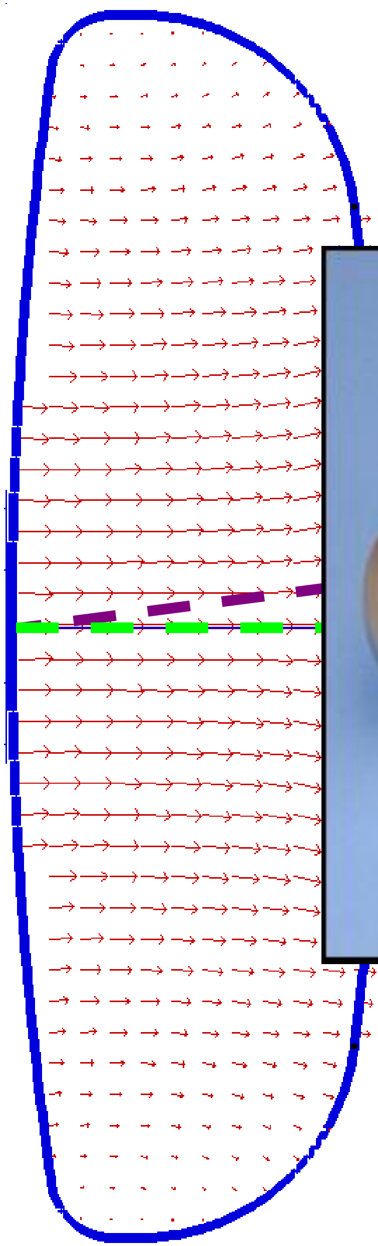
Gun Parameters
433 MHz
26 MV/m peak field
0.6 MW RF Power

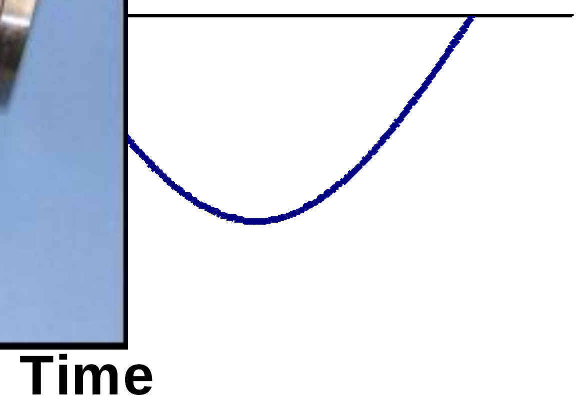


Material Courtesy David Dowell and John Adamski

D. H. Dowell *et al.*, *Appl. Phys. Lett.*, **63**, 2035 (1993)

Photoinjector

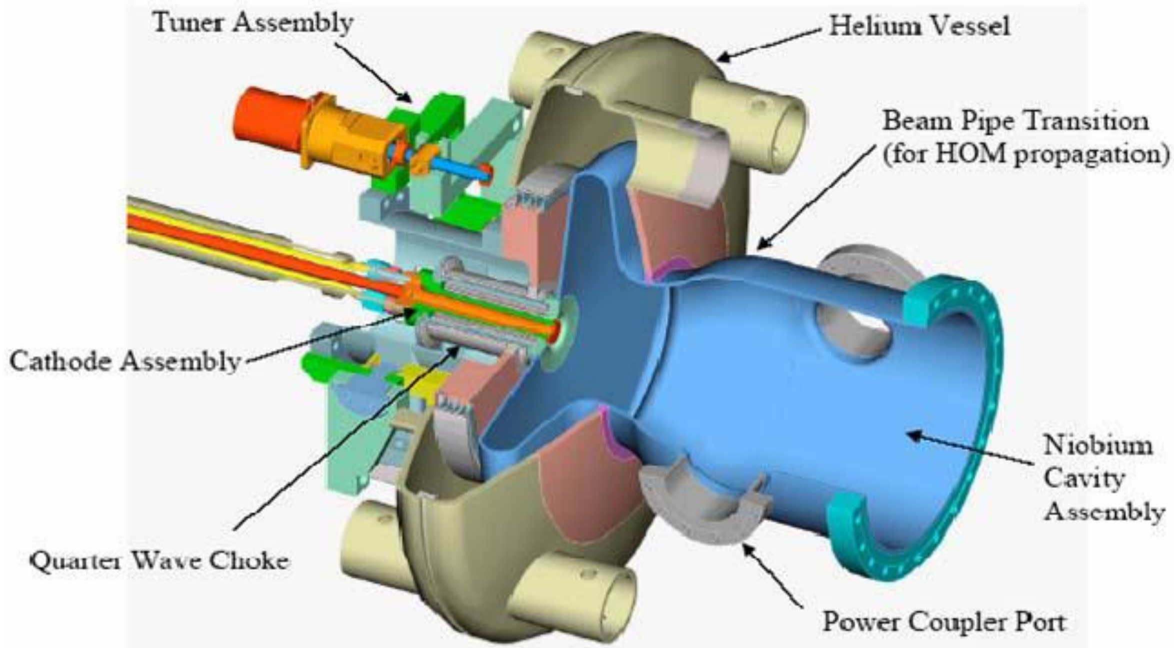




Planned SRF Injector

BNL/AES 703 MHz ½ cell

	High Q e-cooler	High I
f [MHz]	703.75	
q/bunch [nC]	5	0.7
ε_n [µm 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_2Sb	w/ Diamond Amplifier
QE [%]	1 (532nm) 5 (355 nm)	x100



Cathode options

- K_2CsSb (traditional & dispenser)
- Diamond Amplified Cathode

BROOKHAVEN NATIONAL LABORATORY

R. Calaga, PhD Thesis
V. Litvinenko, *et al*, PAC07, 1347

Superconducting RF Photoinjector

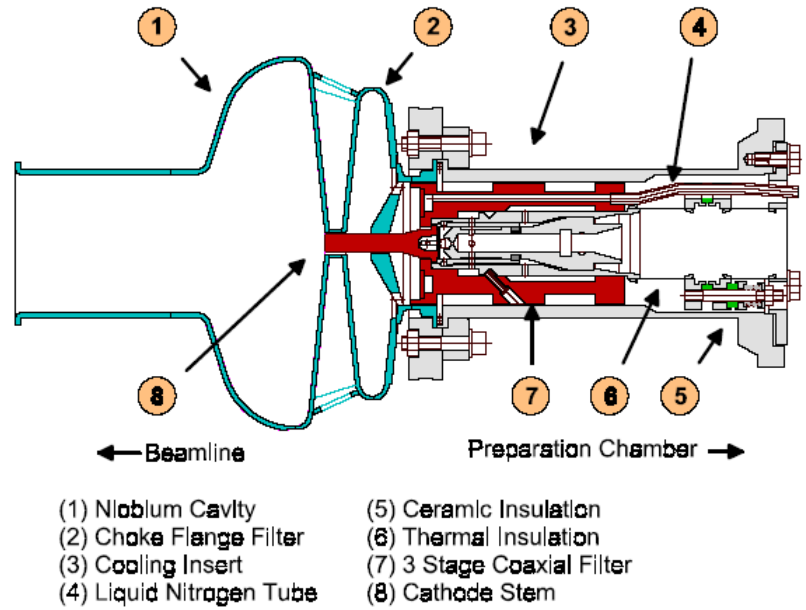
New technology

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

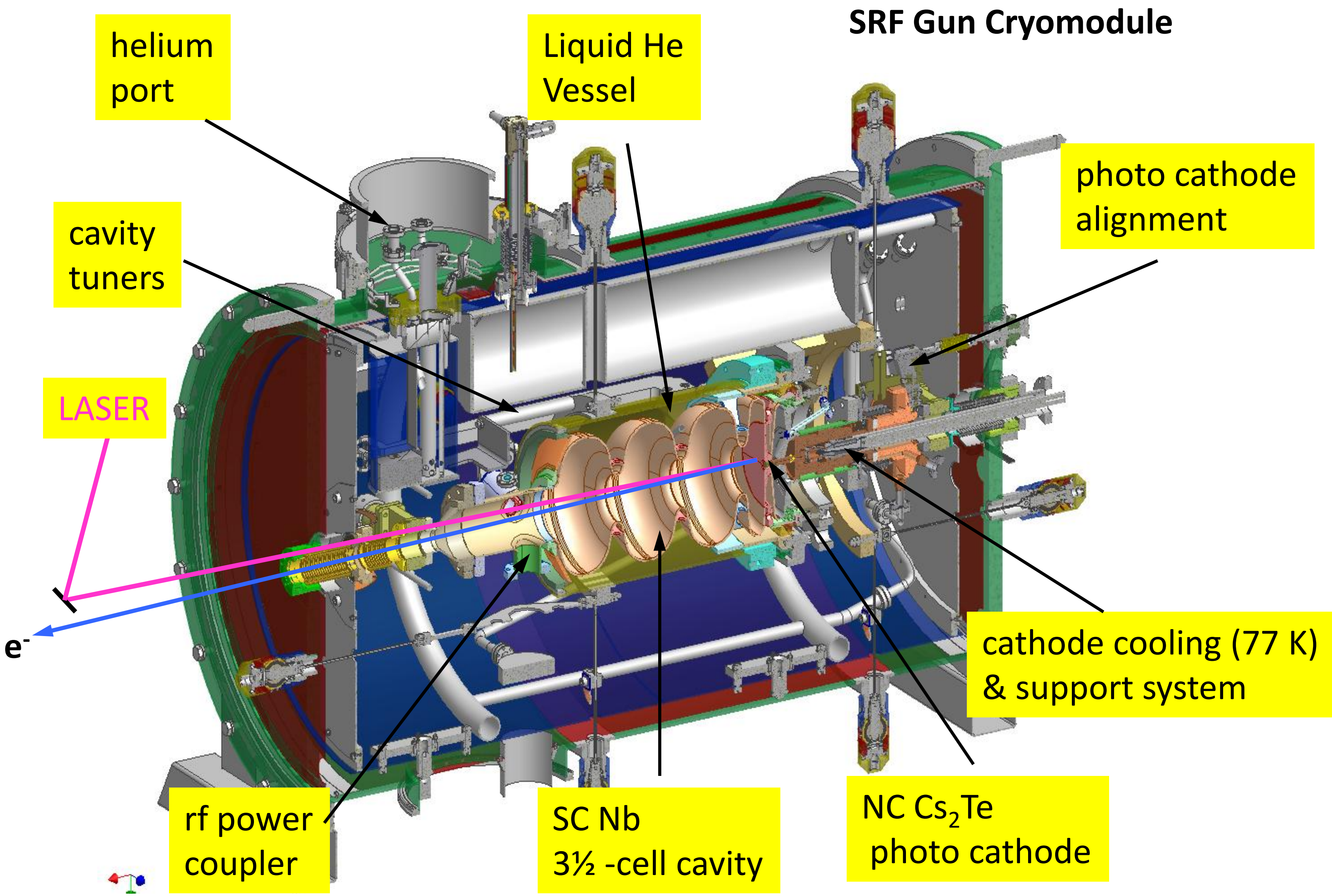
Good vacuum due to cryo-pumping, typically ~10^{-11}Torr

Good for high peak current, high average current

- Future high peak brightness, high flux X-ray FELs
- Electron cooler for RHIC

J. Sekutowicz, et al.; *Phys. Rev. ST Accel. Beams,* **8**, 010701 (2005)
D.Janssen et al., *Nucl. Instr. And Meth. In Phys. Res.,* **A445**, 408 (2000)
A. Michalke et al., EPAC92, 101

SRF Gun at Rossendorf



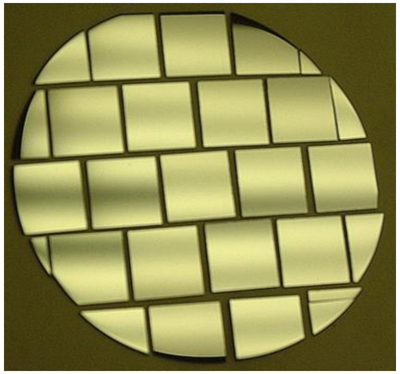
Planned Choke Injectors
Rossendorf 1.3GHz 3.5 cell

	ELBE mode	High charge mode	BESSY-FEL
SRF frequency [GHz]	1.3		
E [MeV]	9.5		
Operation mode	CW		
Driving laser λ [nm]	262		
Photocathode	Cs_2Te		
QE [%]	> 1		> 2.5
I_b [mA]	1	0.5	2.5
Pulse duration [ps]	5	15	40
f repetition [kHz]	13 000	500	1
q/bunch [nC]	0.077	1	2.5
ε [μmrad]	1	2.5	3

Polarized Electron Source "Musts"

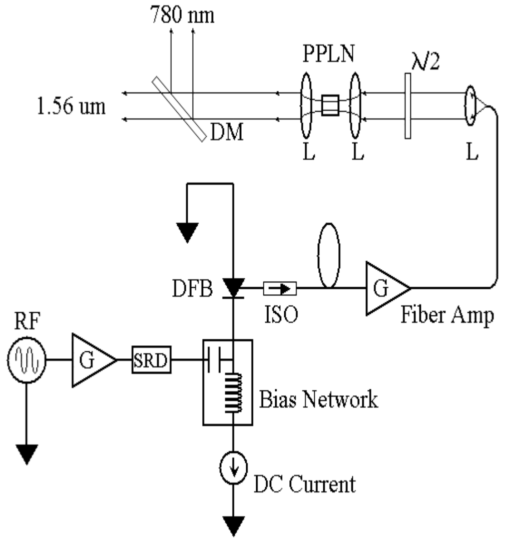
Good Photocathode

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



Good Laser

- "Headroom"
- Suitable pulse structure
- Low jitter



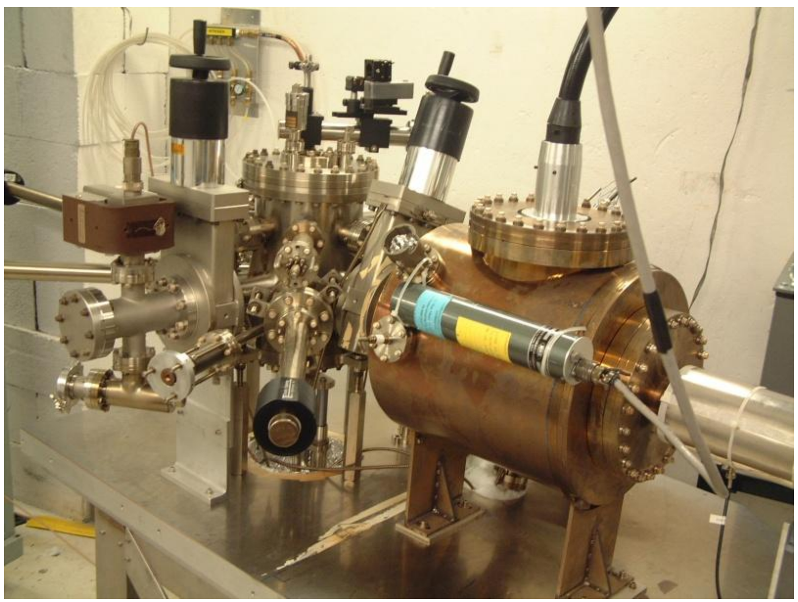
Good Electron Gun

- Ultrahigh vacuum
- No field emission
- Maintenance-free

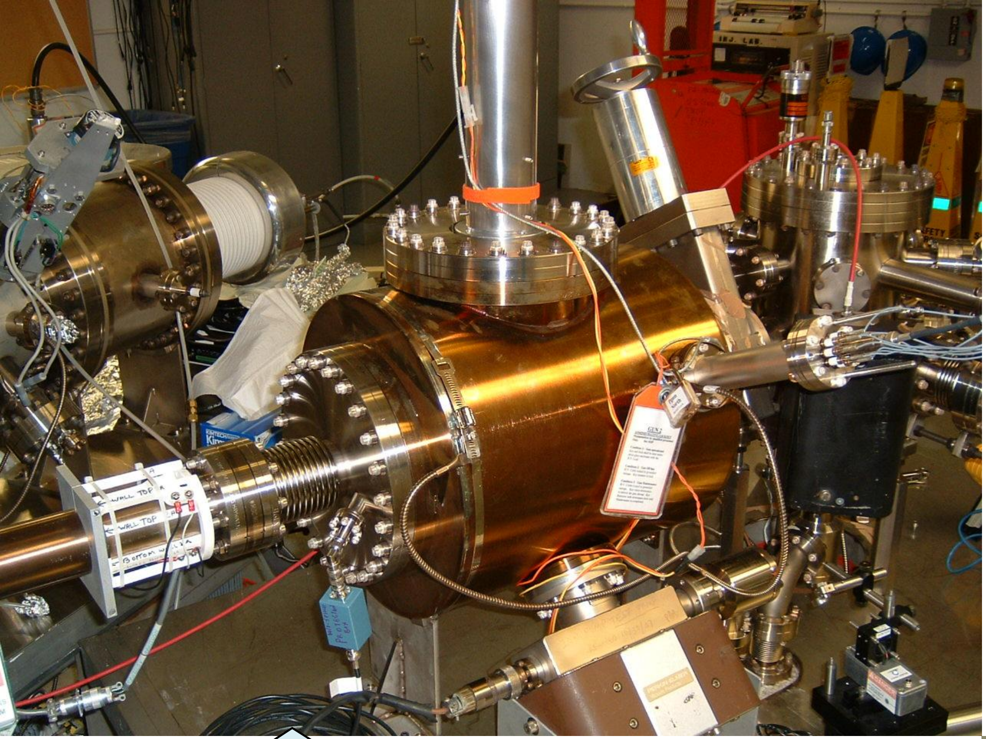
Define "Good Gun"

Good Electron Gun

- Ultrahigh vacuum
- No field emission
- Maintenance-free



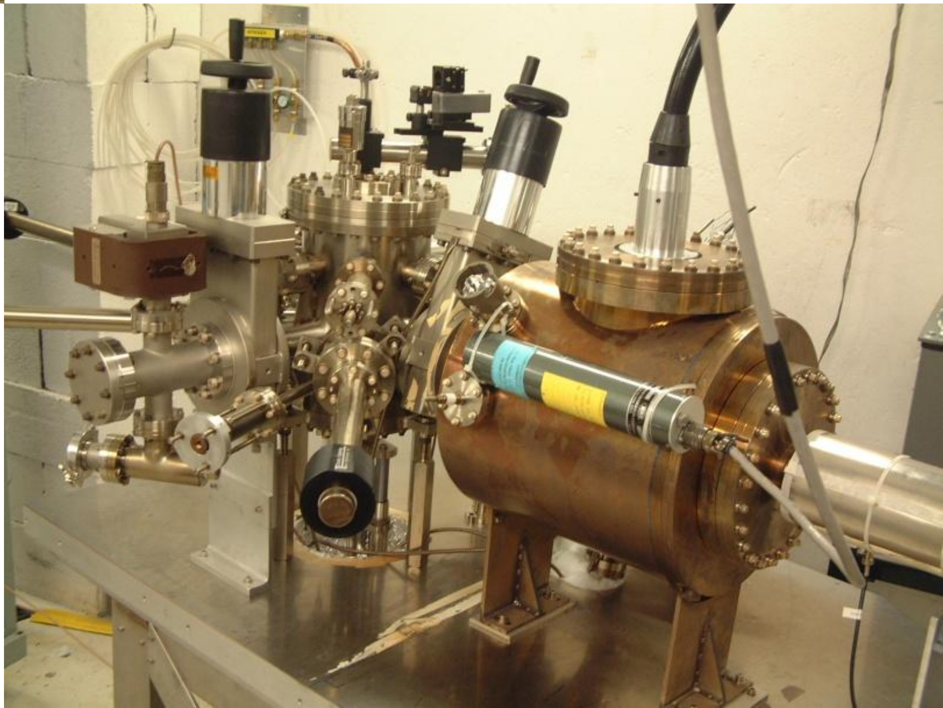
1) Ultra high vacuum
    - Static and Dynamic vacuum
    - Ion-bombardment limits operation
2) Happy at high voltage
    - Field emission from cathode electrode
3) Maintenance Free
    - Vent and Bake
    - Load locked
4) Long lifetime
    - dark lifetime
    - and while you run beam



Paid for by ILC

- 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

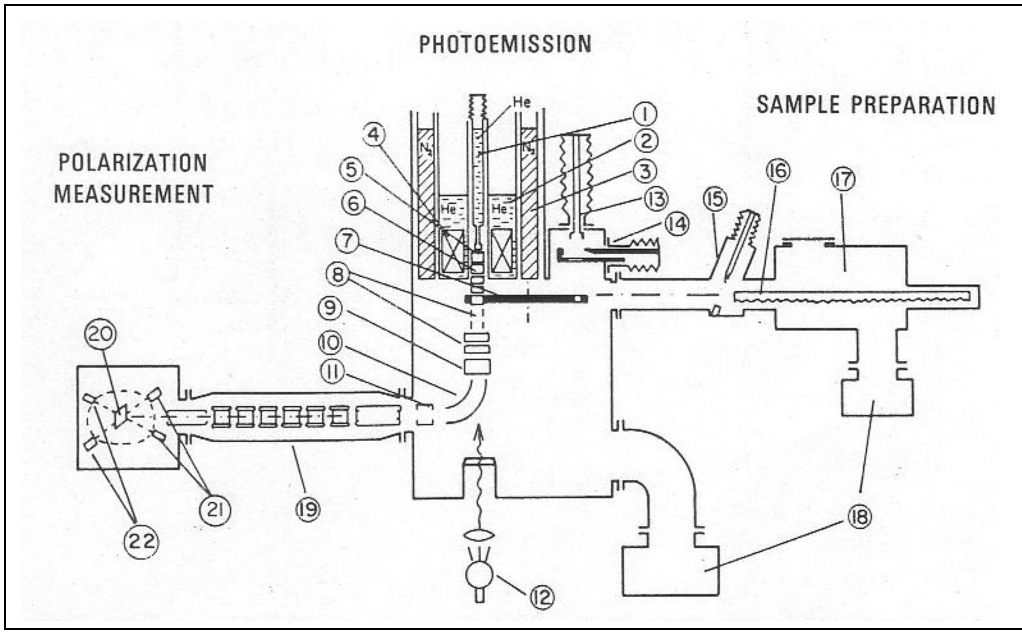


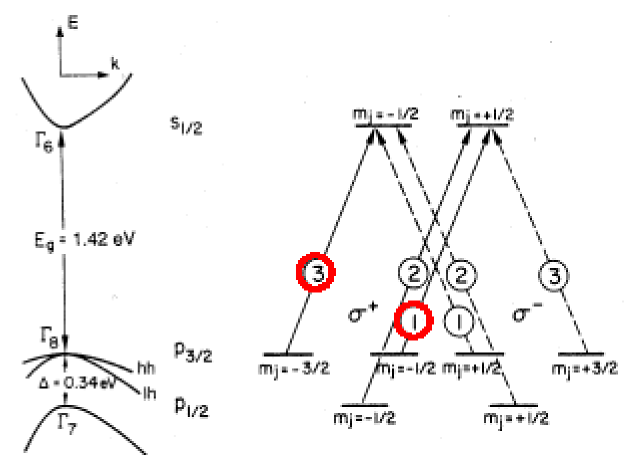
The First GaAs Photoemission Gun

PHYSICAL REVIEW B VOLUME 13, NUMBER 12 15 JUNE 1976

Photoemission of spin-polarized electrons from GaAs

Daniel T. Pierce* and Felix Meier
Laboratorium für Festkörperphysik, Eidgenössische Technische Hochschule, CH 8049, Zürich, Switzerland
(Received 10 February 1976)





$$P = \frac{3-1}{3+1} = 50\%$$

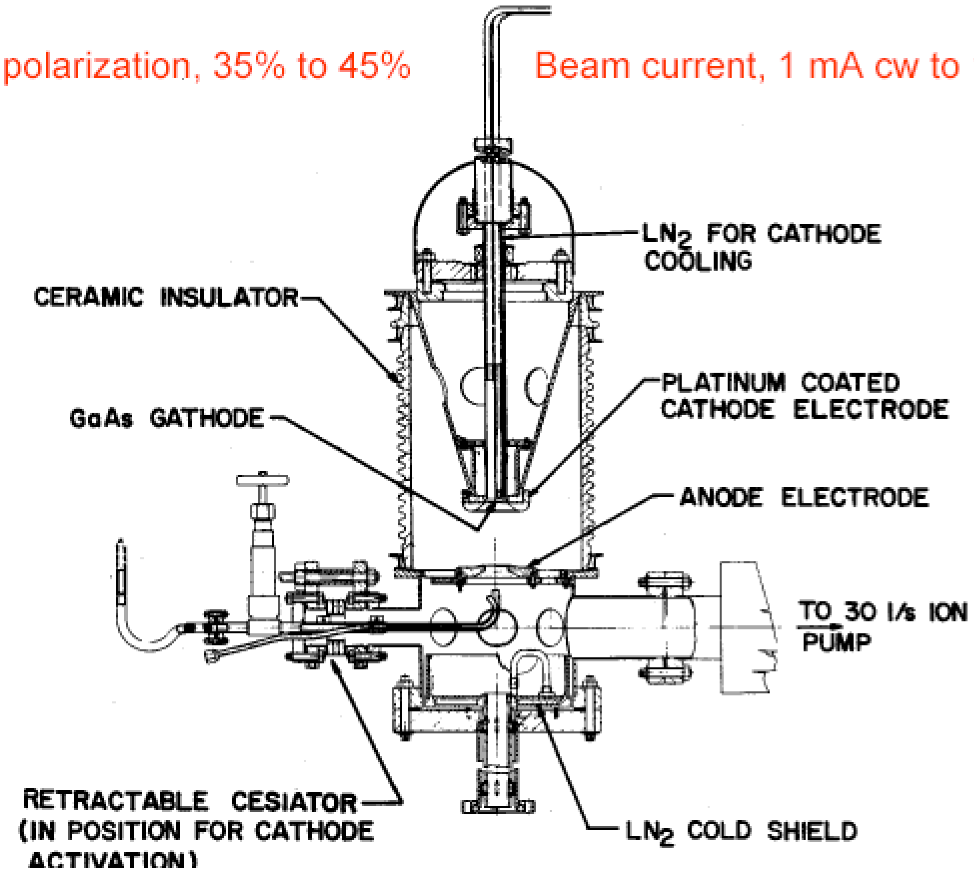
Illuminate GaAs with circularly polarized light near band gap…..

First High Voltage GaAs Photogun

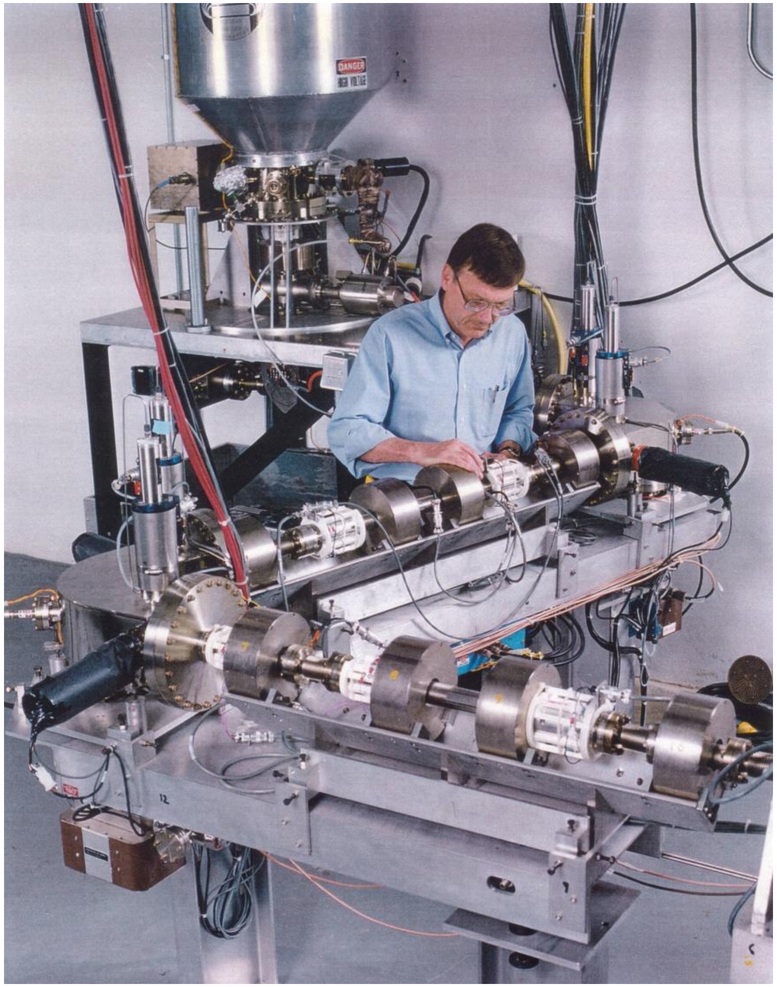
Polarized e⁻ Gun for SLAC Parity Violation Experiment

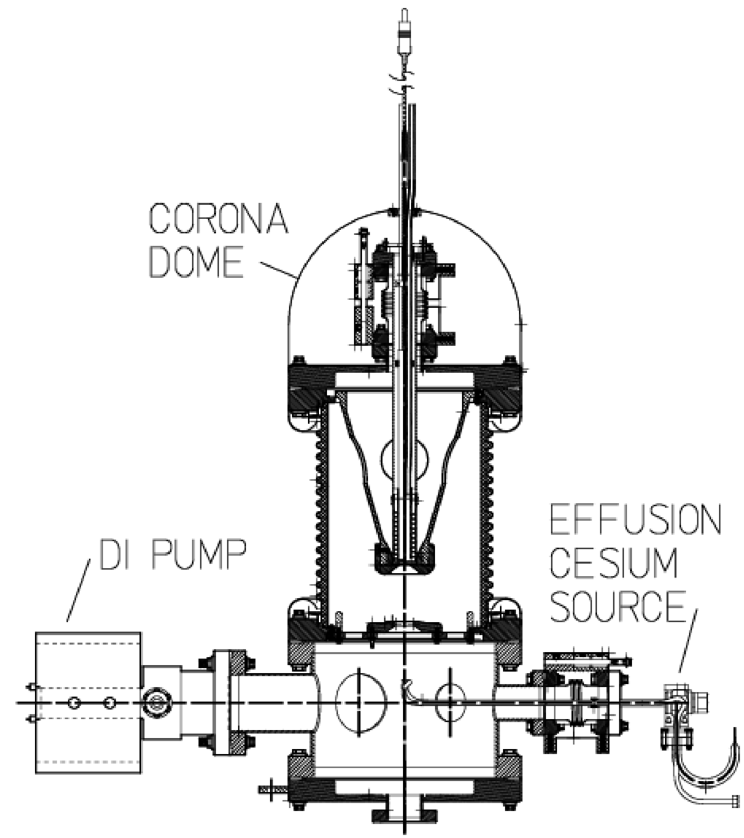
Beam polarization, 35% to 45%

Beam current, 1 mA cw to 15 A peak



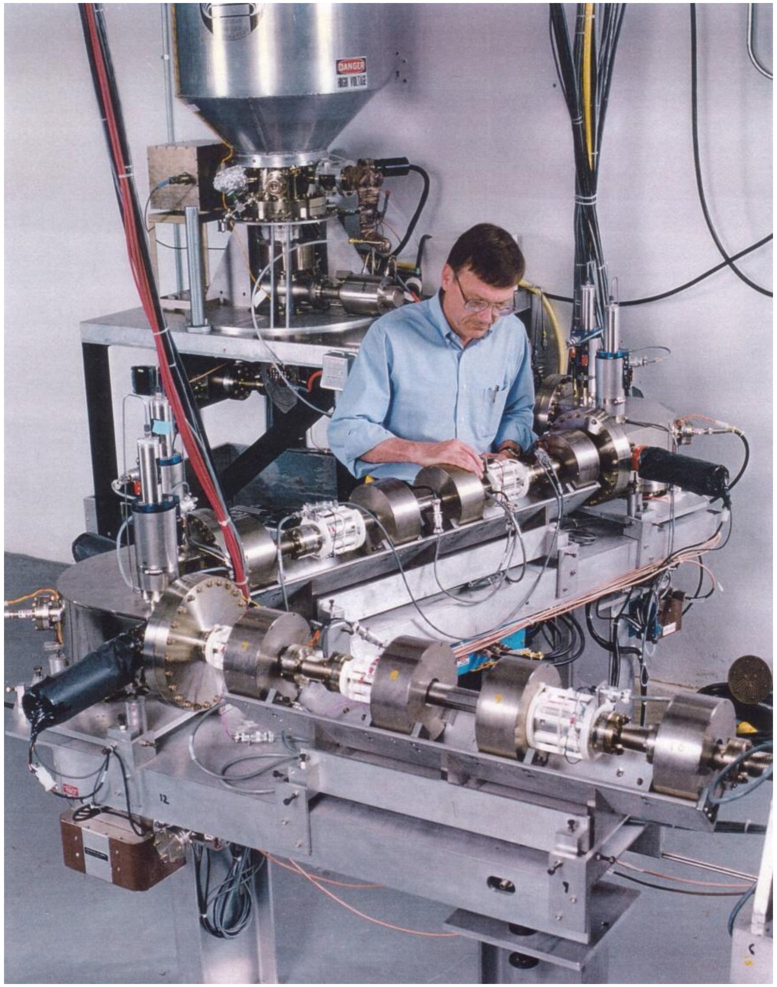
CEBAF's First Polarized e-Source

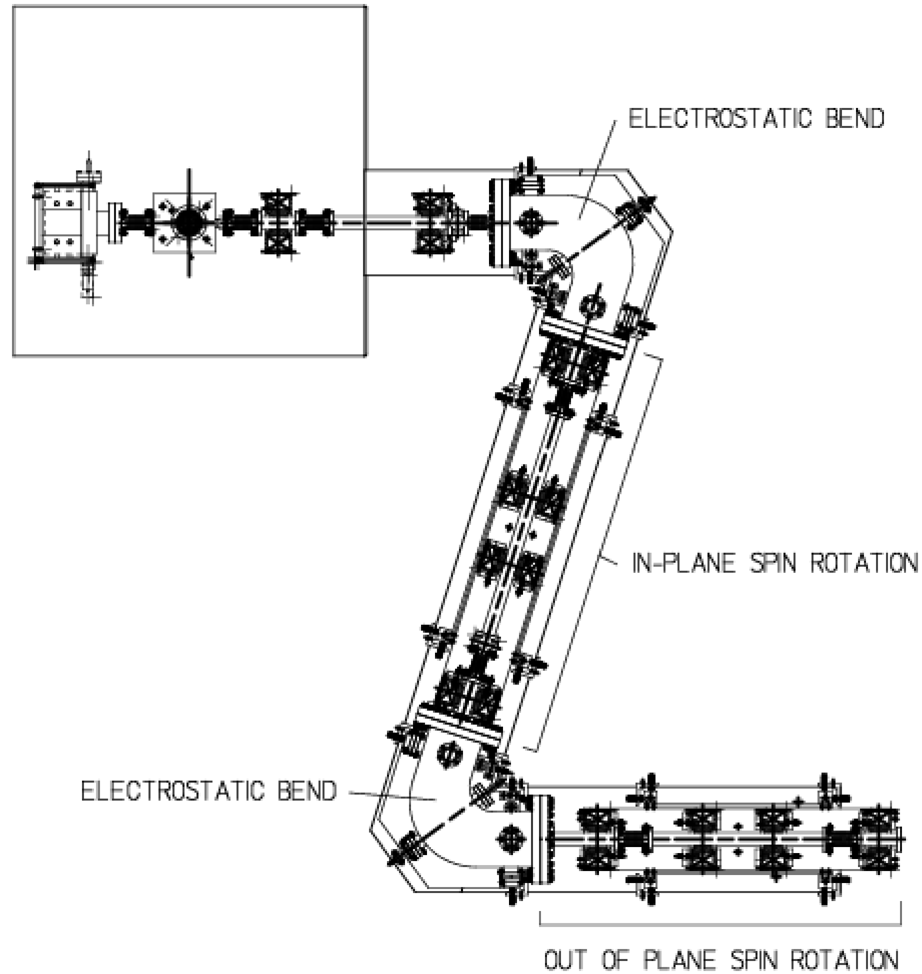




First photogun similar to SLAC photogun from 1977….
just one small ion pump and NEG pump

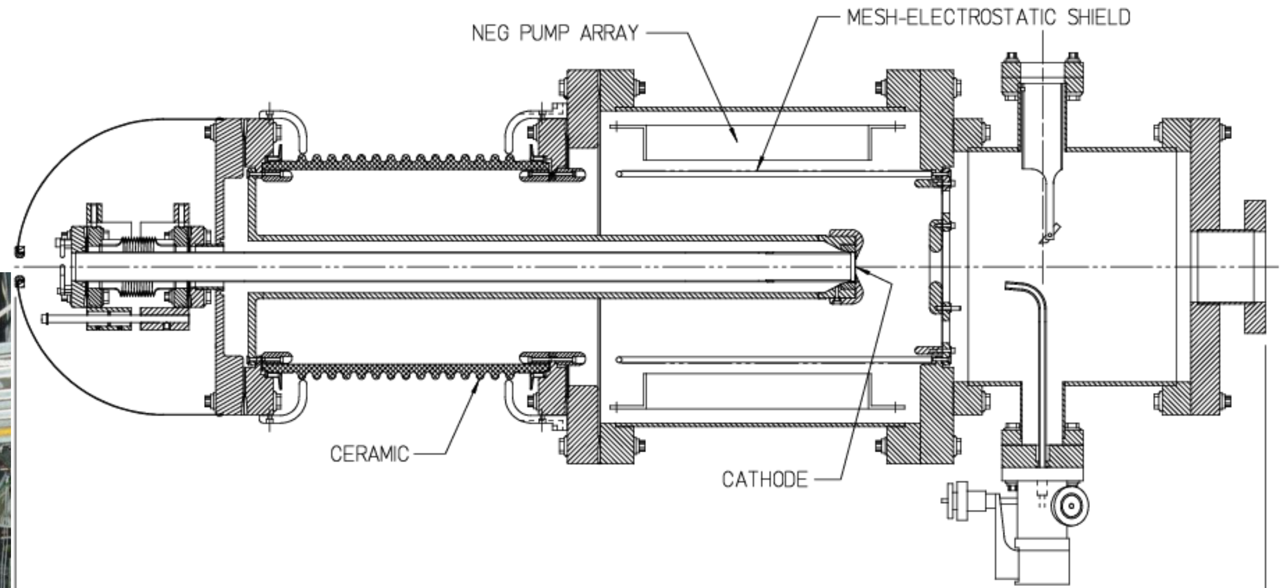
CEBAF's First Photoinjector

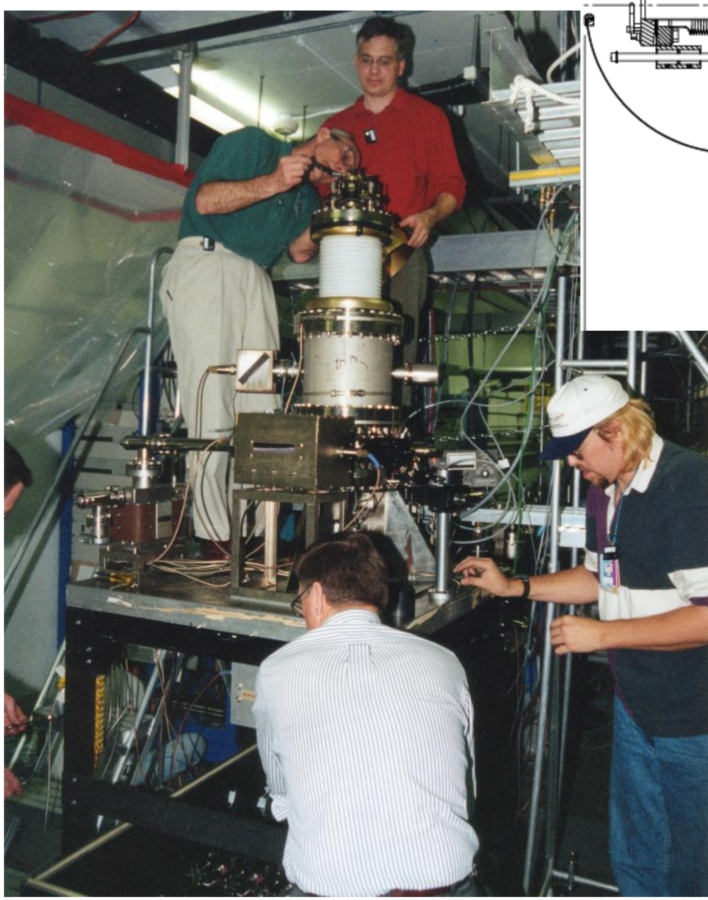




Very complicated spin manipulator

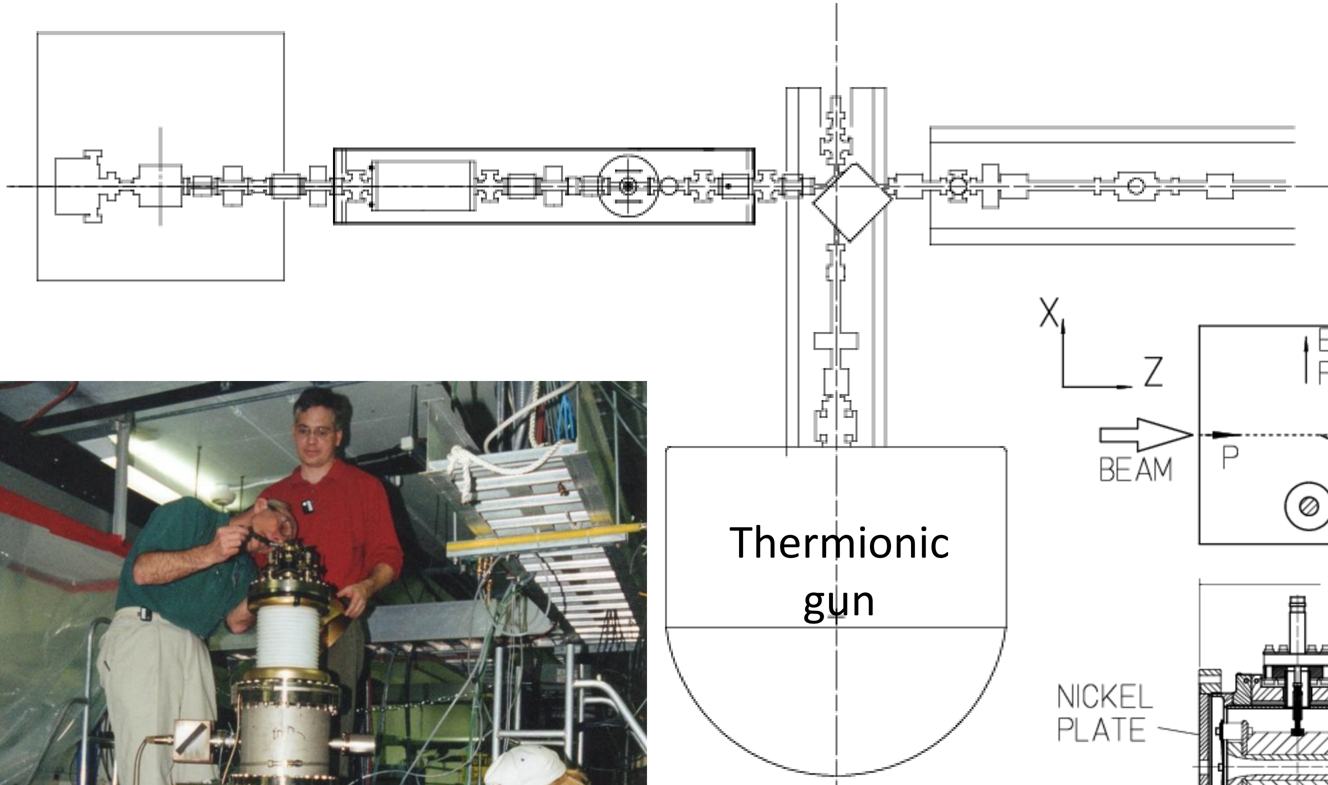
CEBAF's Second Polarized e-Source

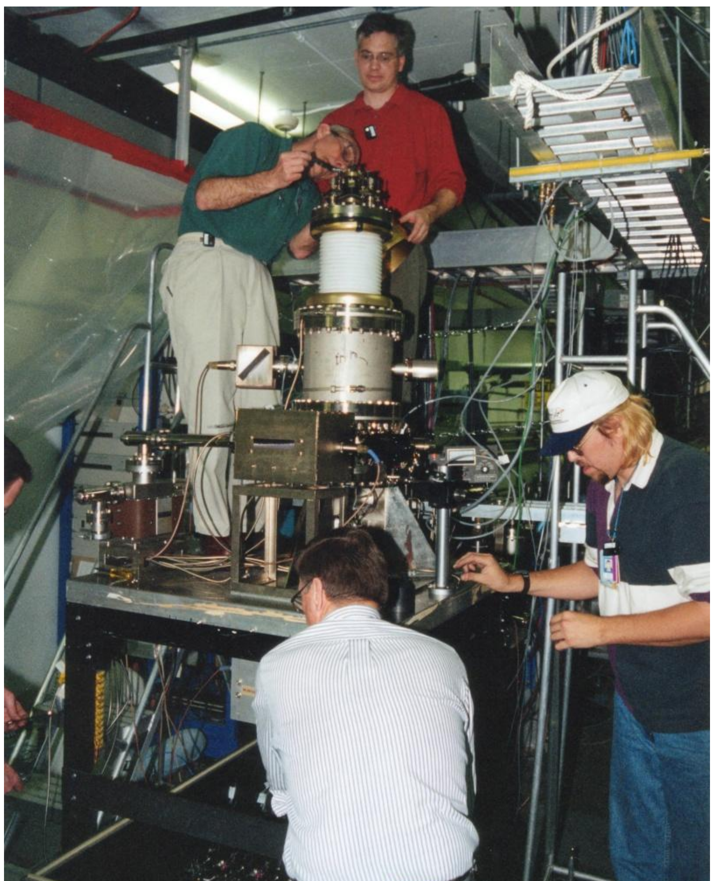


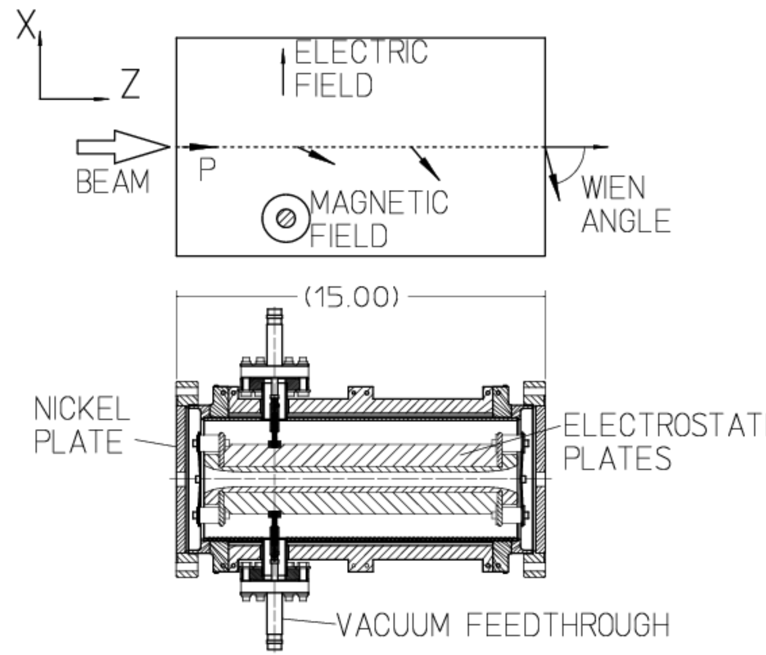


Now with 4000L/s NEG pumping

CEBAF's Second Photoinjector

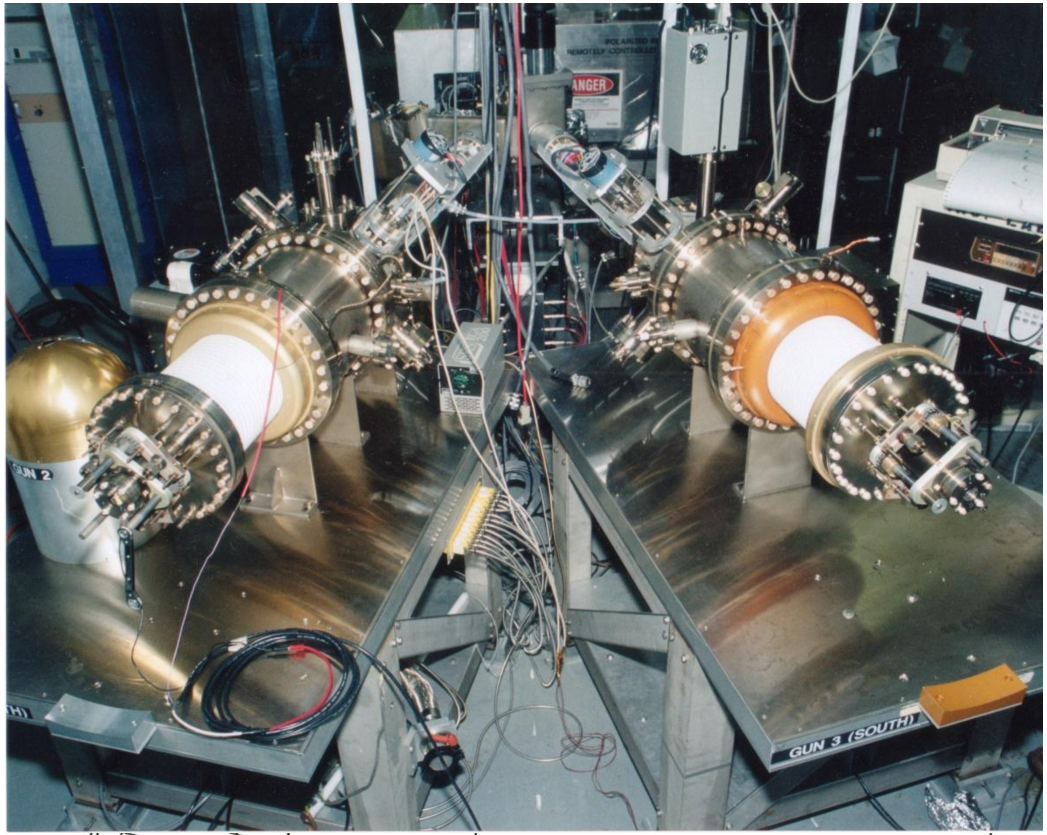


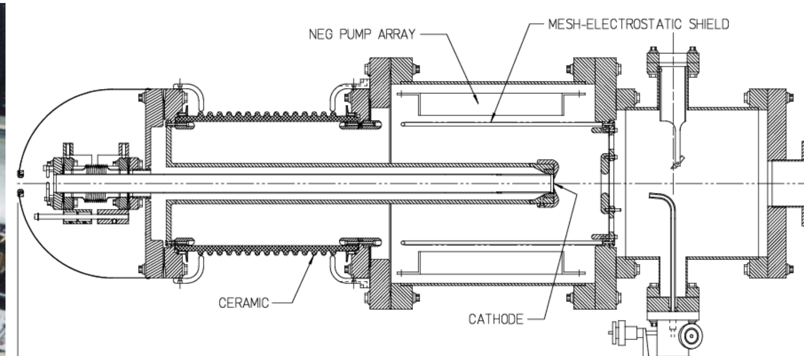




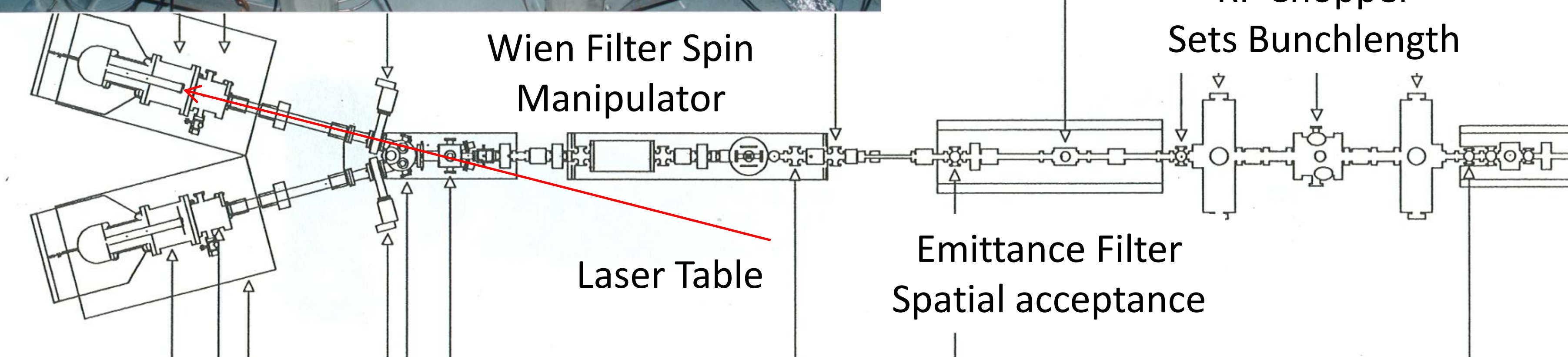
and a Wien-Spin Manipulator

CEBAF's Third Photoinjector

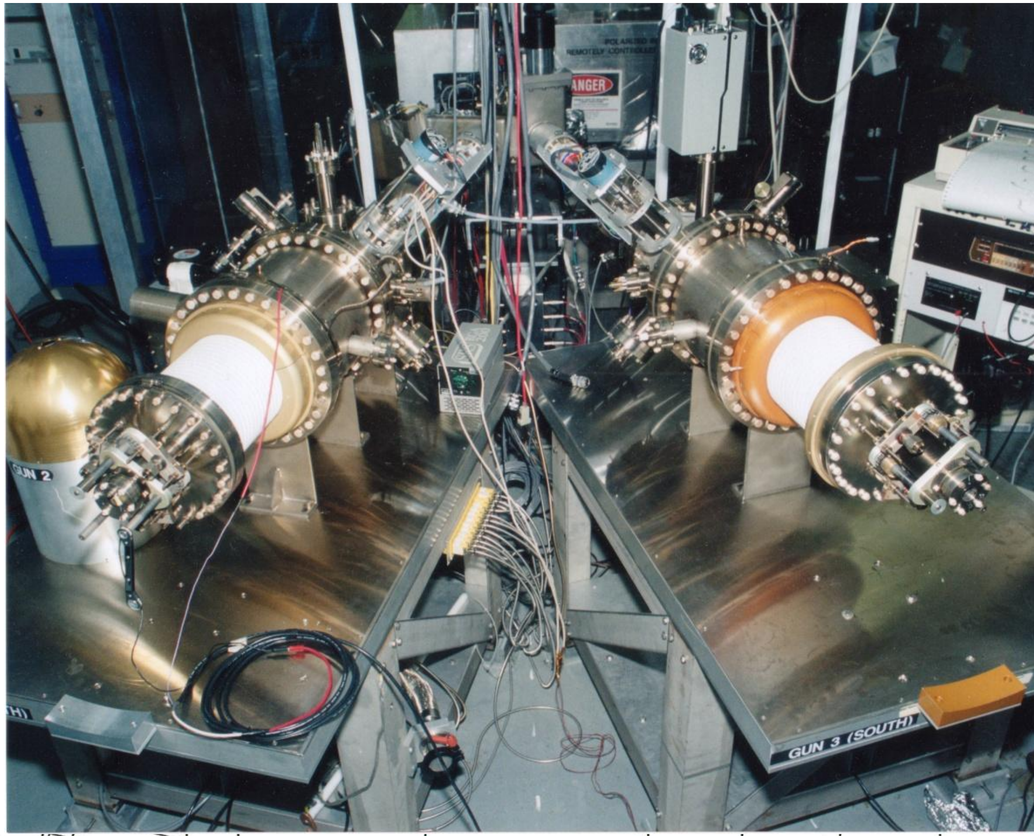




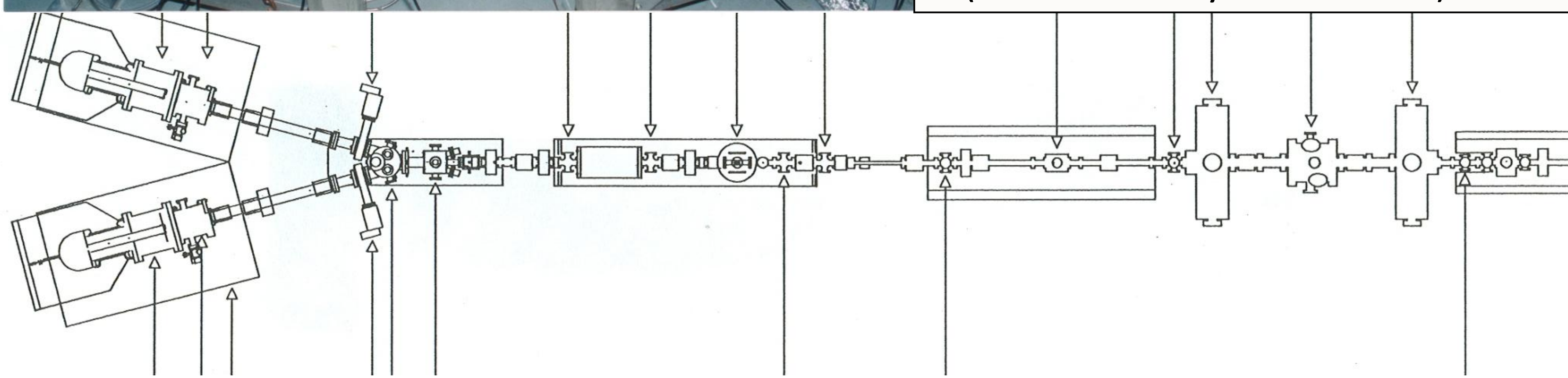
- Vent/bake photoguns in horizontal plane
- No more short focal length electron optical elements
- Can deliver 100uA avg. current for about 1 week before "doing something"



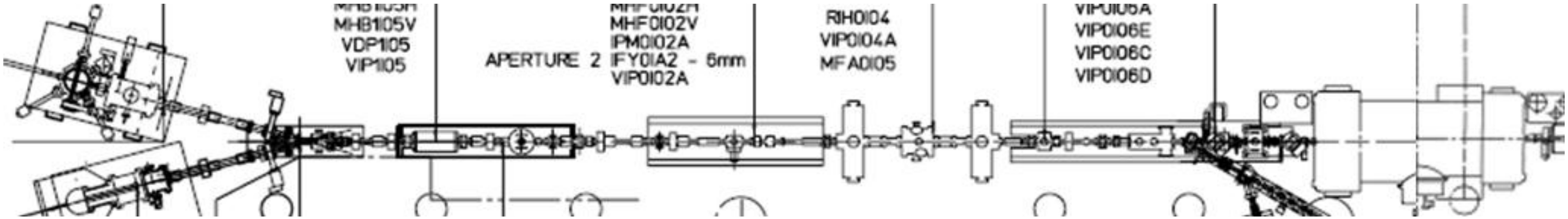
CEBAF's Third Photoinjector

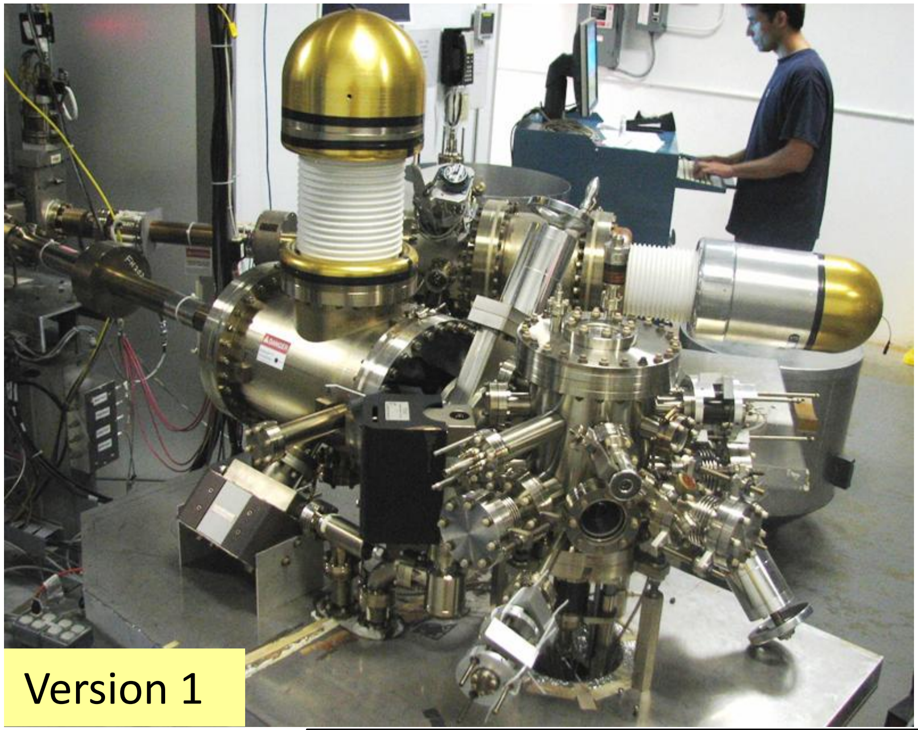


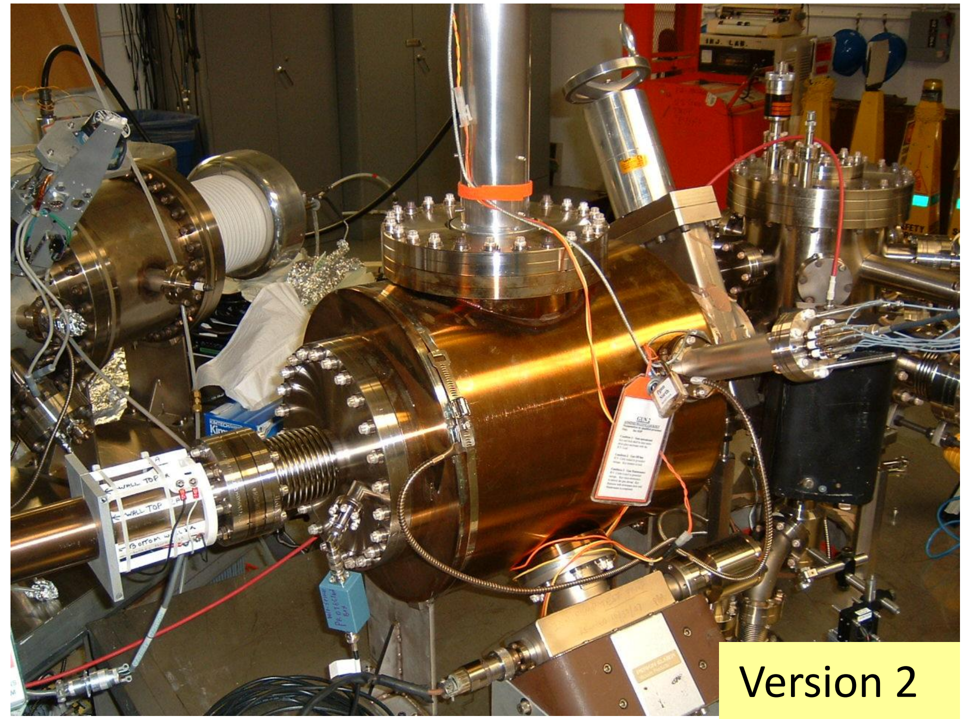
- Two-Gun Photoinjector - One gun provides beam, the other is a "hot" spare
- vent/bake guns – good vacuum, long lifetime, but…
- *Cesium gets deposited on cathode electrode and eventually field emission kills photocathode*
- 4 days to replace photocathode (can't run beam from one gun while other is 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

Cons:

- Cesium gets applied to electrode
- Takes about four days to replace the photocathode, i.e. to "bake" the gun

Pros:

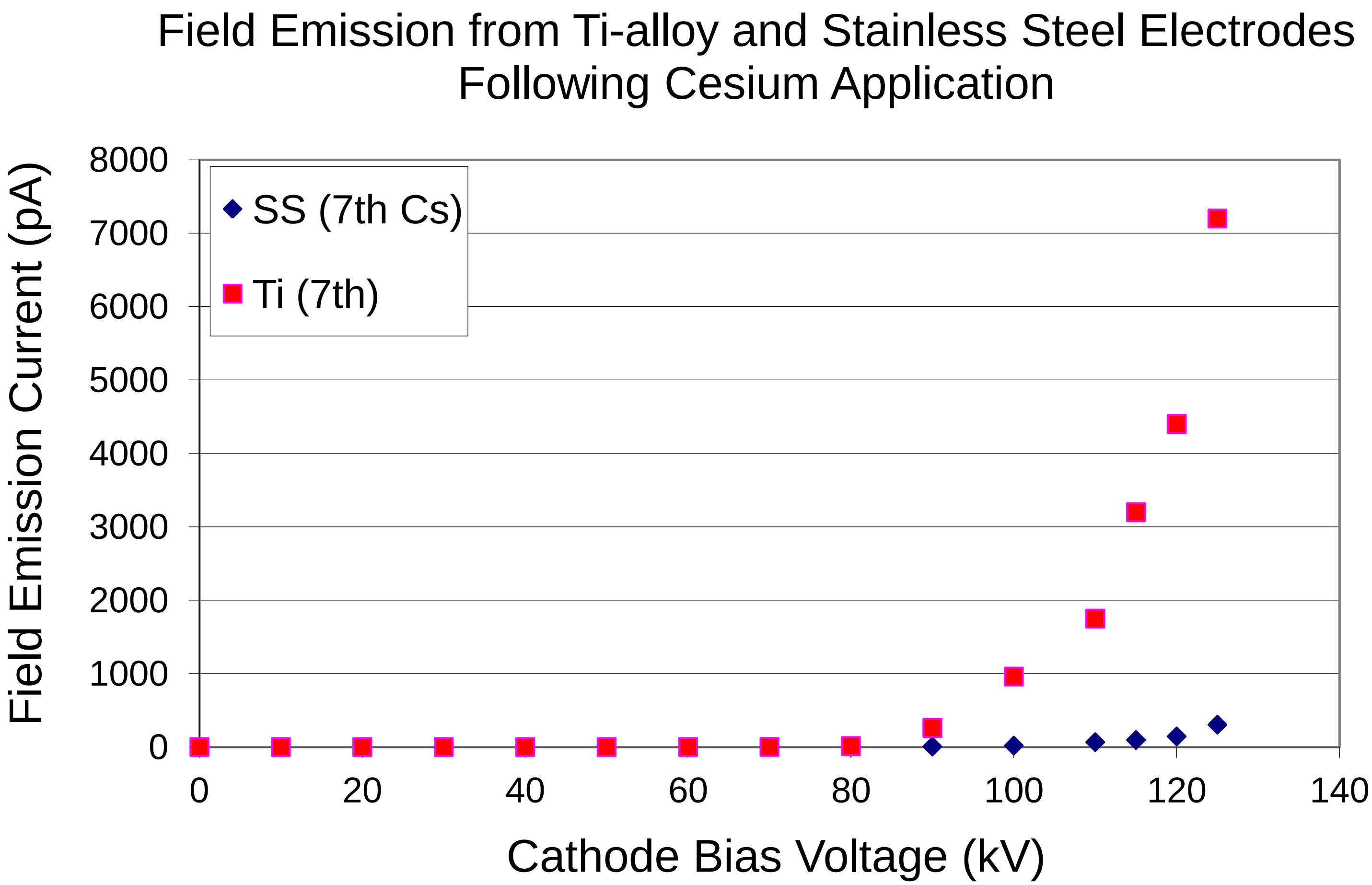
- Quick photocathode replacement
- No cesium in high voltage chamber

Cons:

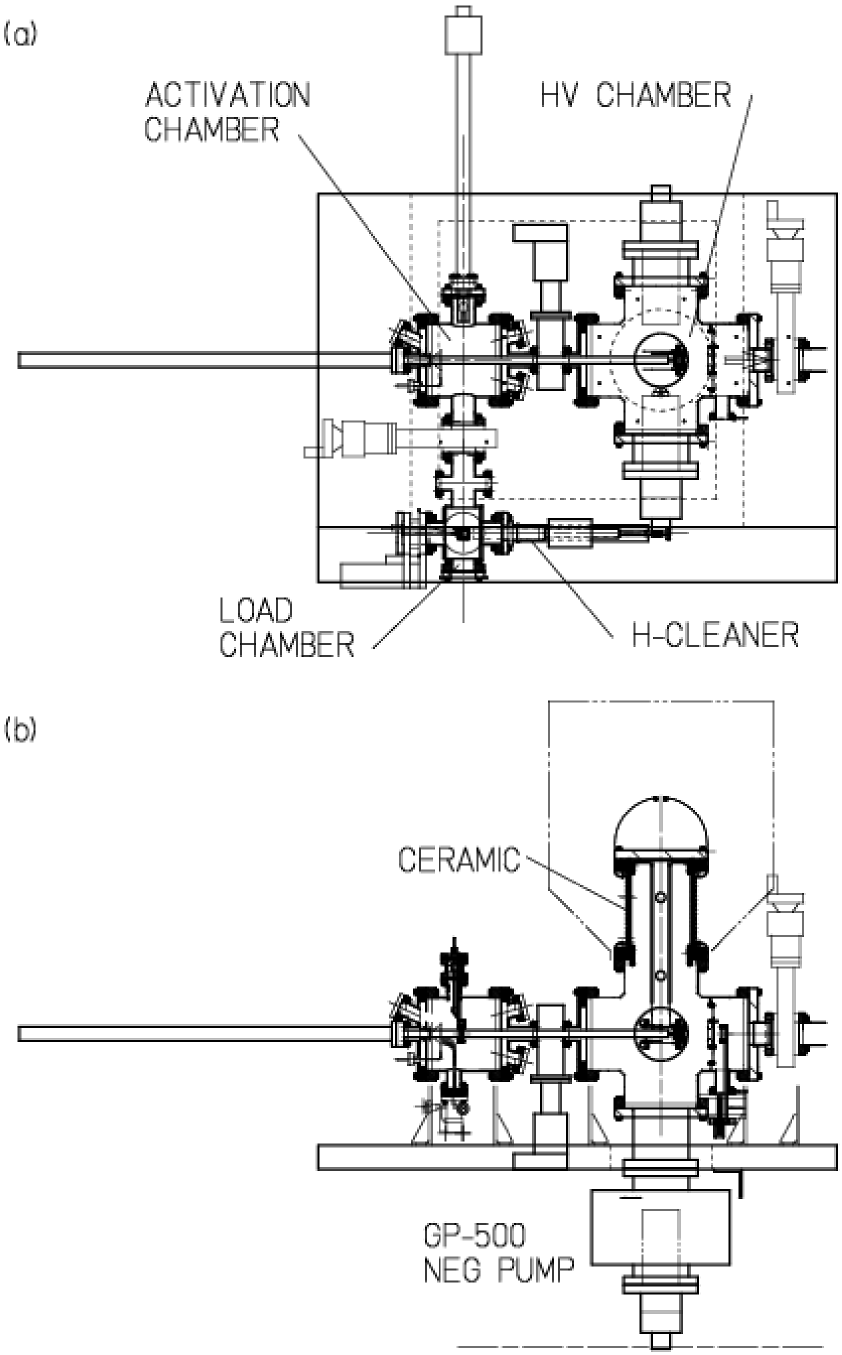
- Movable photocathode adds complication
- More expensive

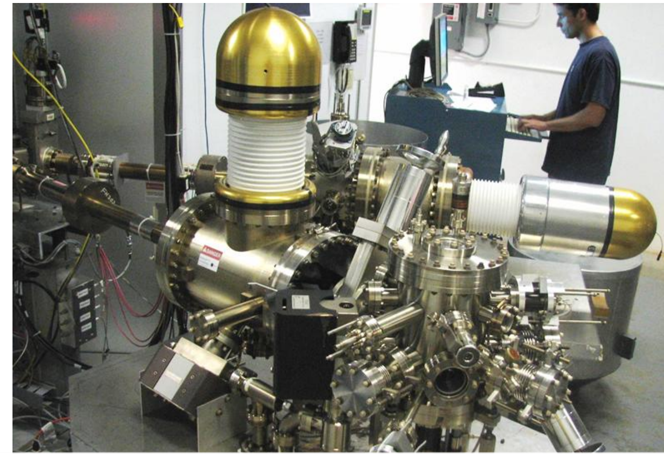
In my opinion…vent/bake is the right choice when getting started in polarized electron business

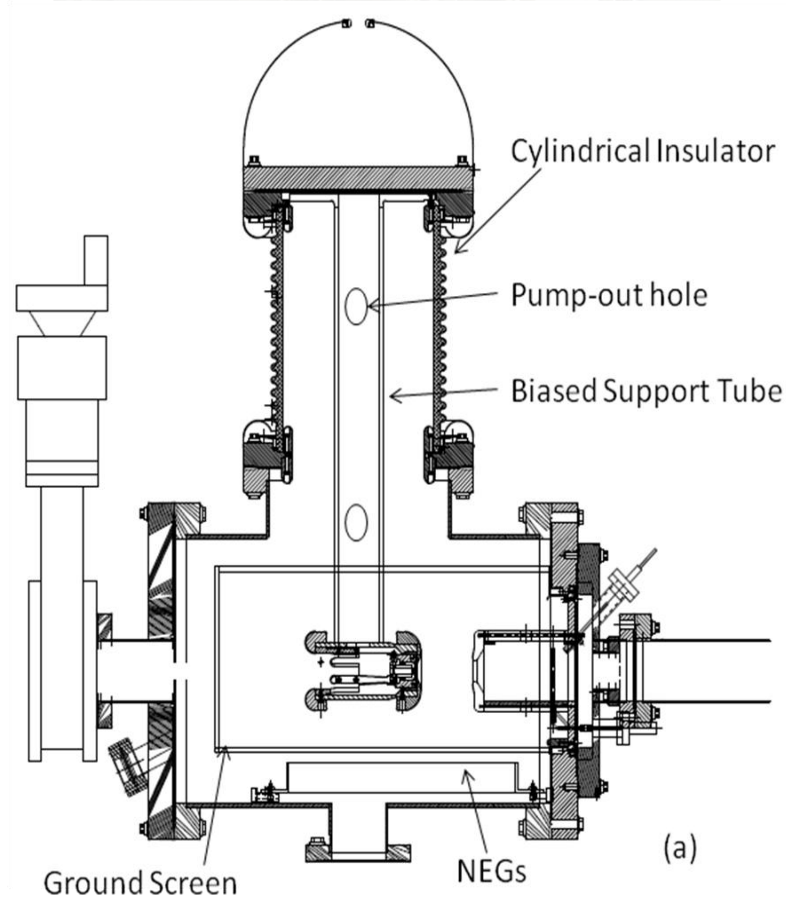
SS vs. Ti 7th Application of Cs



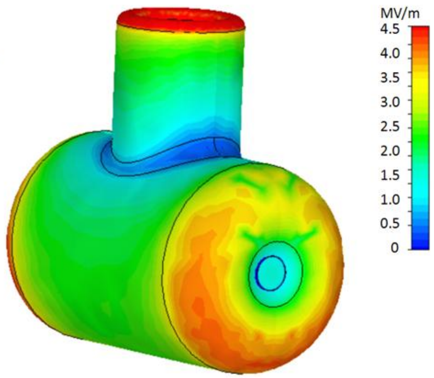
So after third or fourth photocathode activation, things get ugly….


(a)
ACTIVATION CHAMBER
HV CHAMBER
LOAD CHAMBER
H-CLEANER
(b)
CERAMIC
GP-500 NEG PUMP




Cylindrical Insulator
Pump-out hole
Biased Support Tube
Ground Screen
NEGs
(a)

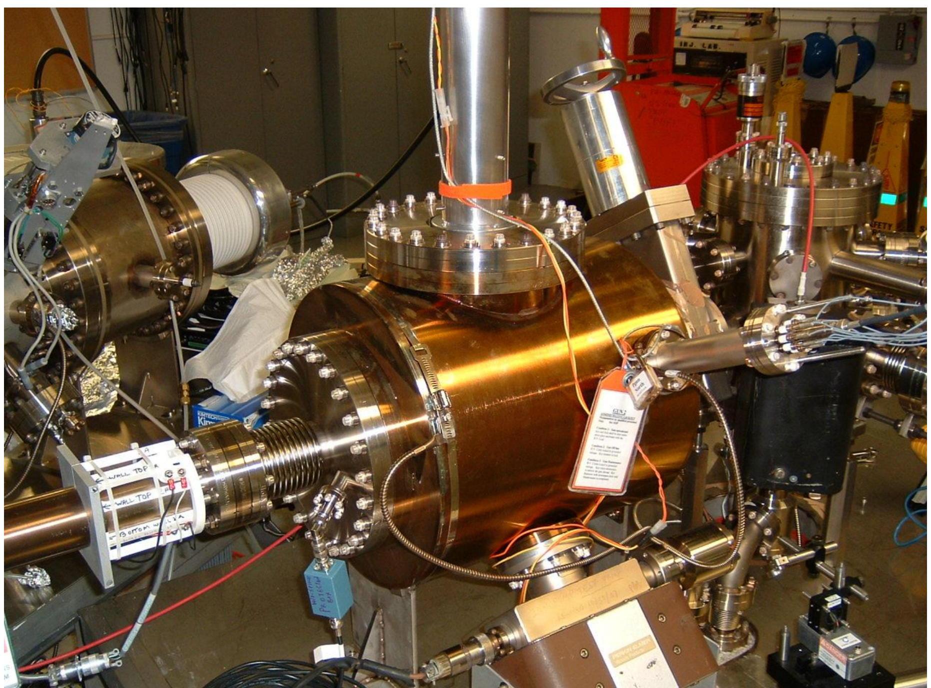
CEBAF's Inverted Photogun

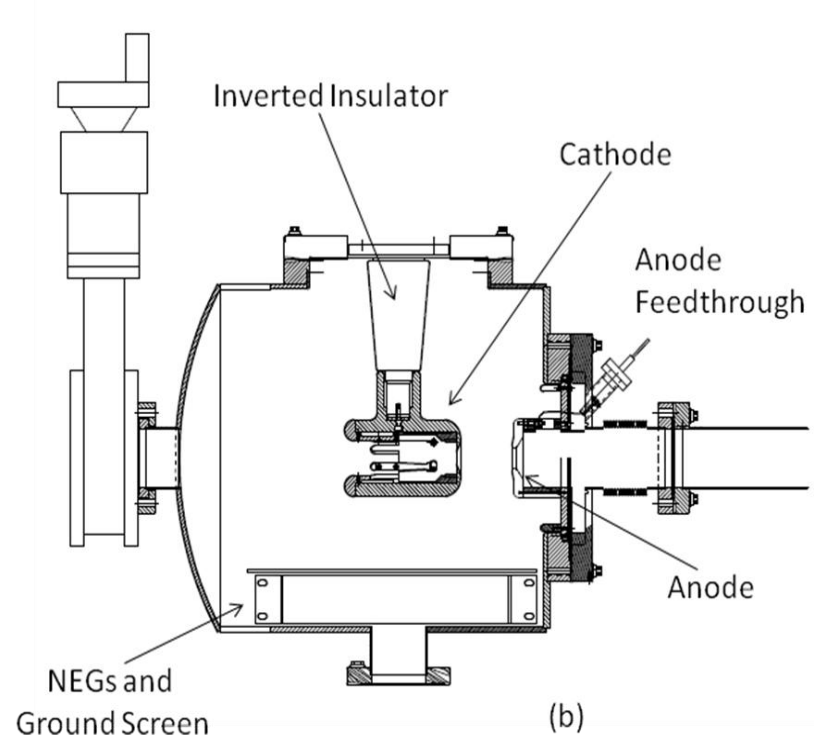


Medical x-ray technology

New Ceramic

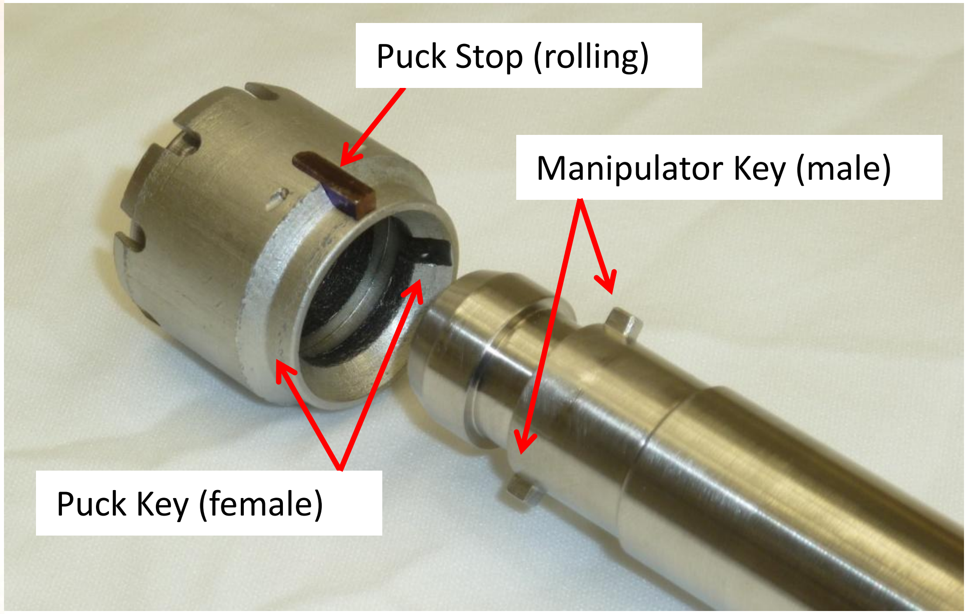
- Compact
- ~$5k
- Less metal at HV
- No SF6 of N2





Key Features:

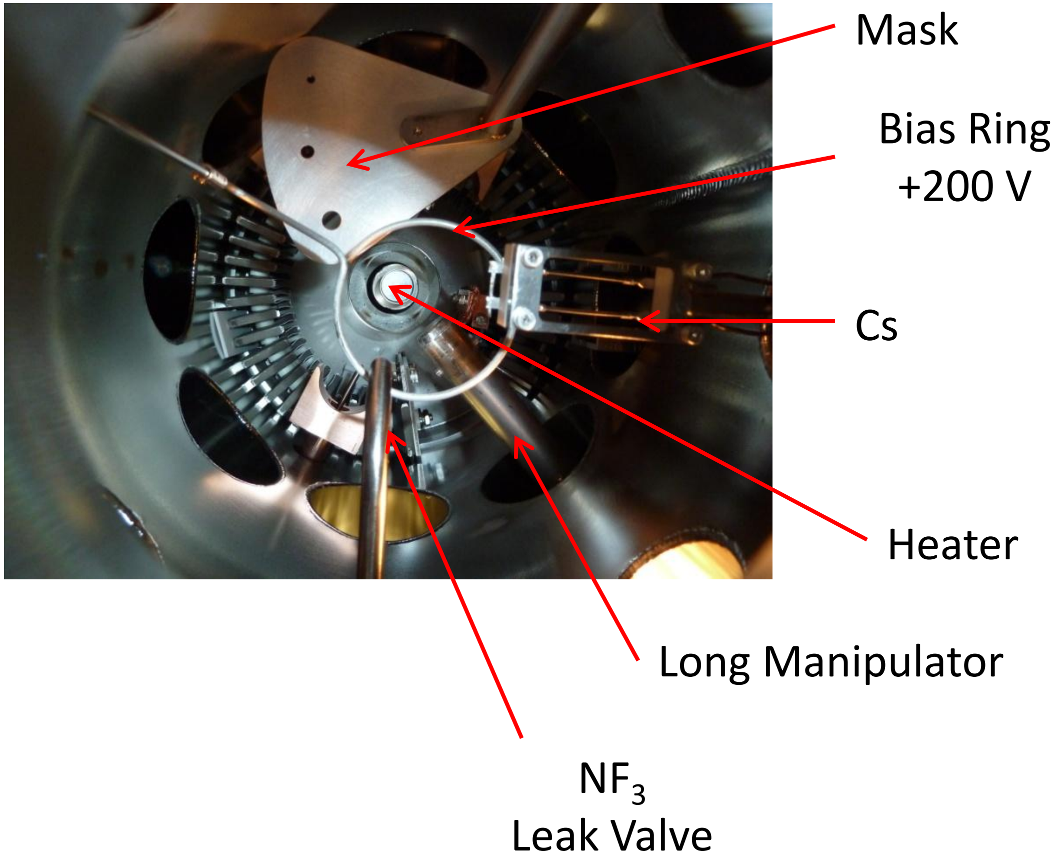
- 5 pucks can be stored in Storage Manipulators
- 8 hours to heat and activate new sample
- Mask to limit active area
- Suitcase for installing new photocathodes (one day to replace all pucks)



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

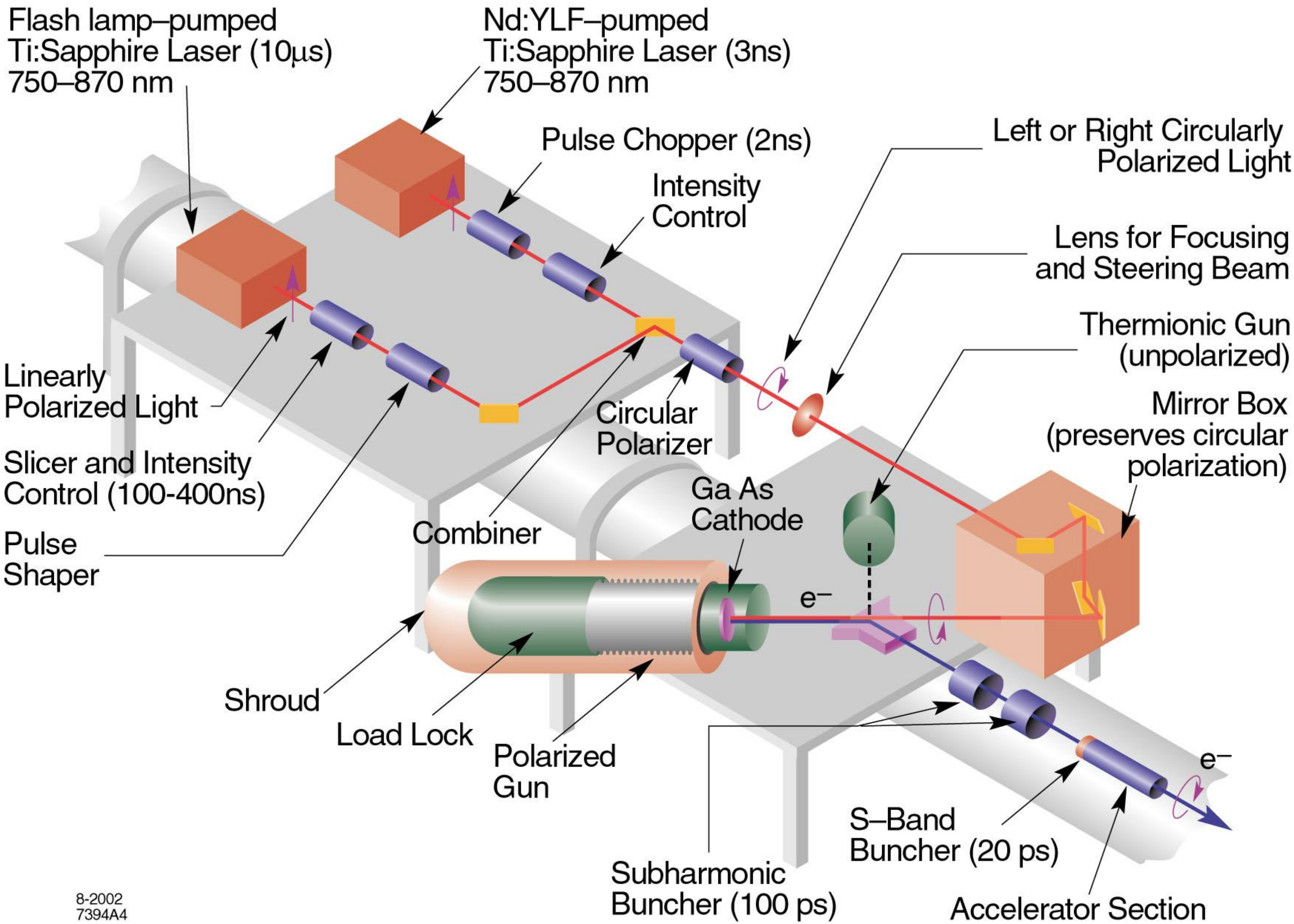


DC High Voltage GaAs Photoguns

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

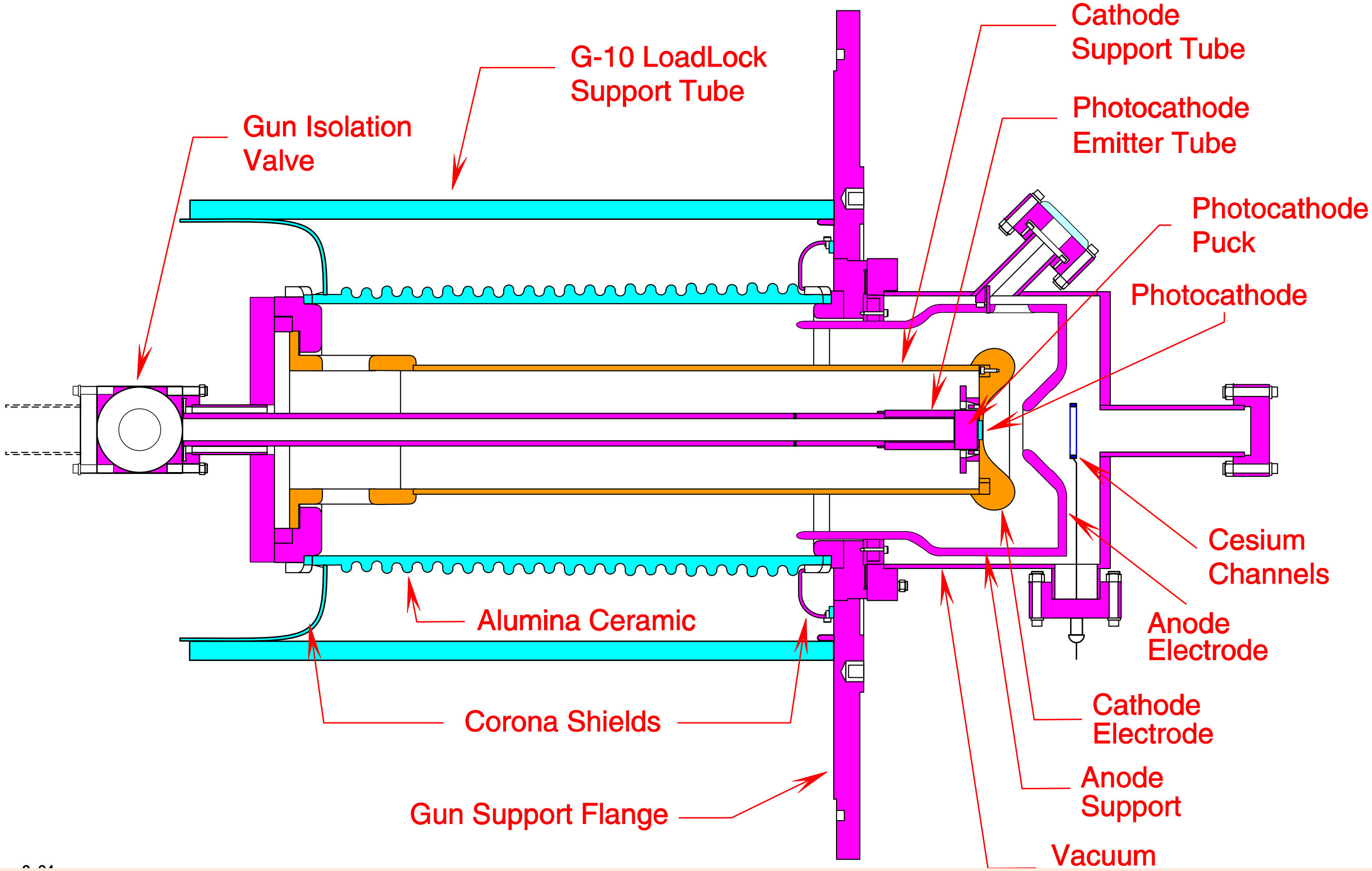
Historical or diminished scope | Under construction | Proposed | operating

SLAC Polarized e-Source



Stanford Linear Accelerator PES

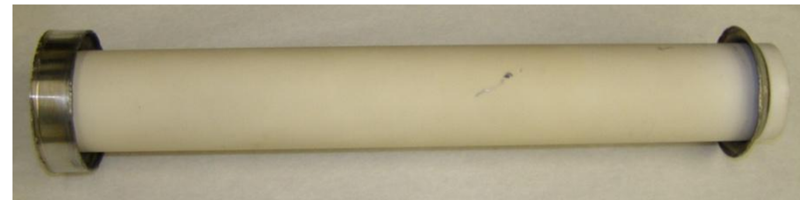
R. Alley et.al., Nucl. Instr and Meth A 365 (1995) 1-27

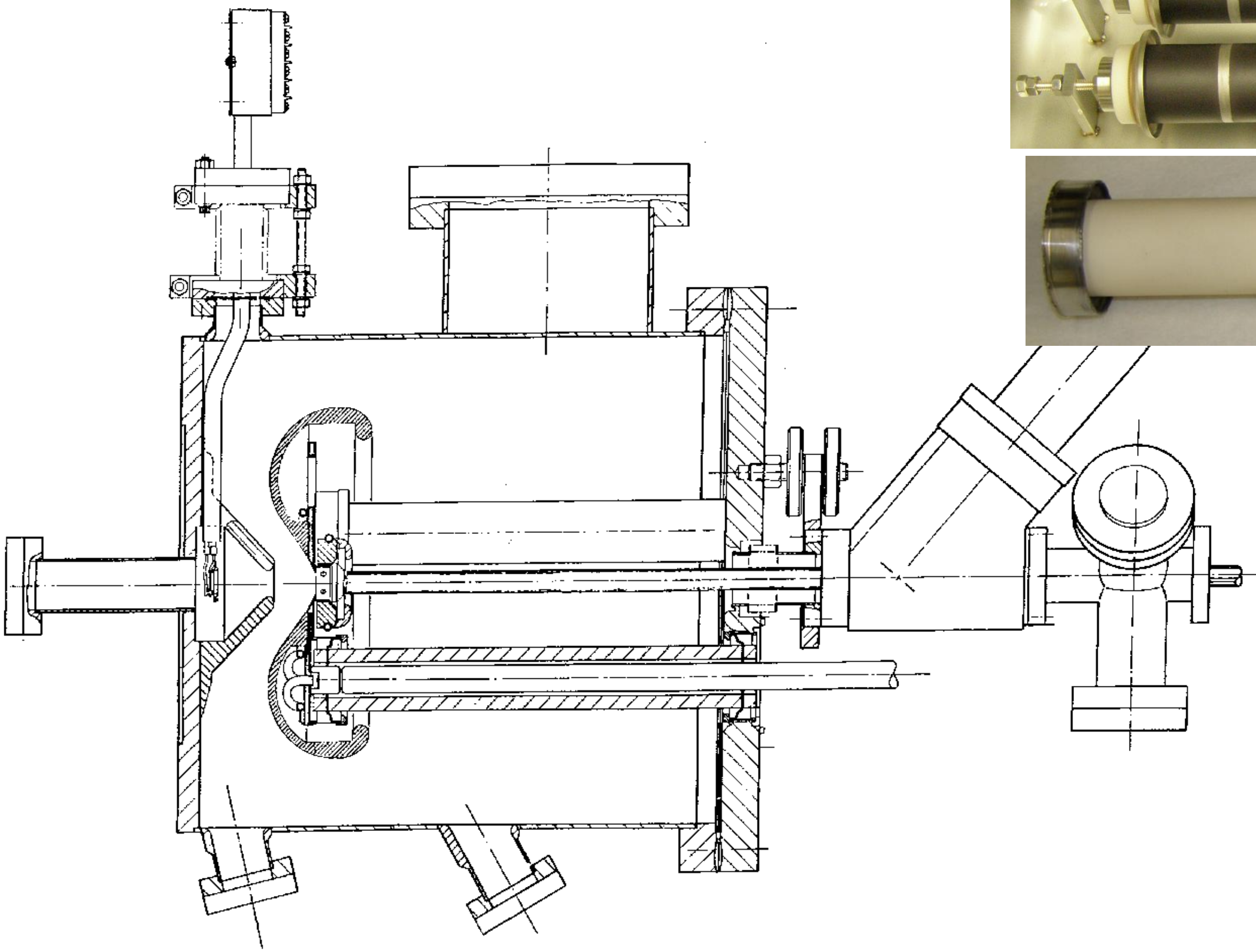


- First load-locked gun used at an accelerator (?)
- High bunch charge, low avg. current, very long operating lifetime
- Four days to replace photocathode, because load lock at HV…

SLAC Inverted Gun

Experimented with coating to bleed off charge

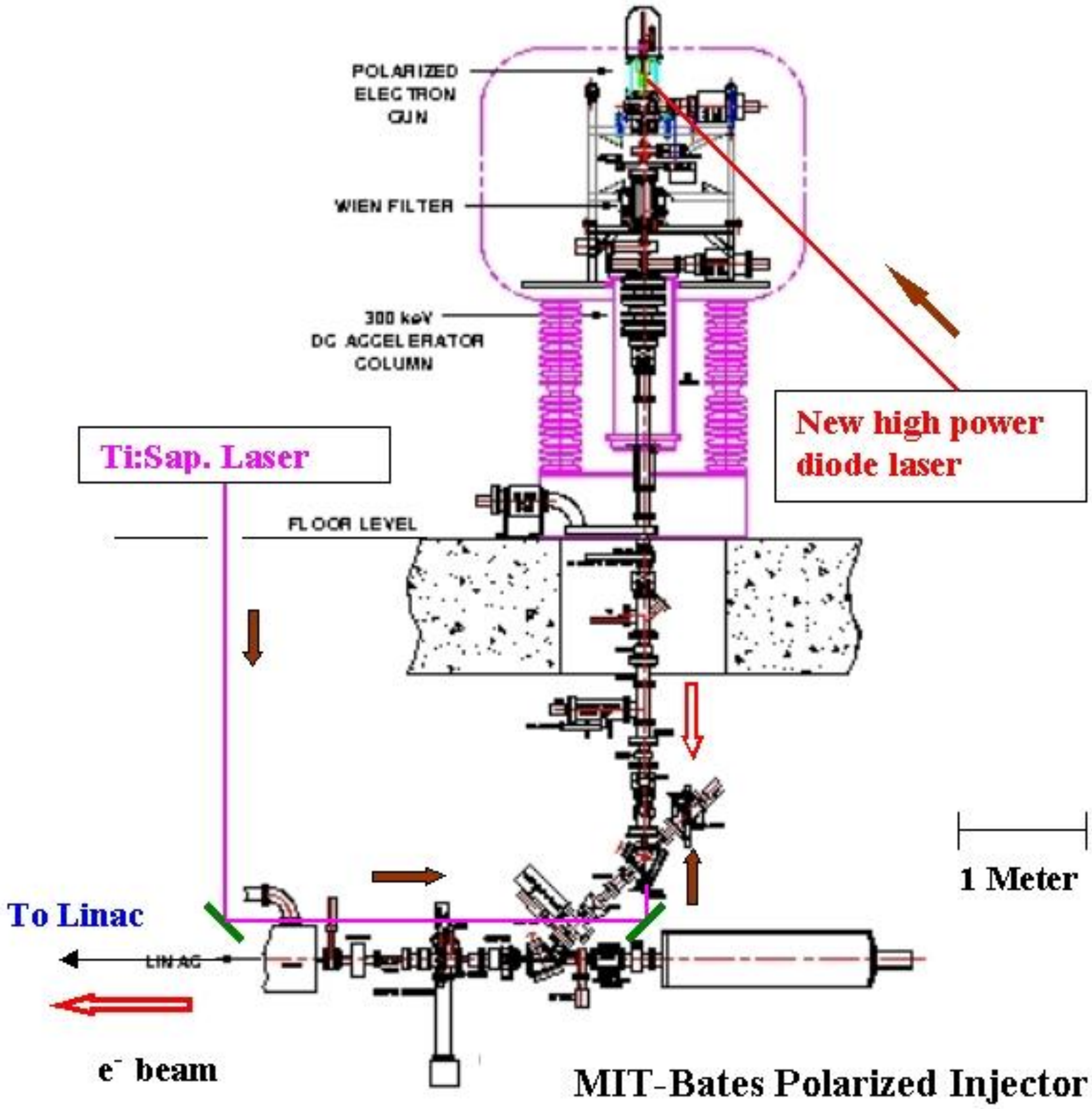


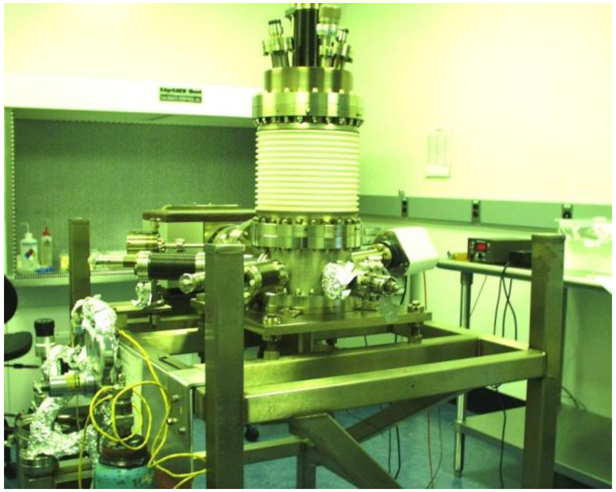


- Load lock at ground potential
- Cathode cooling via two of the tube insulators
- But still adding Cs to electrode

M. Breidenbach et al., Nucl. Instrum. Meth. A 350, 1 (1994)

MIT Bates Polarized Electron Gun



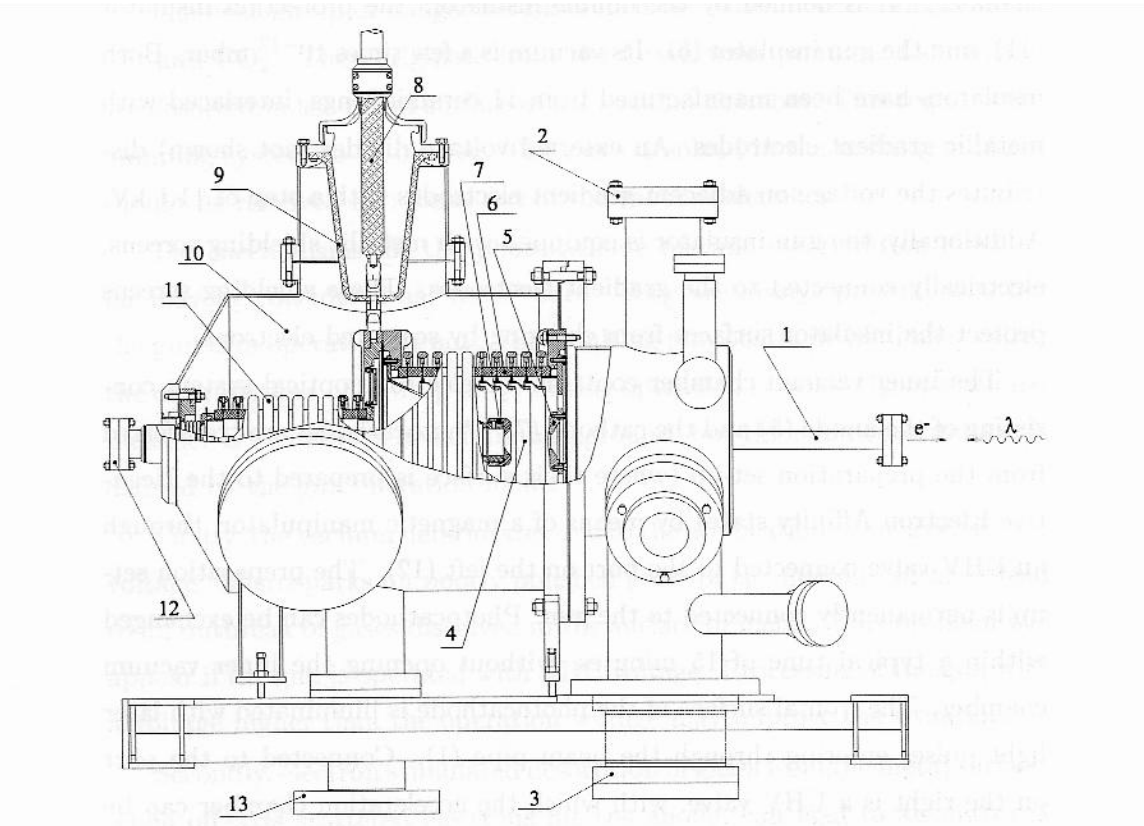


- 60 kV gun provides > 5 C/day,
- Spare guns prolong operating lifetime,
- Gun swaps every few weeks.

MIT-Bates Polarized e-Source

Every lab prepares for Plan B, in this case, a spare photogun for when the production gun breaks

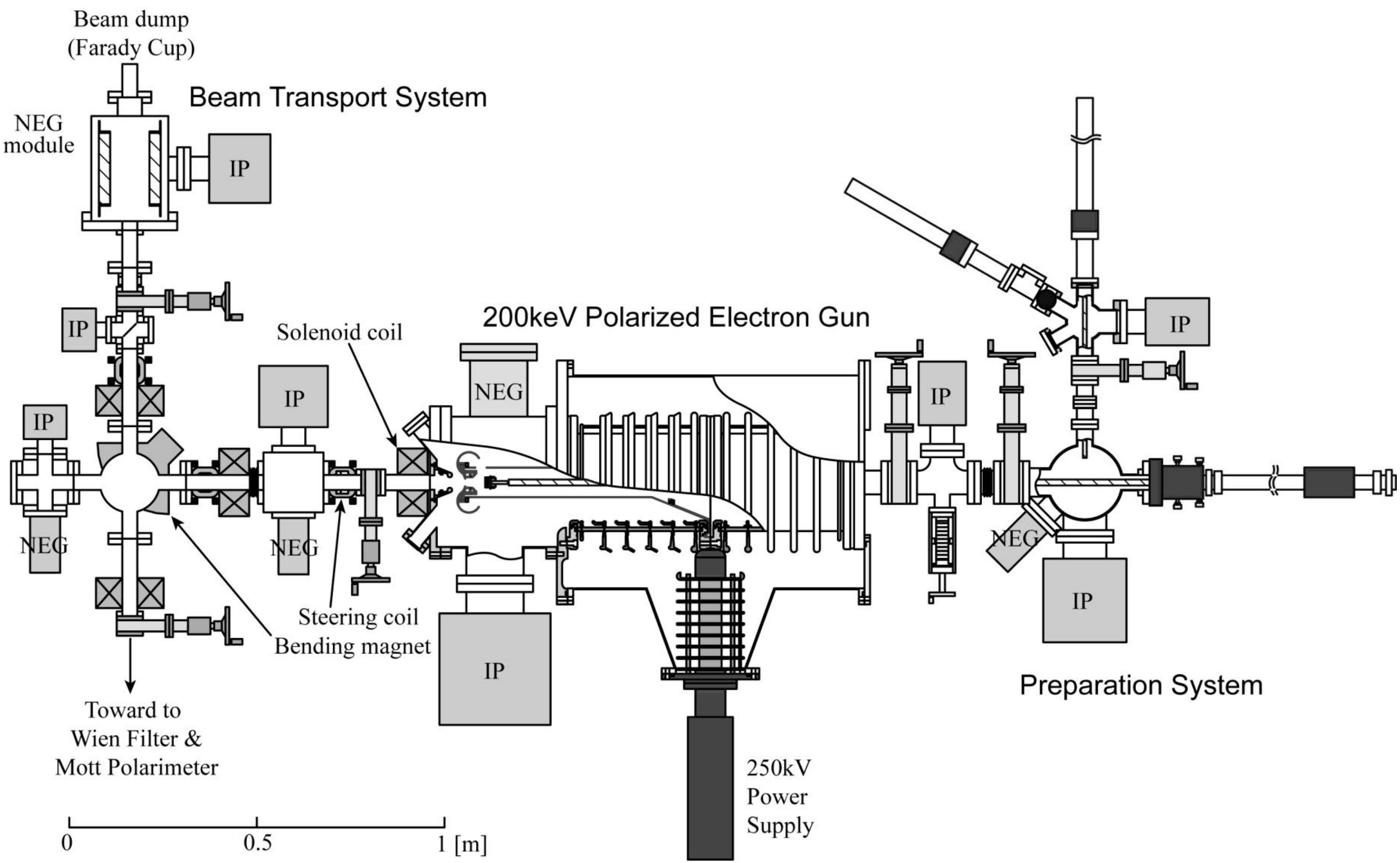
NIKHEF Load-Locked Polarized Photogun



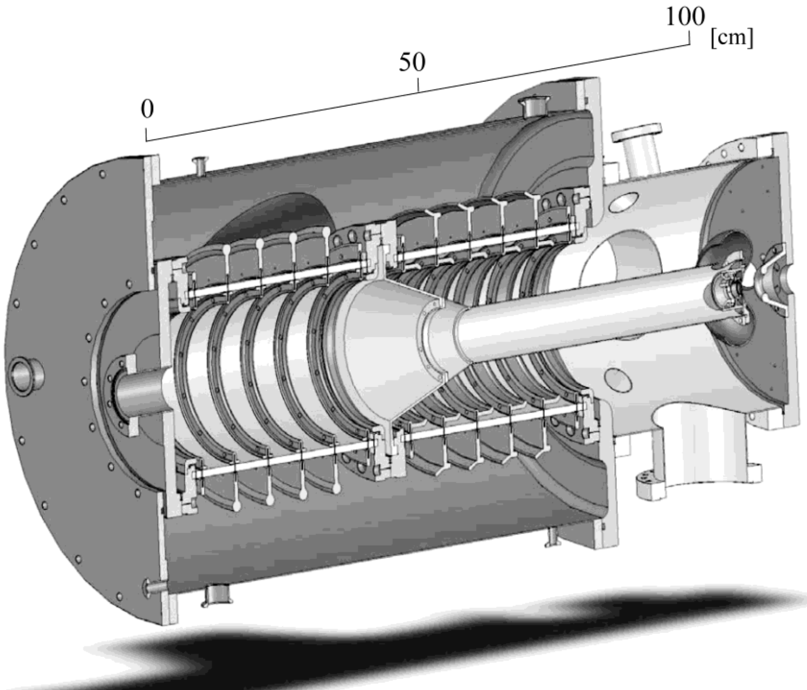
From Doctoral Thesis, Boris Leonidovich Militsyn

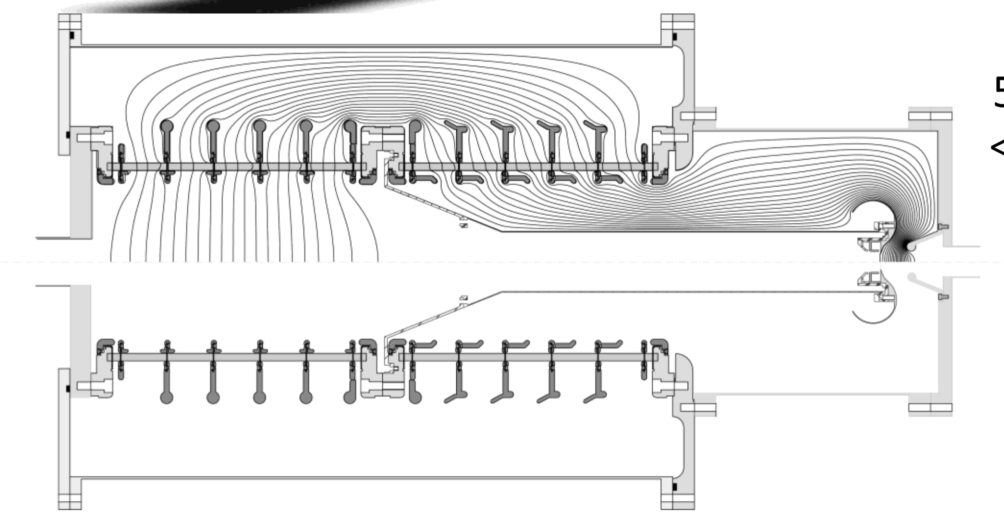
- Designed and built at Novosibirsk
- Double insulator design, load lock apparatus at ground potential
- Pulsed-high voltage

200keV Polarized e-source at Nagoya University



200keV gun basic performance





Base pressure: 2x10^{-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)

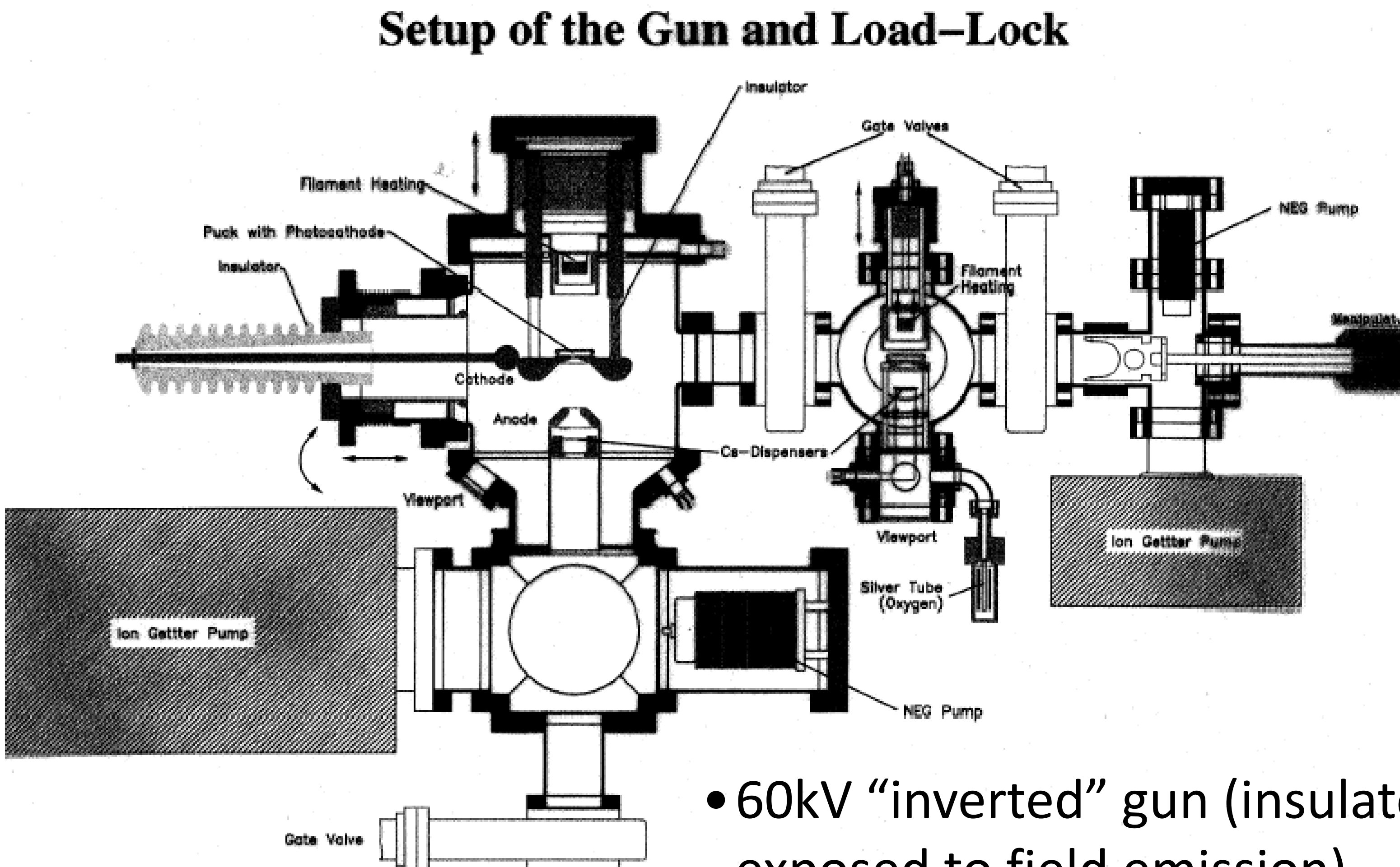
<u>Electrode</u>

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

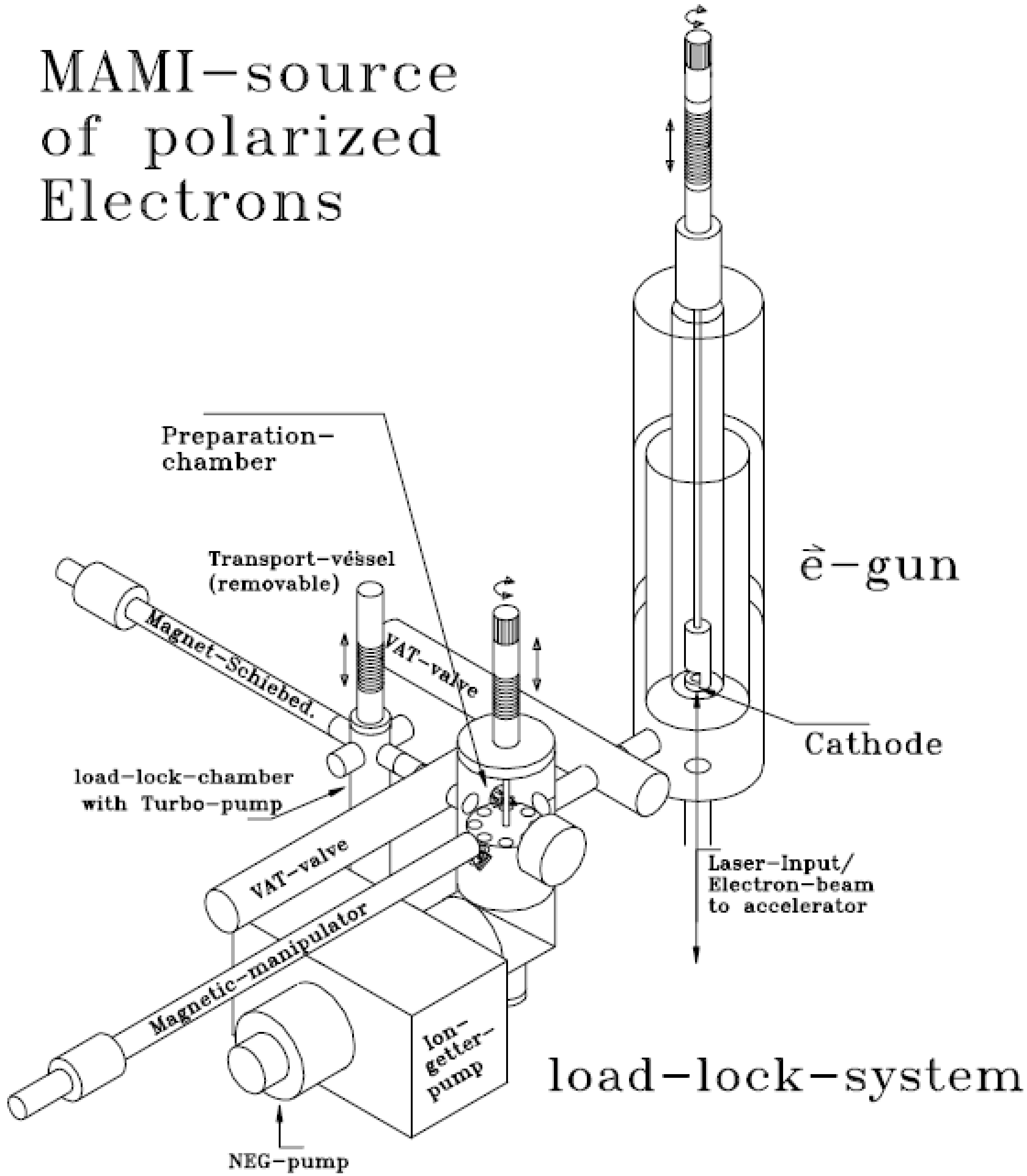
<u>Ceramic</u>

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

Bonn- ELSA Polarized Electron Gun

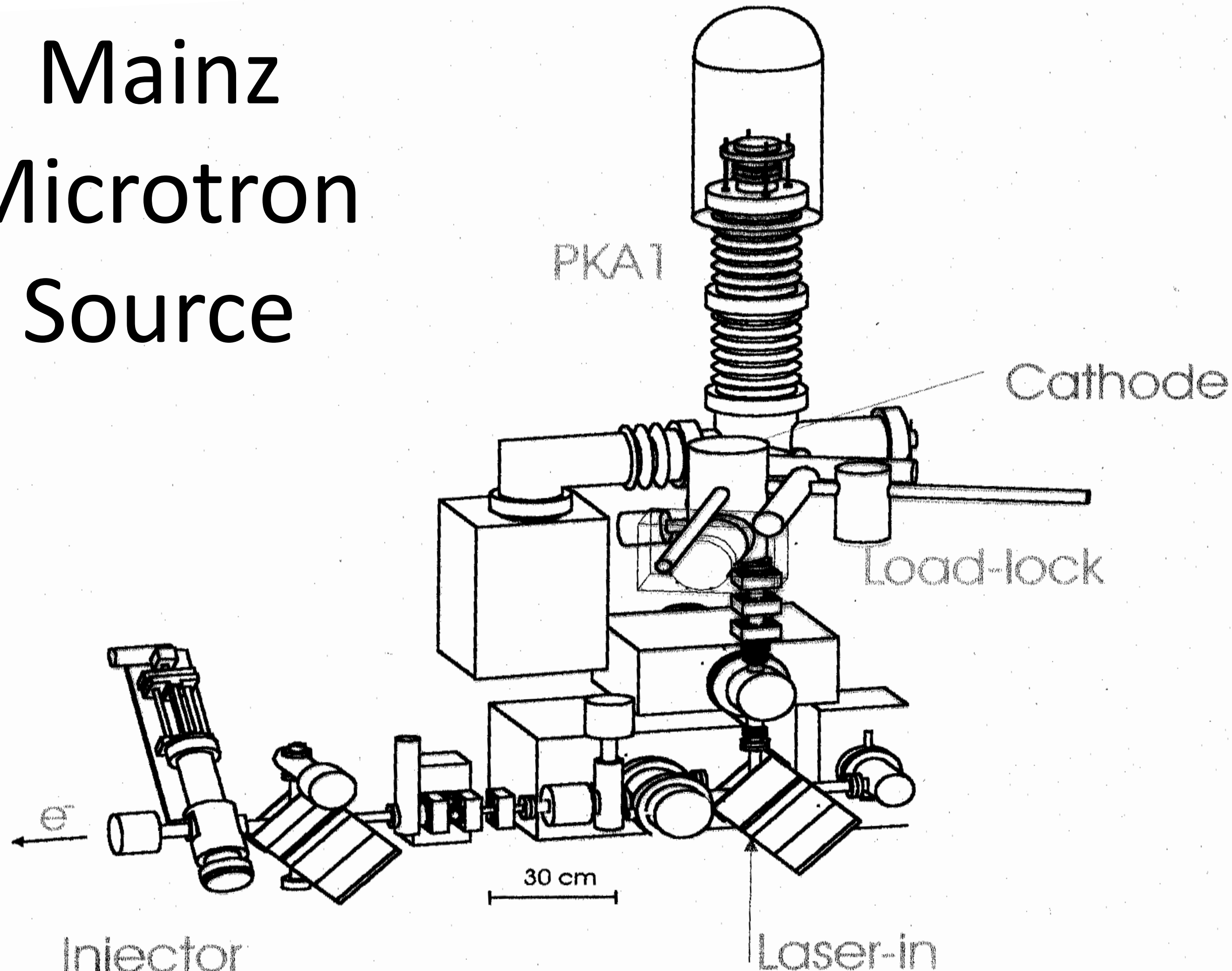


- 60kV "inverted" gun (insulator not exposed to field emission)
- Clever use of commercial inexpensive HV electrical feedthrough
- Load-lock apparatus at ground potential



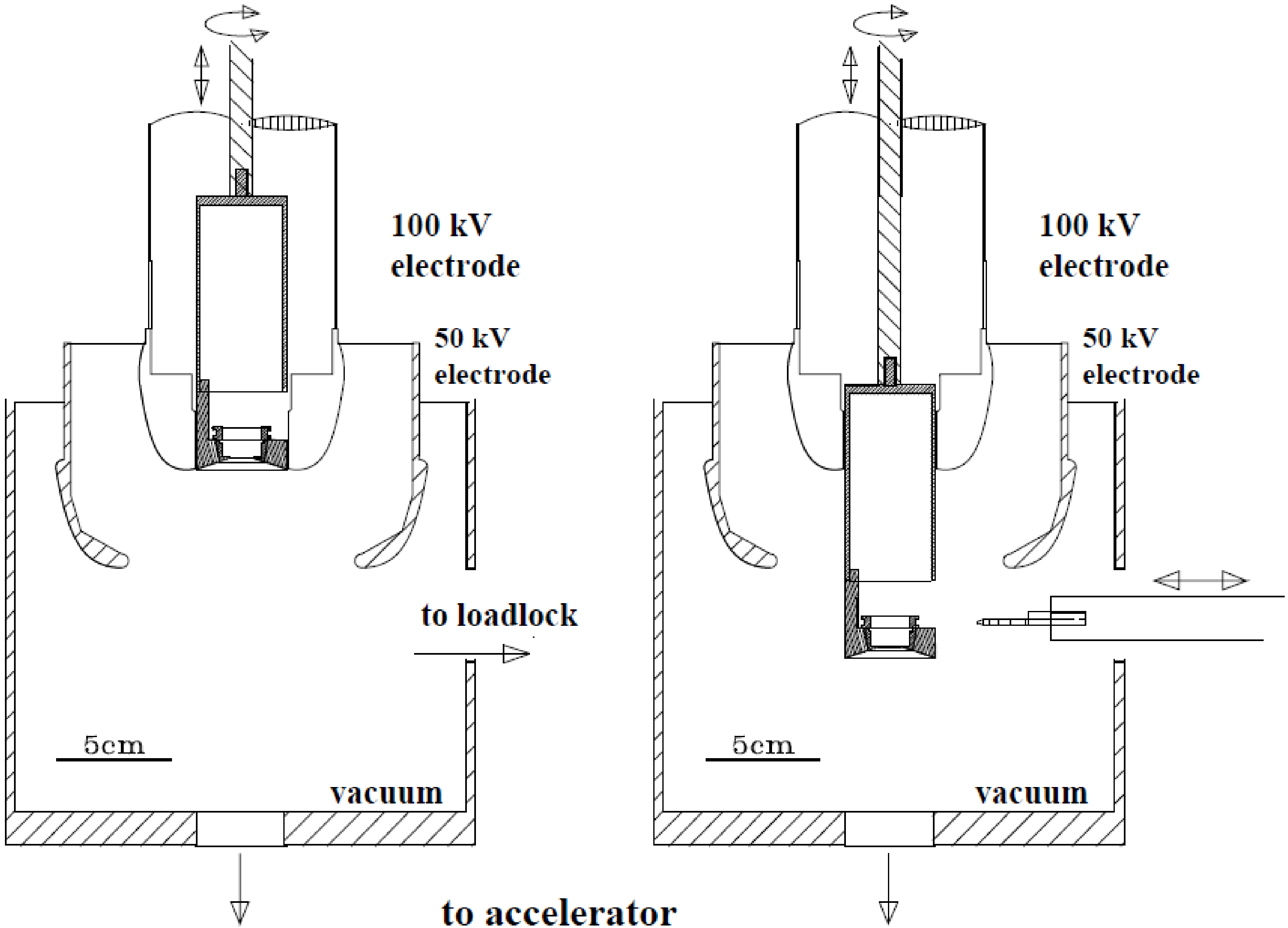
- 100kV load locked gun
- The 2nd load locked gun used at an accelerator
- Load lock apparatus at ground potential
- Multiple photocathode samples in vacuum
- Allows rapid photocathode swaps.

Mainz Microtron Source



Polarized electron source Installation
at the injector of MAMI

Replacing Photocathodes



University of Nebraska-Lincoln PES

From “A Simplified GaAs Polarized Electron Source,” H. M. Al-Khateeb, …, T. Gay.

Rev. Sci. Instrum., Vol. 70, No. 10, October 1999

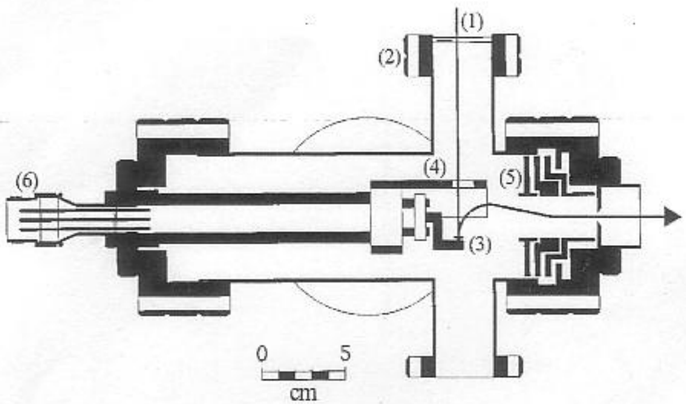
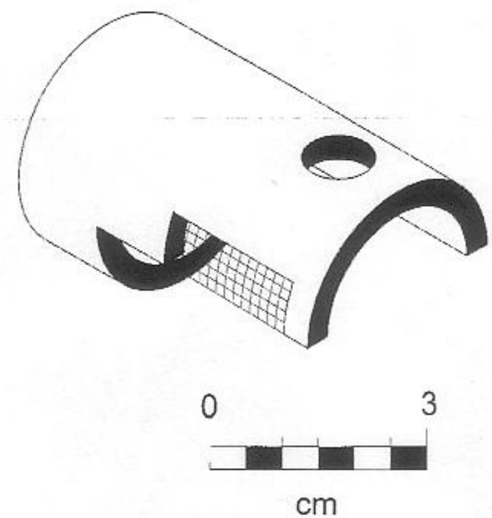
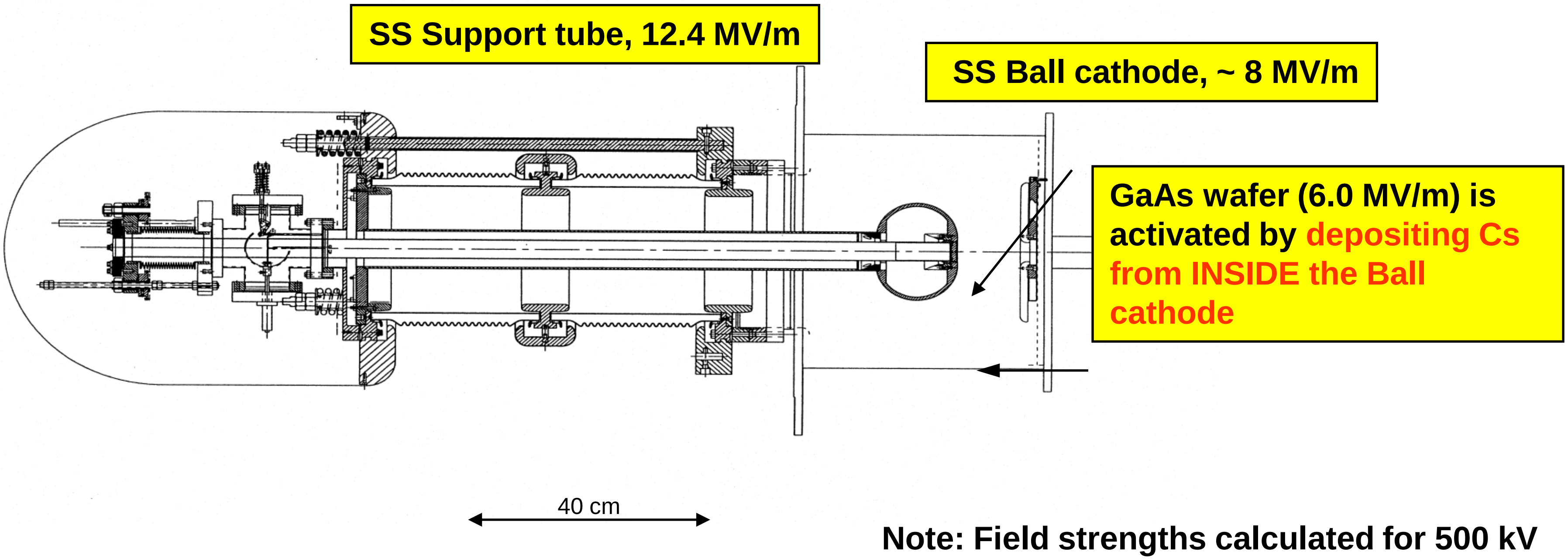


FIG. 1. Side view of the GaAs source chamber: (1) laser beam; (2) laser beam entrance window; (3) GaAs crystal; (4) cylindrical spin rotator; (5) electrostatic lenses; (6) electrical feedthrough.



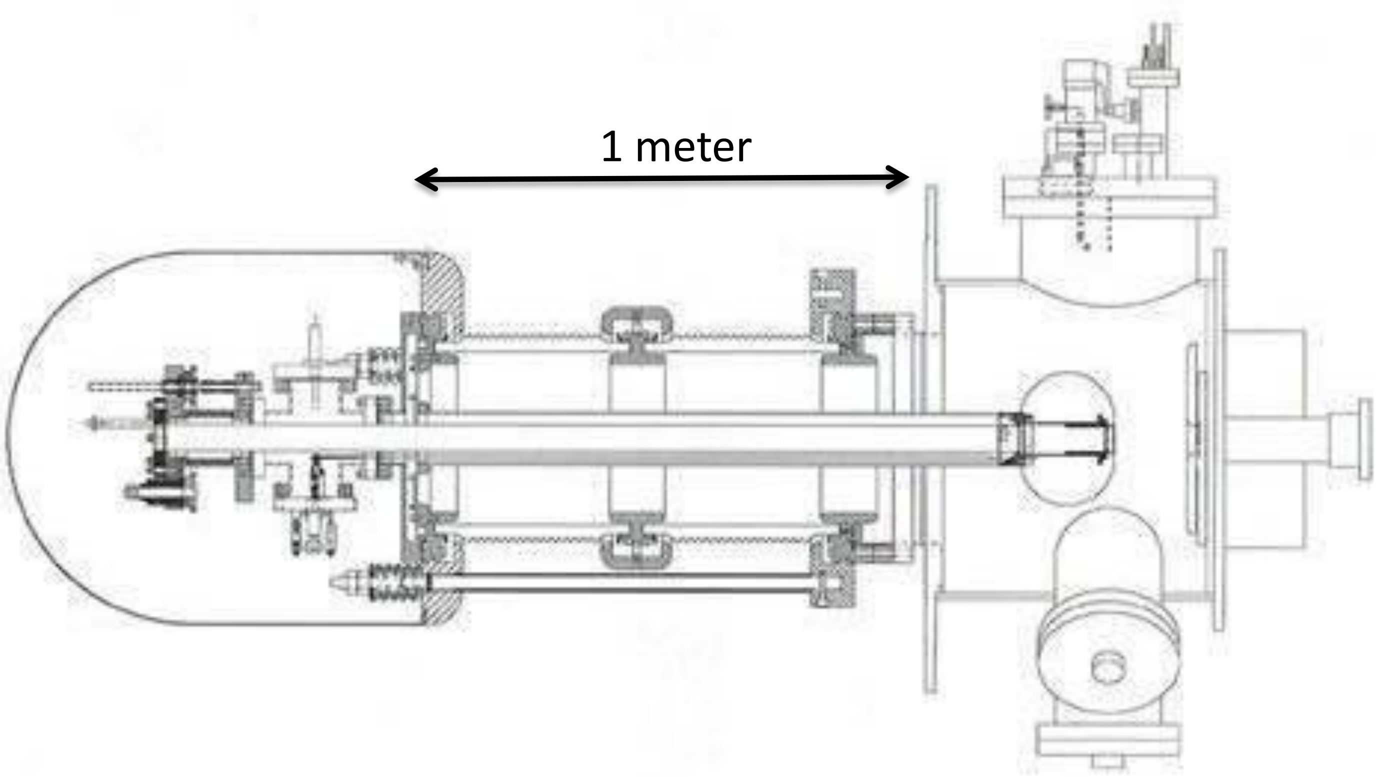
Features; compact, inexpensive, 56 L/s turbo pump, baked at 150 C, pressure ~ 10^{-10} Torr.

JLab 10 kW Upgrade IRFEL DC Photogun



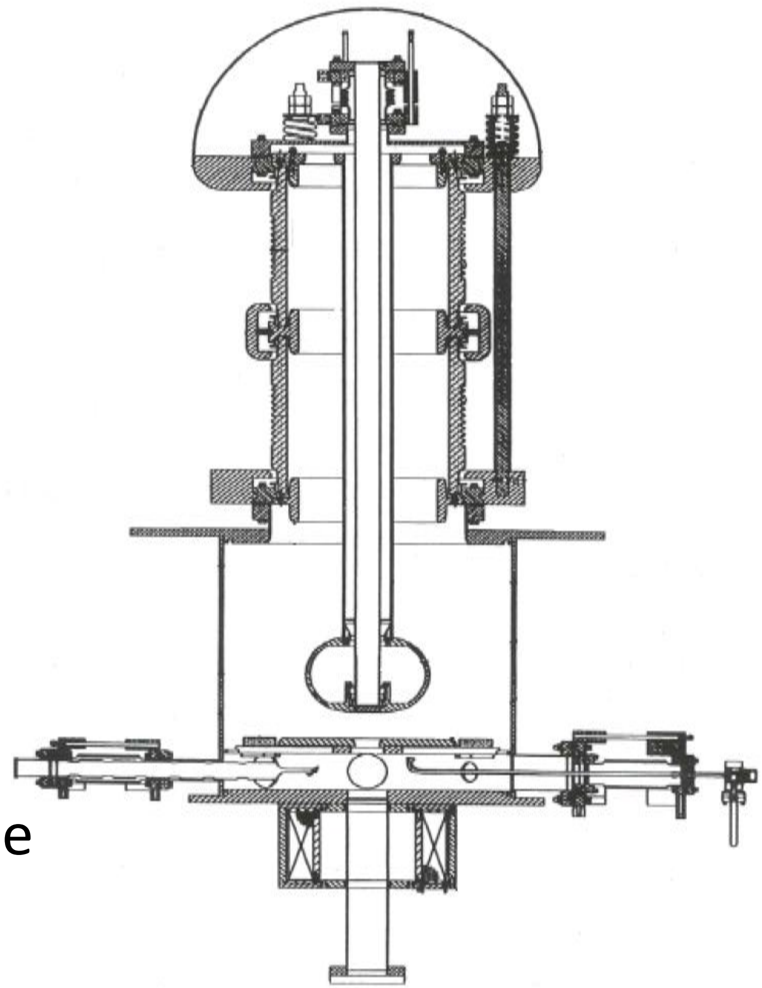
- Operating voltage ~ 320 kV. Field emission is the limiting factor to achieve desired voltage/field
- Bulk GaAs, unpolarized beam, pumped with green light Nd:YLF laser at repetition rates to 75 MHz
- Average CW operating current as high as 5 mA
- Modification allows cesiation behind electrode

Jlab FEL DC photoemission gun



DC Photoinjector

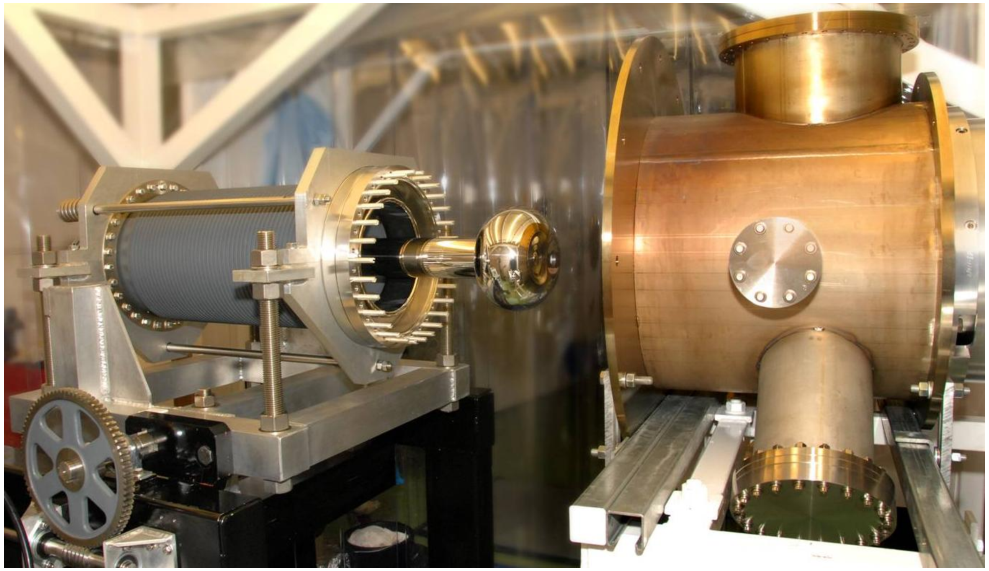
- Typical cathode bias of -100kV to -500kV
- Open structure, typically very good vacuum (<10^{-11} Torr)
  - Allows use of chemically sensitive cathodes (Cs: GaAs)
- Typical gradient of 5 MV/m, limits peak current density to ~10 A/cm^2
- Good for low peak current, high average current applications
  - Energy recovery linac based free electron lasers (Jlab FEL)
- Ion back-bombardment is the primary source of cathode degradation (lifetime measured in Coulombs extracted)



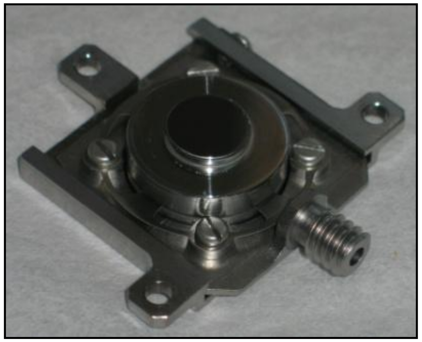
B. M. Dunham *et al.*, PAC07

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*

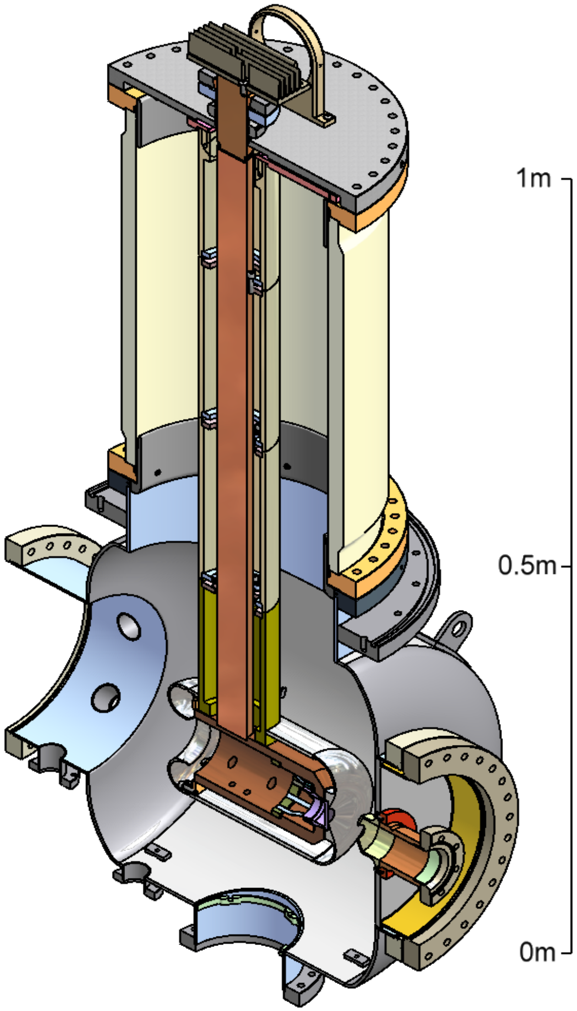


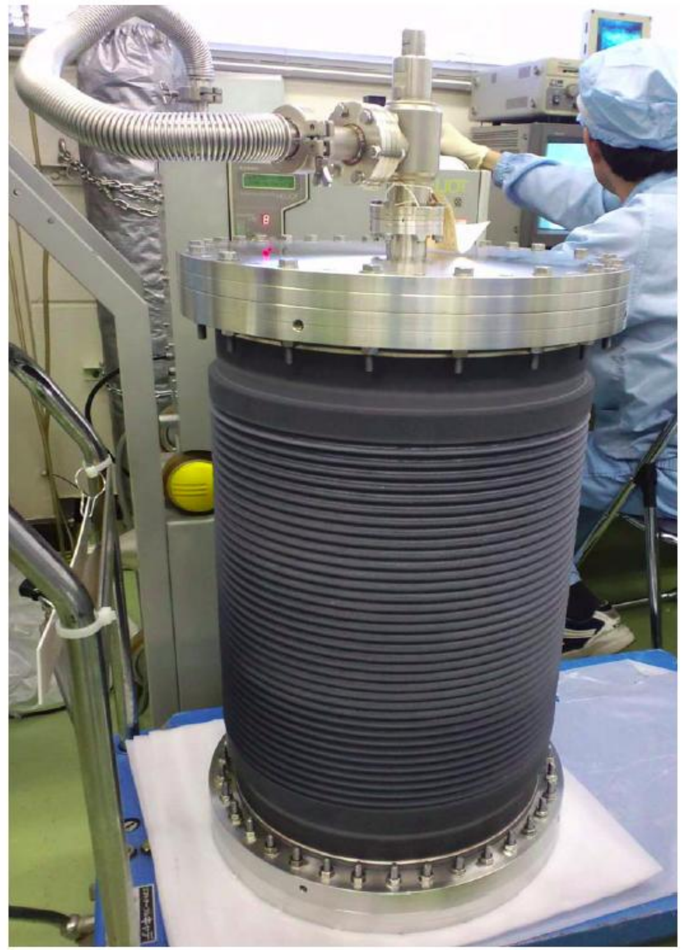
New photocathode design

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

Courtesy B.L. Militsyn

Cornell 750 kV Gun



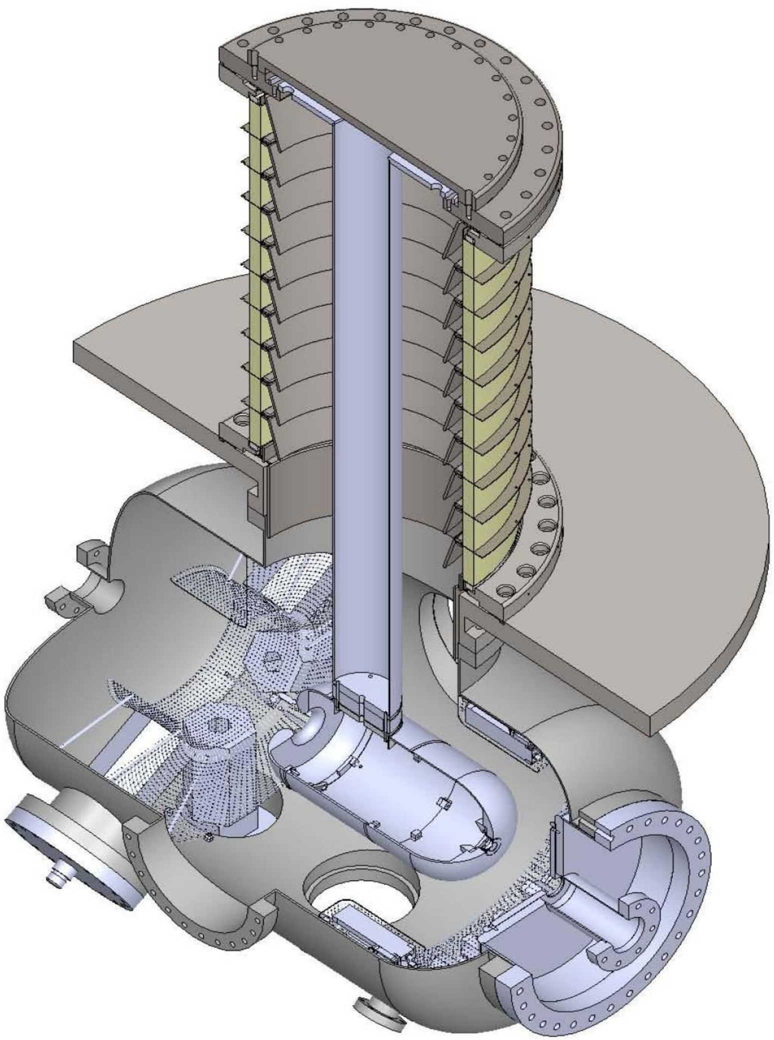


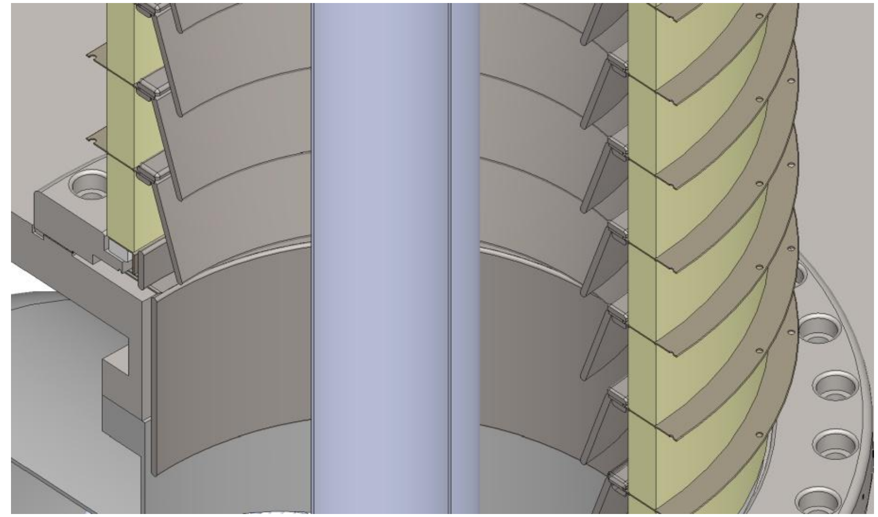
- Ceramic with bulk resistivity and improved braze design installed
- Measured resistivity of 6.45 x 10^{10} Ohm-cm gives 30 μA current draw at 500 kV
- Ceramic by Morgan, brazing and welding by Kyocera

Similar initiatives at JLab FEL and Daresbury ERLP

Courtesy Bruce Dunham, Cornell

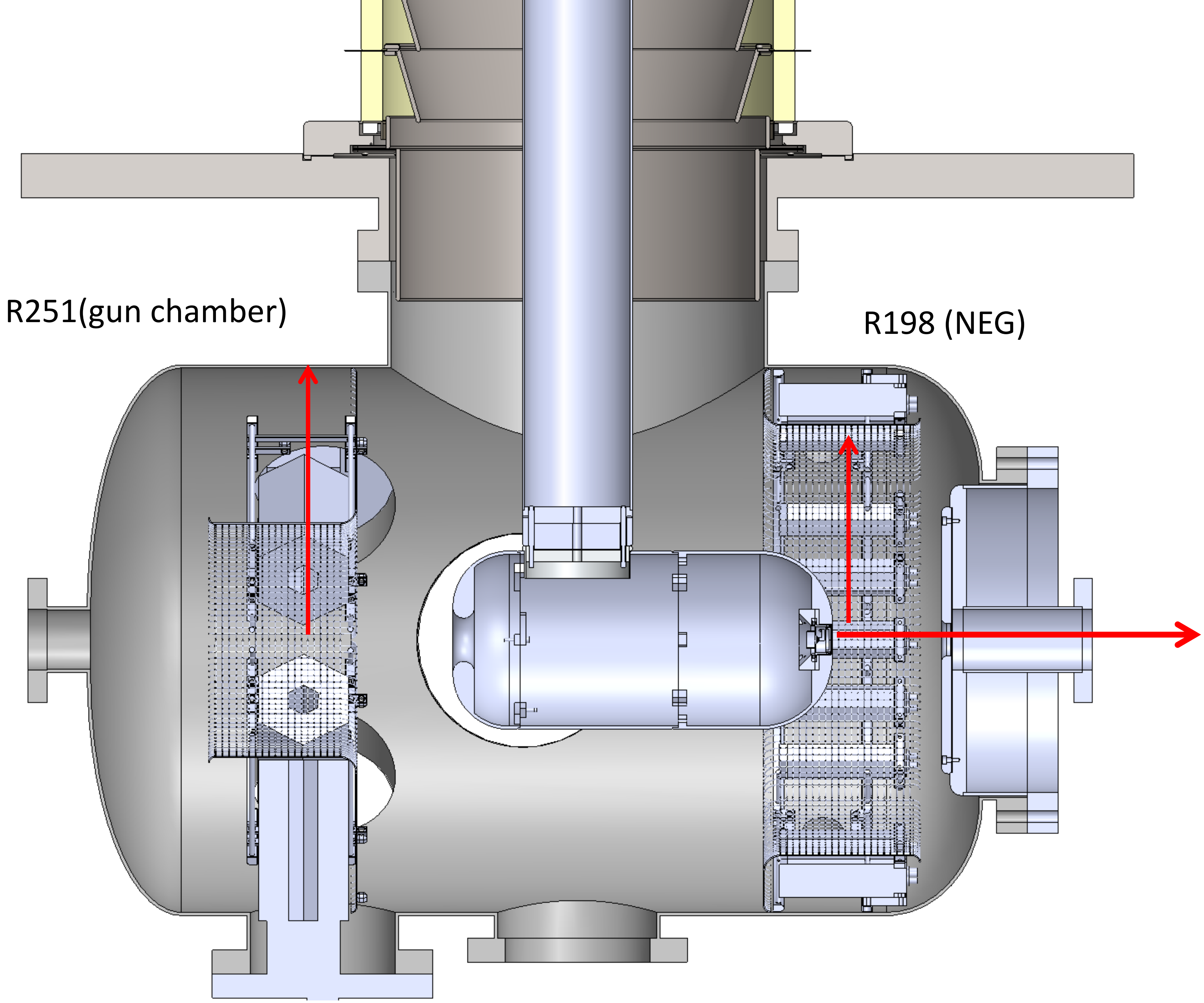
500 kV photocathode DC gun at JAEA





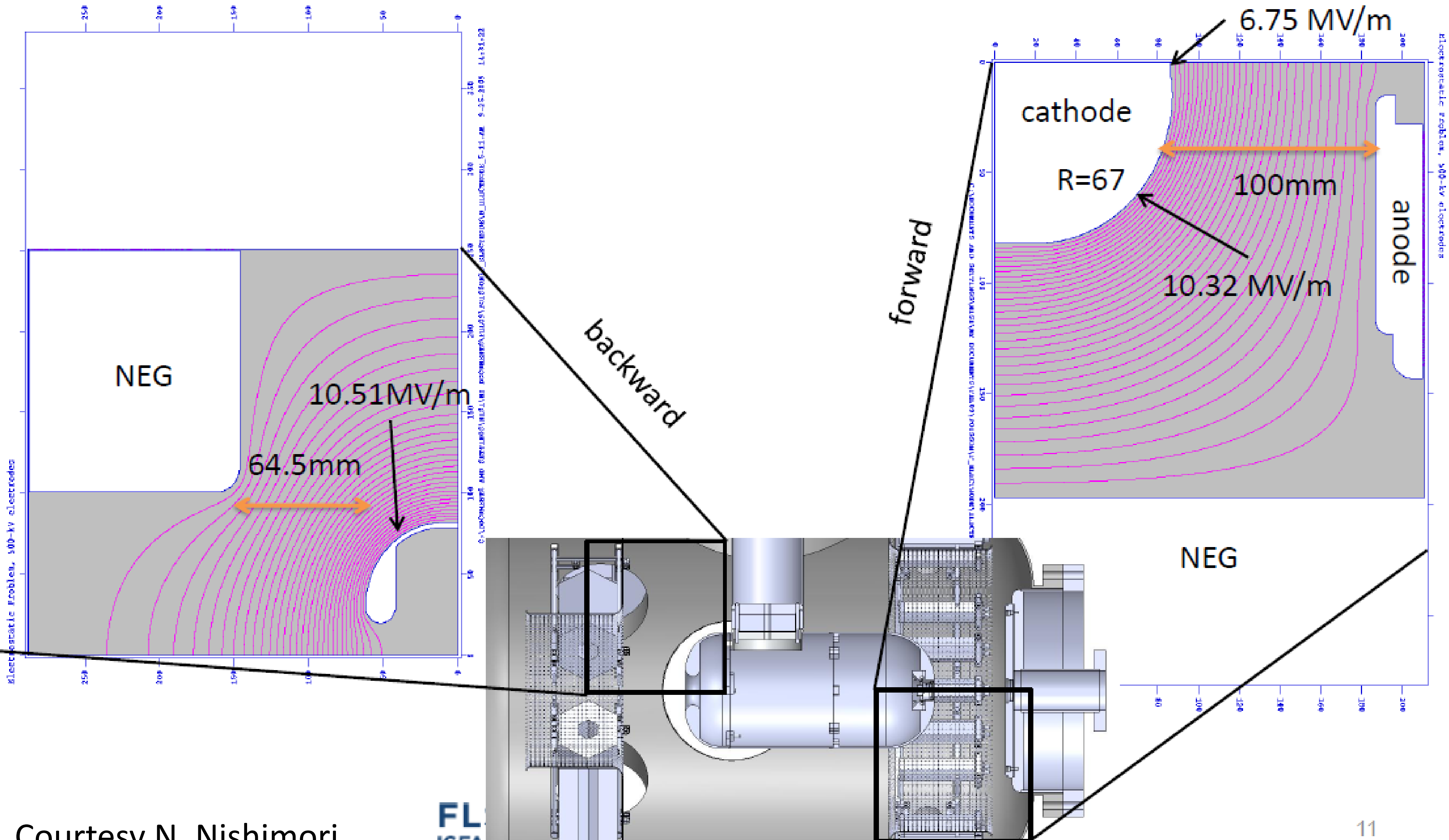
- High DC voltage >= 500kV
  - ✓ CockCroft Walton power supply
  - ✓ Segmented insulator with guard rings
  - High voltage testing
- Electrodes and vacuum
  - Cathode and anode electrodes
  - ✓ Low outgassing material (titanium)
  - NEG pumps

Courtesy N. Nishimori, Japan Atomic Energy Agency



Courtesy N. Nishimori, Japan Atomic Energy Agency

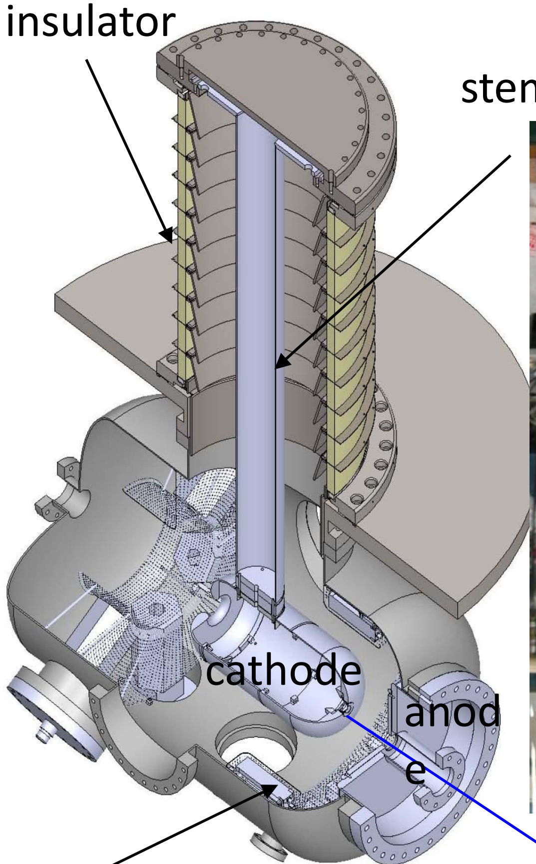
Cathode electrode: POISSON calculation



Courtesy N. Nishimori

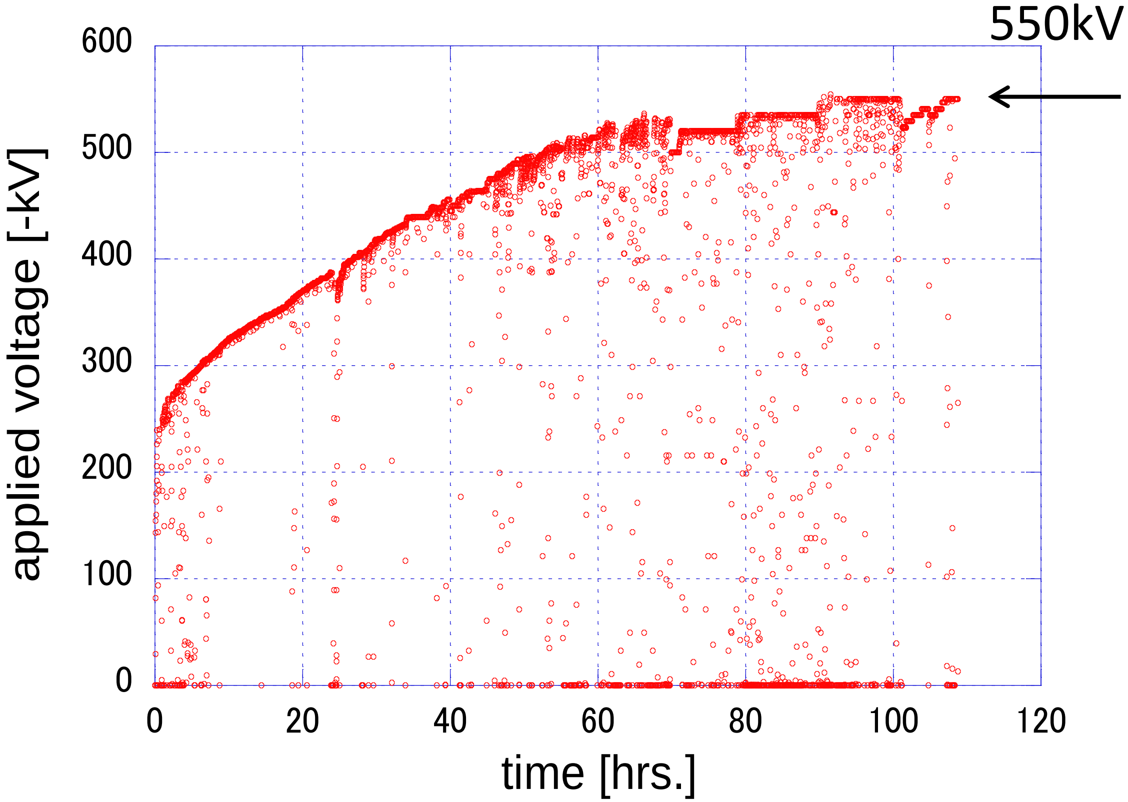
Status of 500kV DC gun at JAEA, N. Nishimori

HV testing of segmented ceramics with a stem electrode



stem electrode

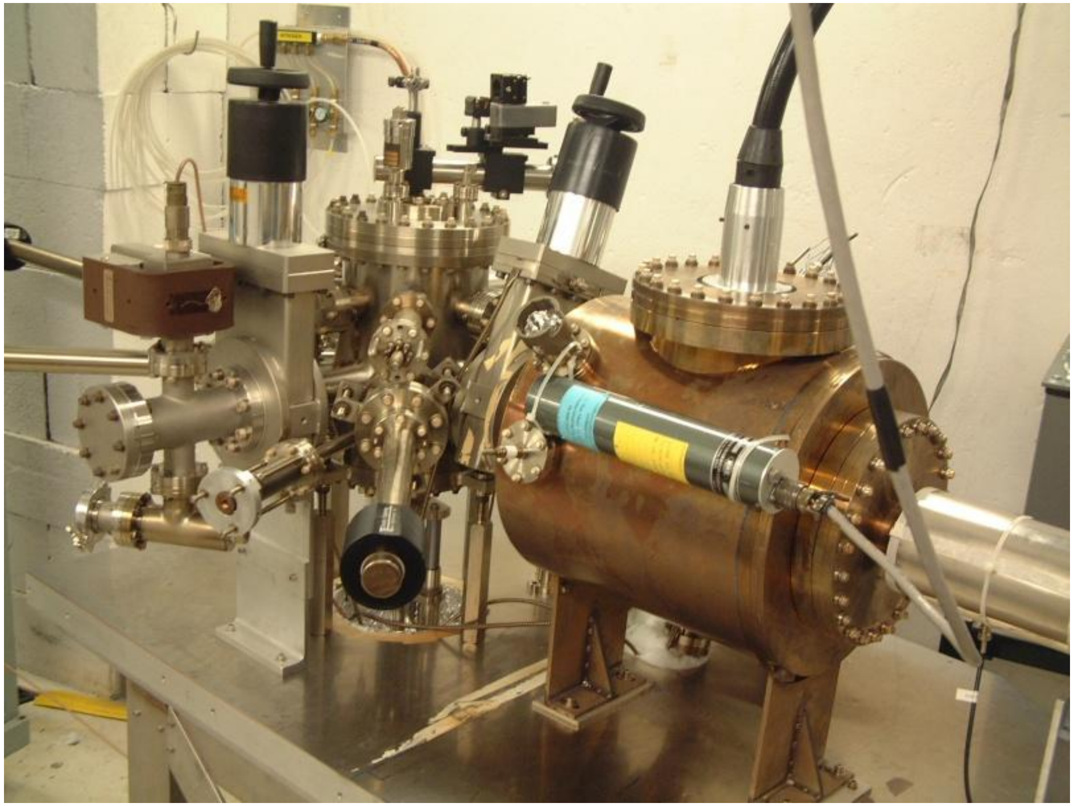
- HV processing up to 550 kV
- 500 kV for eight hours without any discharge

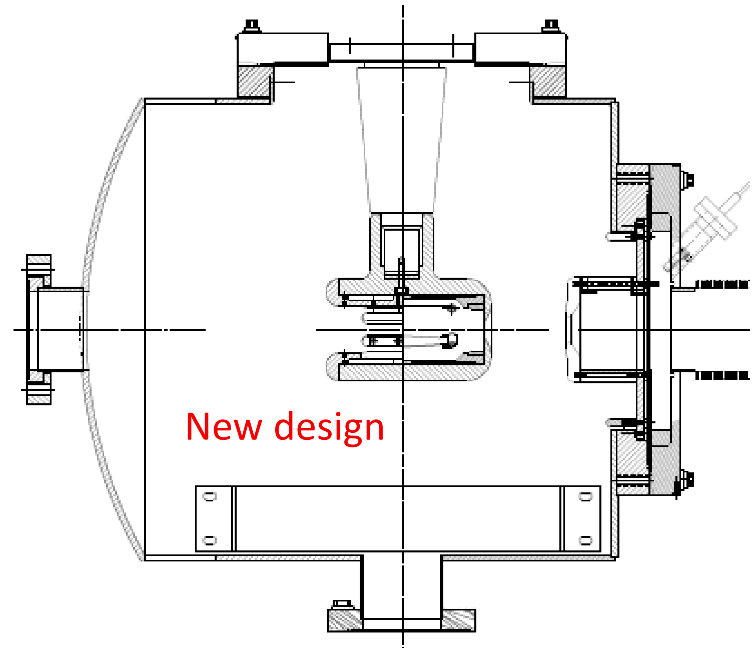


R. Nagai et al., RSI 81 033304 (2010).

Courtesy N. Nishimori, Japan Atomic Energy Agency

The CEBAF 200kV Inverted Gun





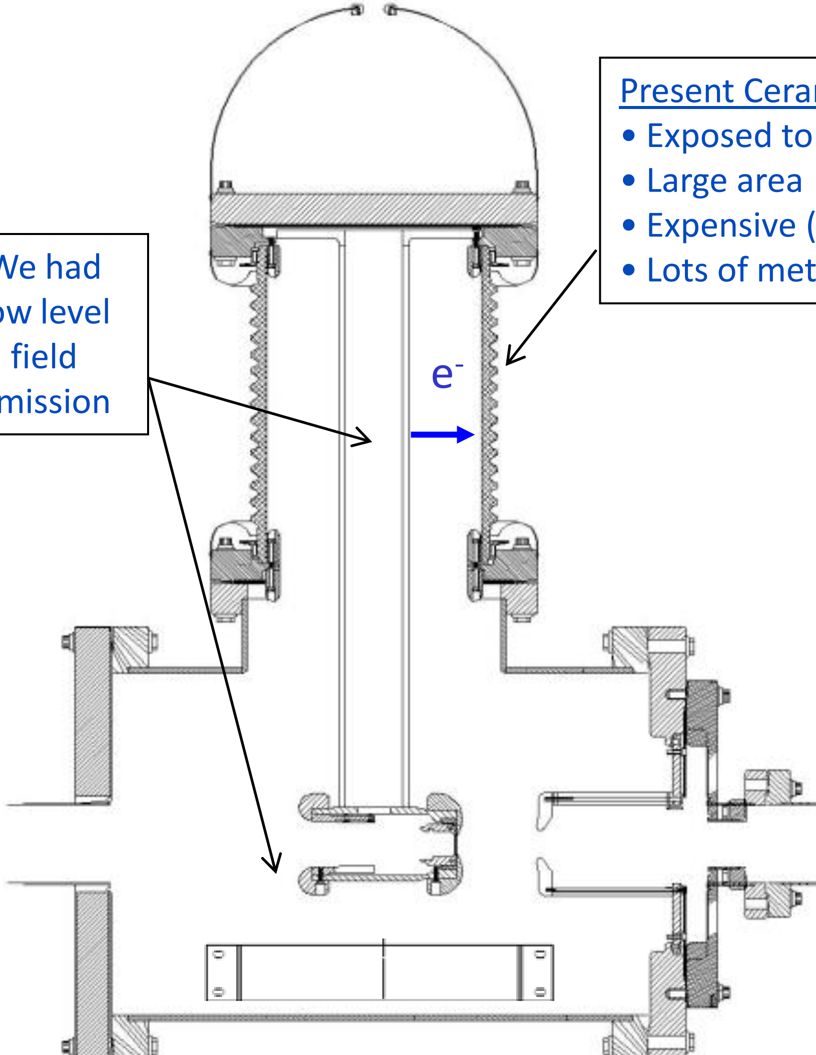
Higher voltage = better beam quality.

The inverted design might be the best way to reach voltages > 300kV

Old Gun Design

New “Inverted” Design

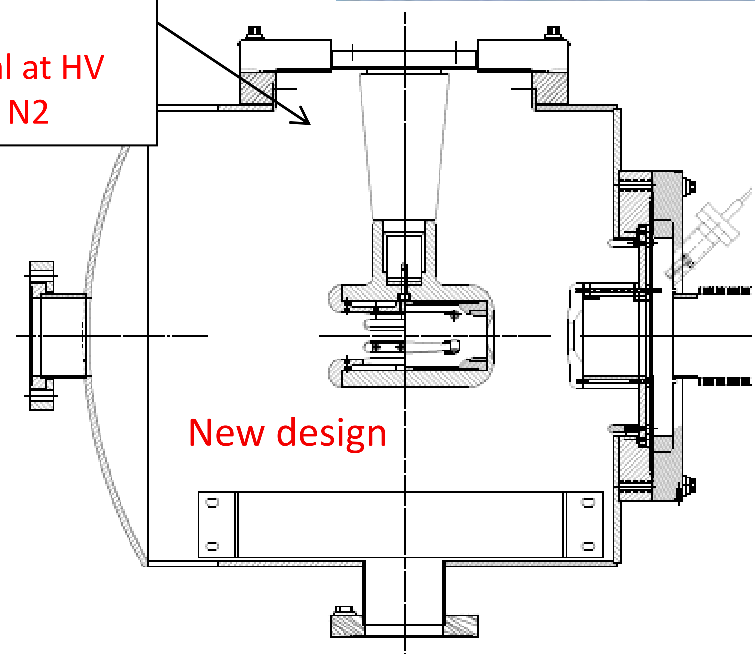
We had low level field emission



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

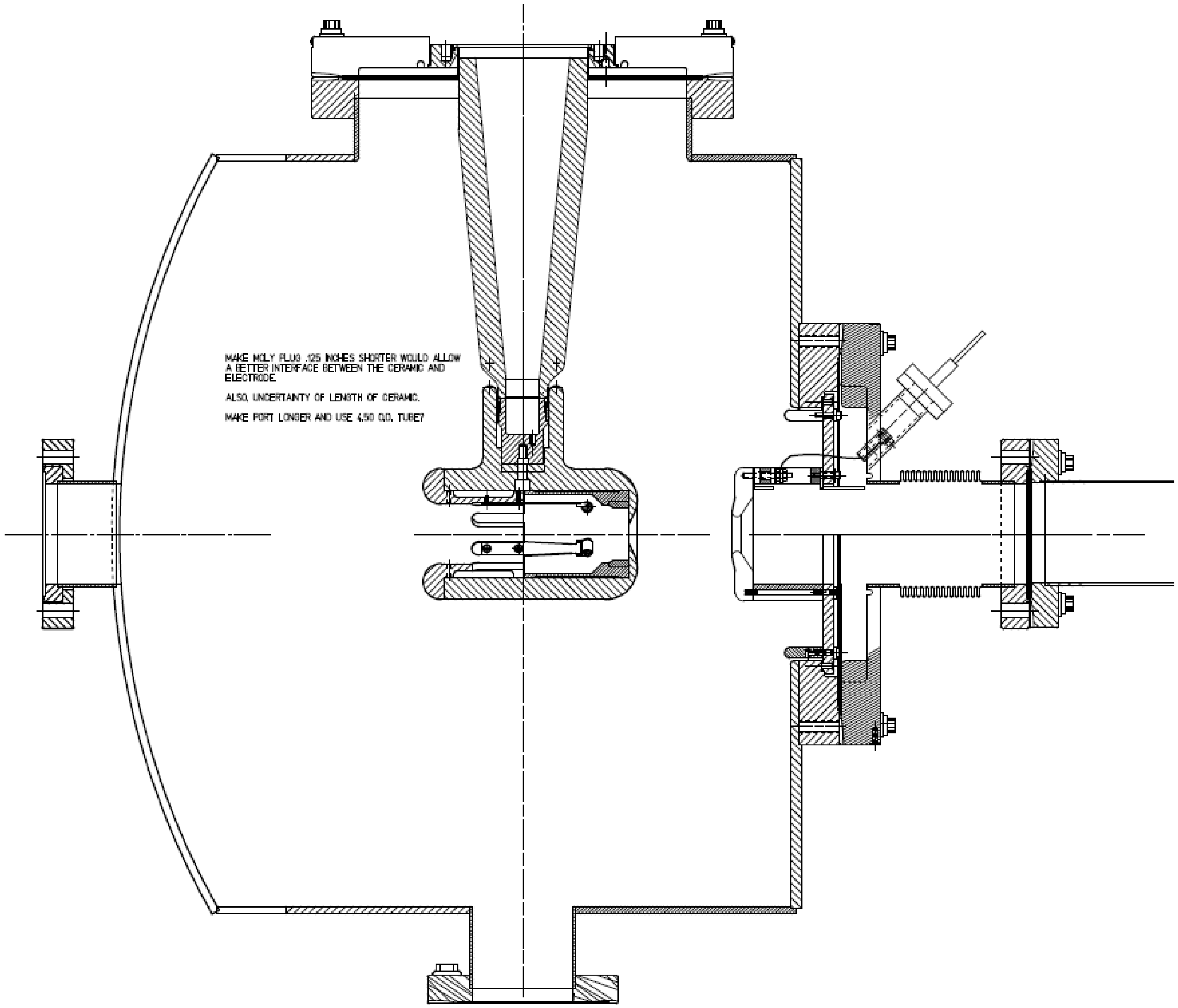
Medical x-ray technology

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

350kV Inverted Gun



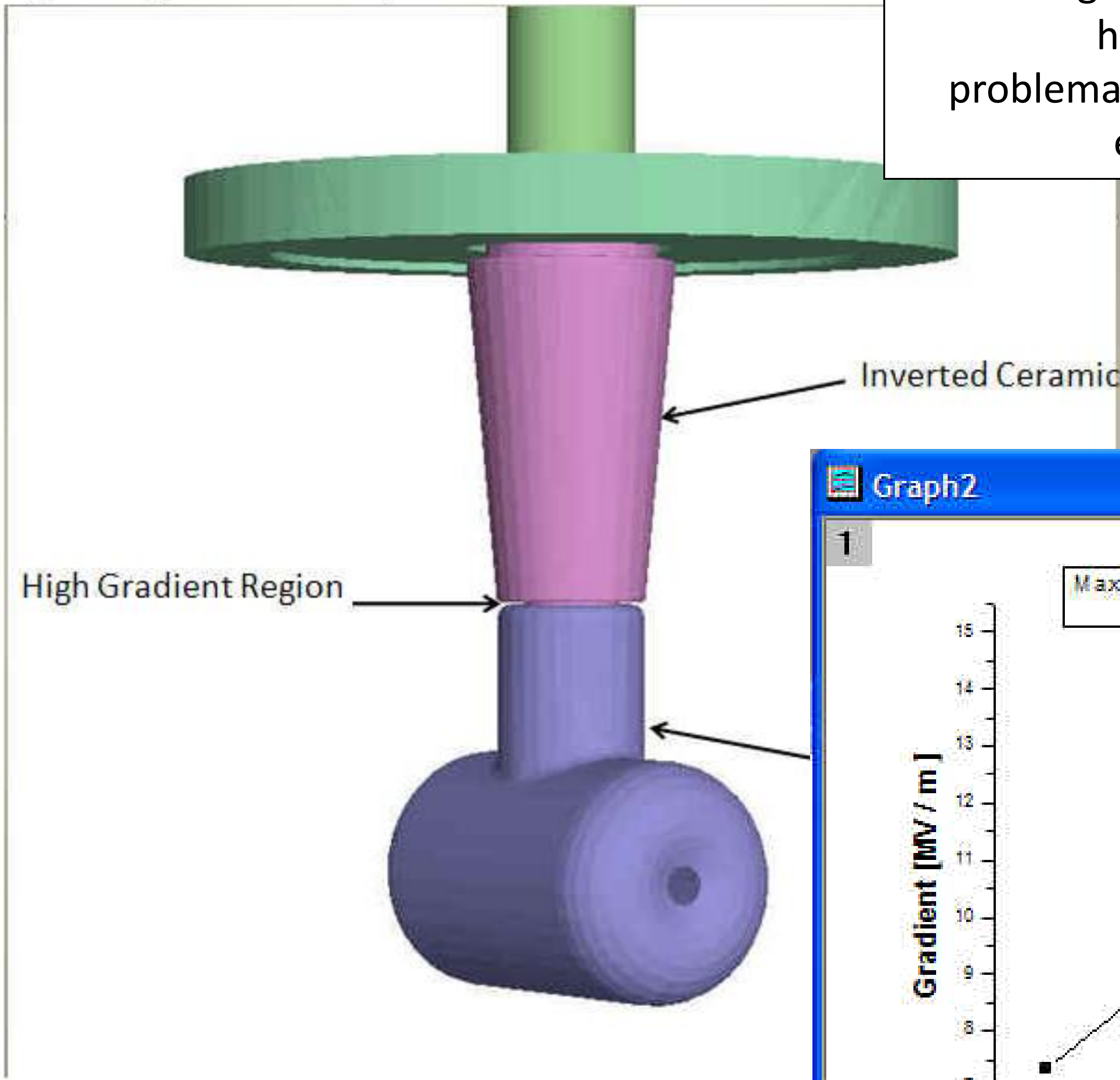
Minimum field gradient at cathode

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

cylinders: $\frac{r_2}{r_1} = e$

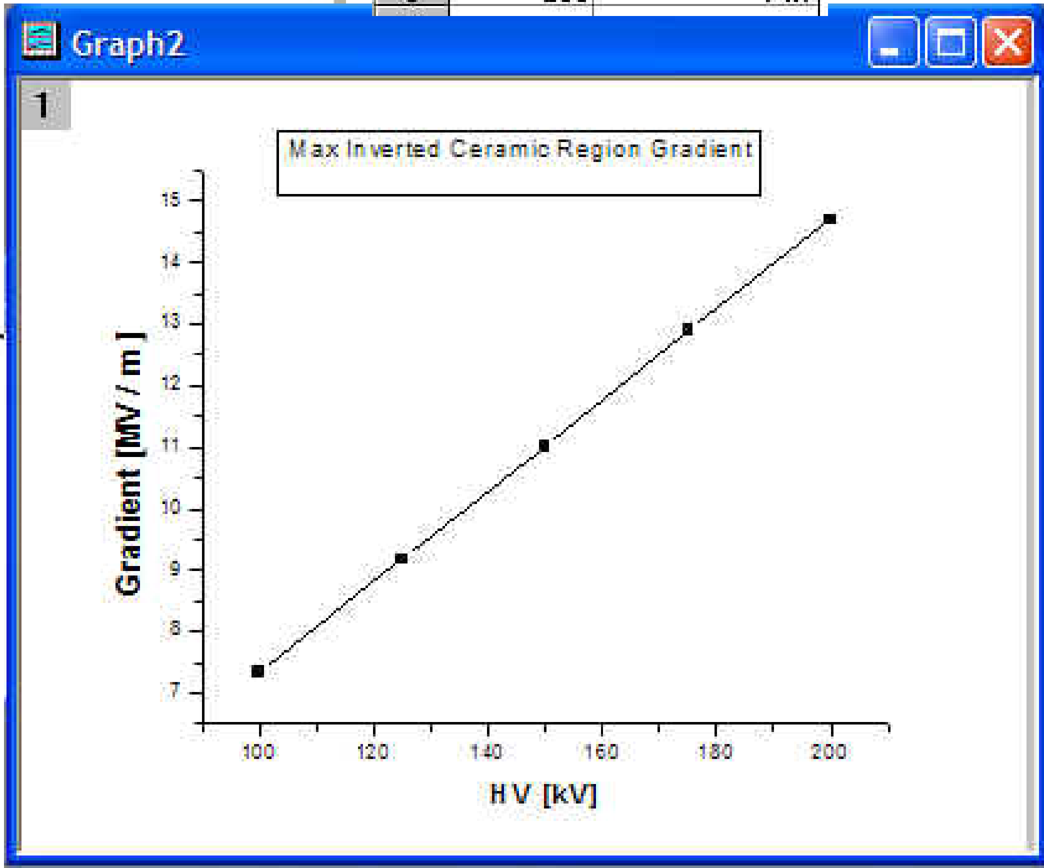
Our design has one region of "unintended" high gradient – could be problematic…..exploring new designs via electrostatic modeling

Figure 1: Highest Gradient Region



Data2 - InvCeramic Region Max ...

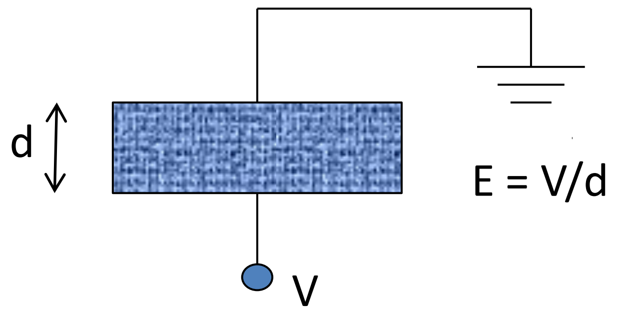
	A1(X)	A2(Y)
	HV [kV]	Gradient [MV/m]
1	100	7.35
2	125	9.18
3	150	11
4	175	12.9
5	200	14.7

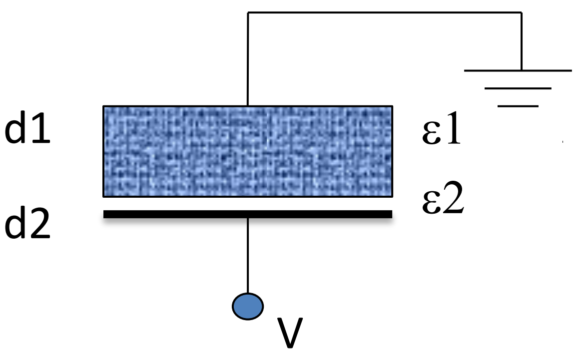


Work of Ken Surles-Law

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

HV breakdown in capacitors with delamination gap

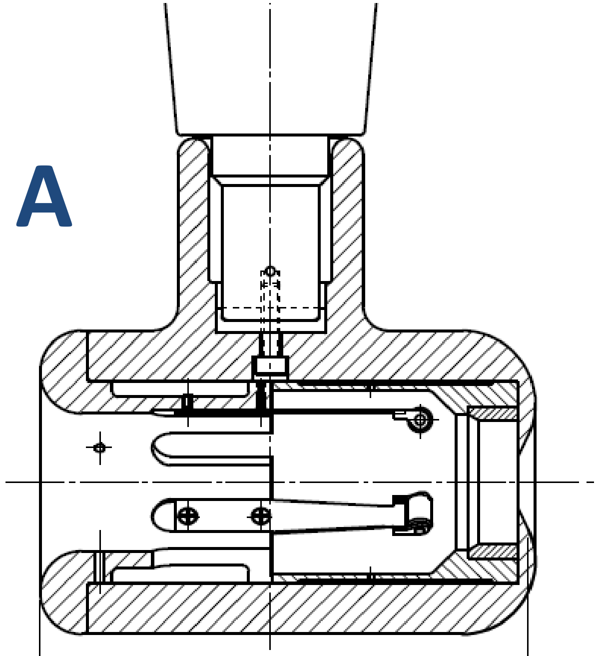




$$E2 = \frac{V}{d2 + d1\left(\frac{\varepsilon 2}{\varepsilon 1}\right)} \sim \frac{V\,\varepsilon 1}{d1}$$

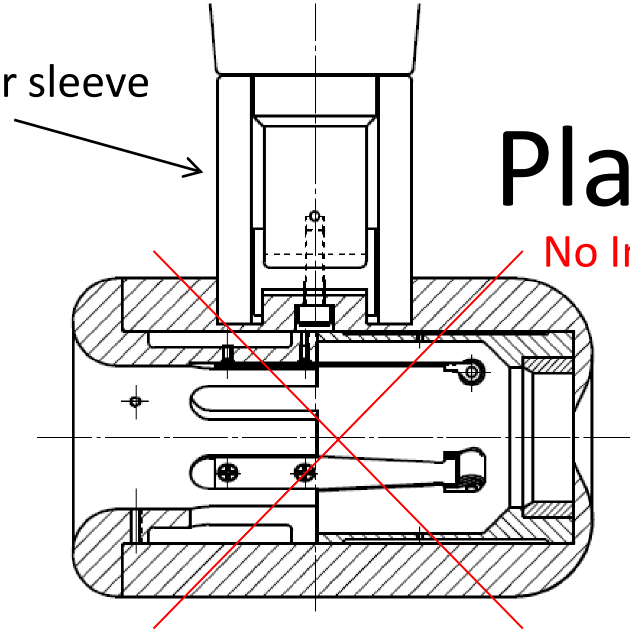
"High Voltage Engineering: Fundamentals", Kuffel, Zaengl, Kuffel

Plan A



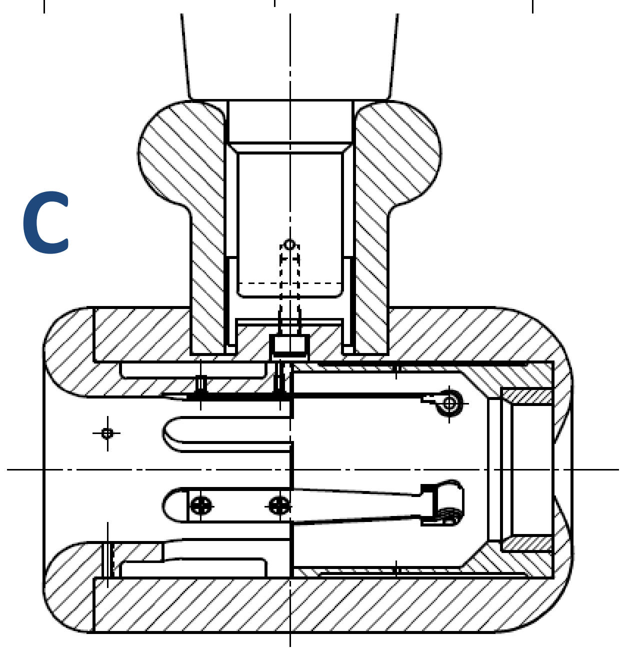
Plan B

Insulator sleeve



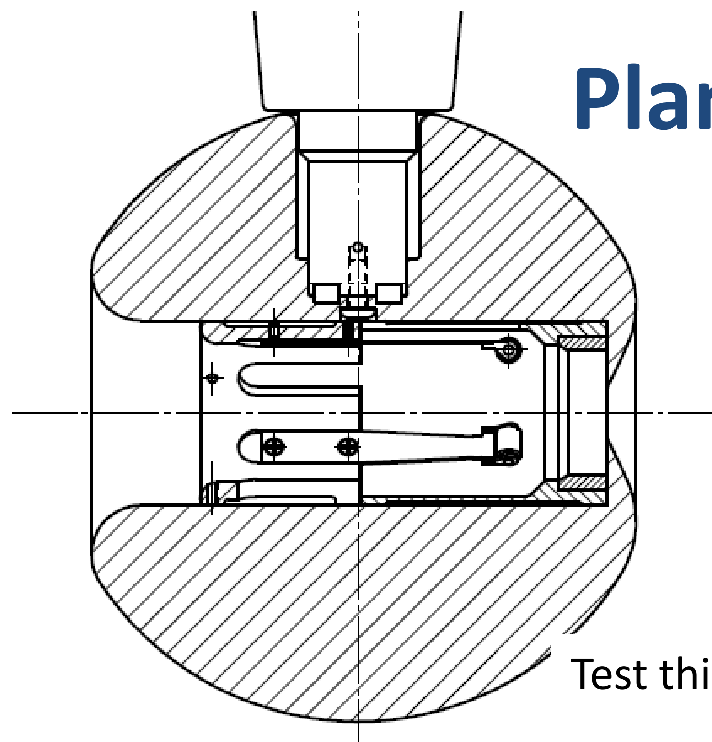
No Improvement

Plan C



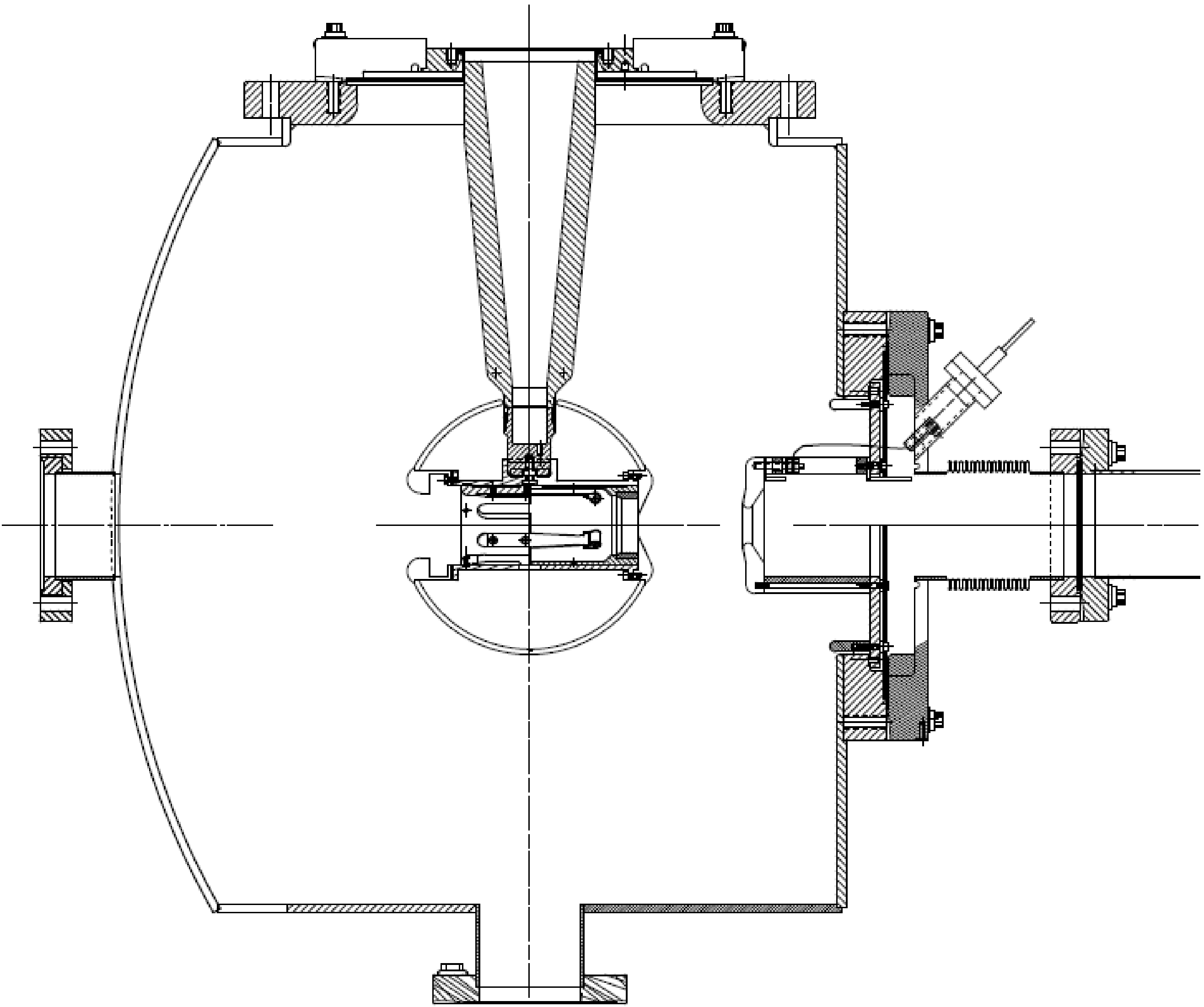
In hand, but untested

Plan D



Test this year

350kV Inverted Gun

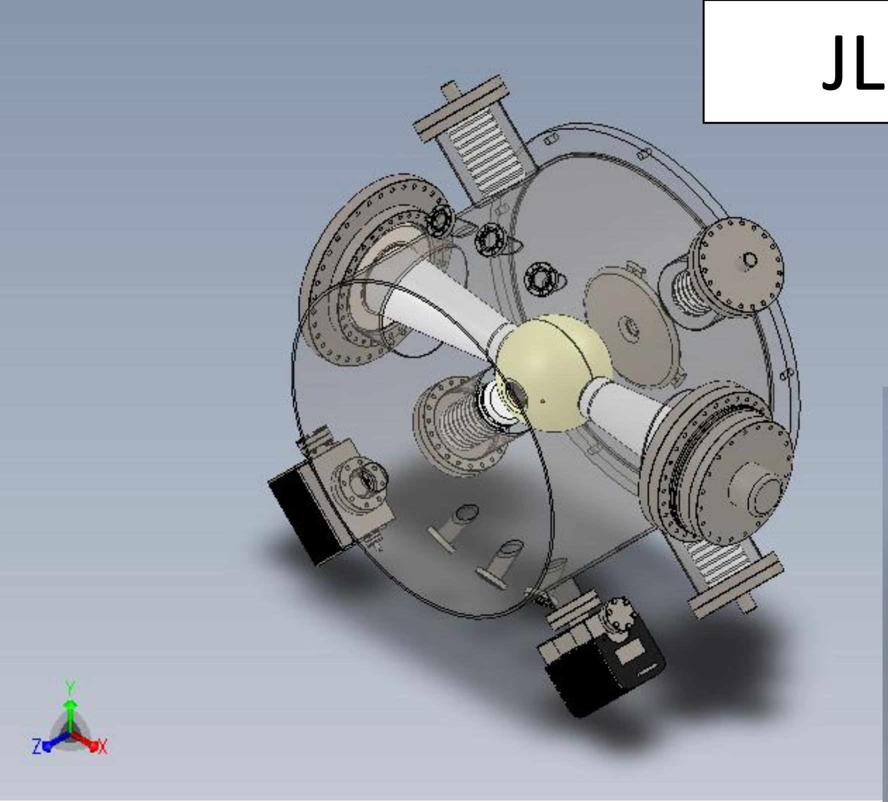


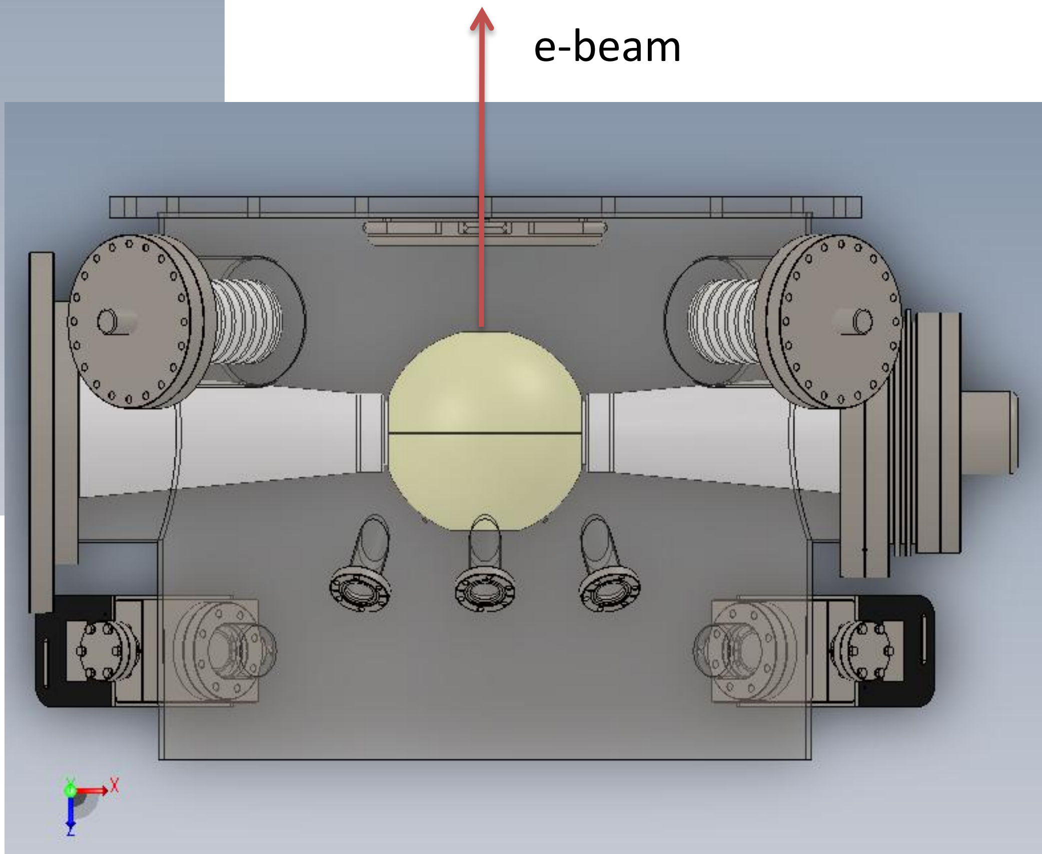
Minimum field gradient at cathode

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

cylinders: $\frac{r_2}{r_1} = e$

JLab FEL 500kV inverted gun



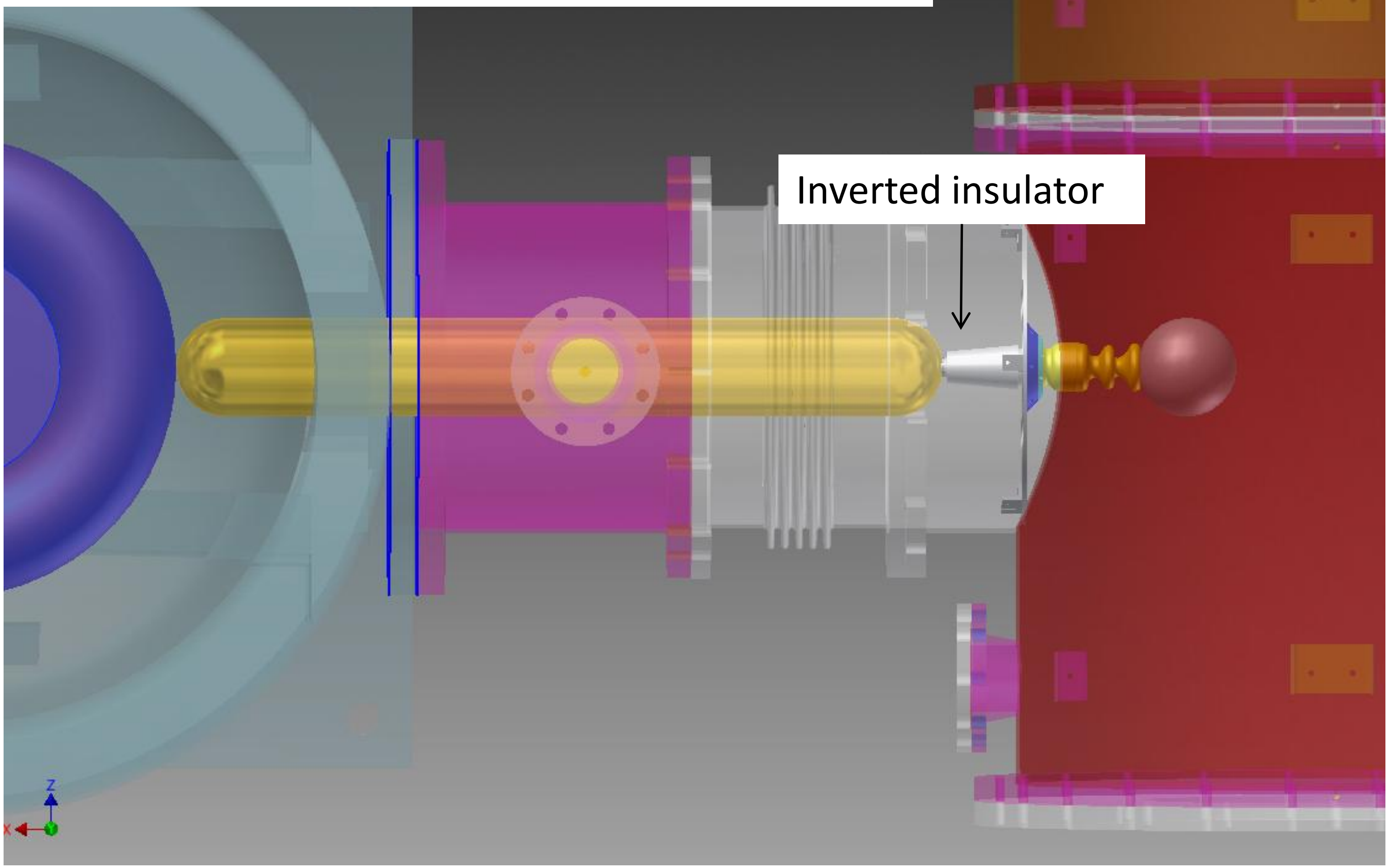


- Condition to 600kV, operate at 500kV
- 3x bigger inverted insulator compared to CEBAF gun
- One insulator for HV: one for cooling
- Niobium electrode – no diamond paste polishing
- Work in-progress

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

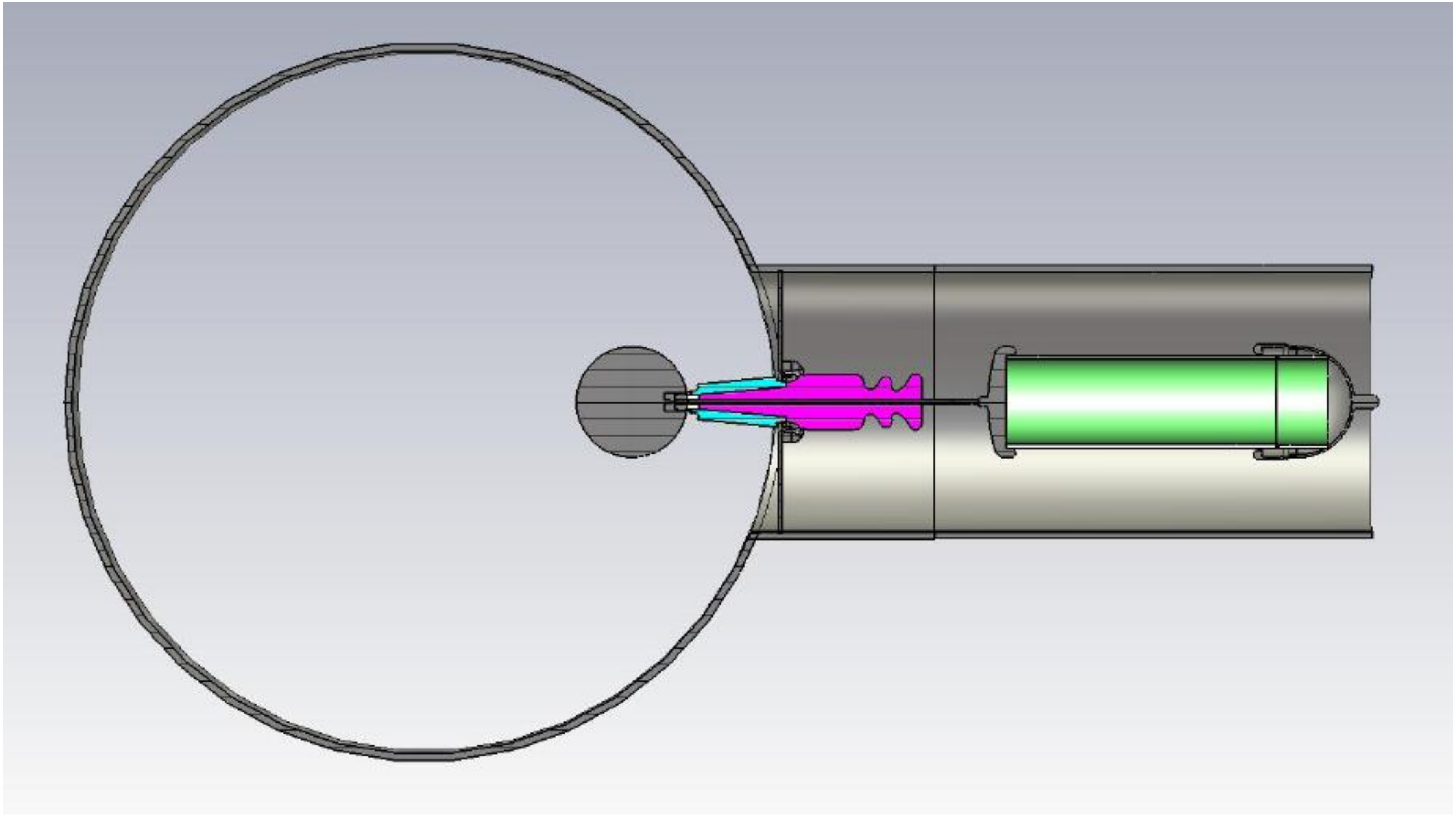
HV Issues: inside and outside the gun

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

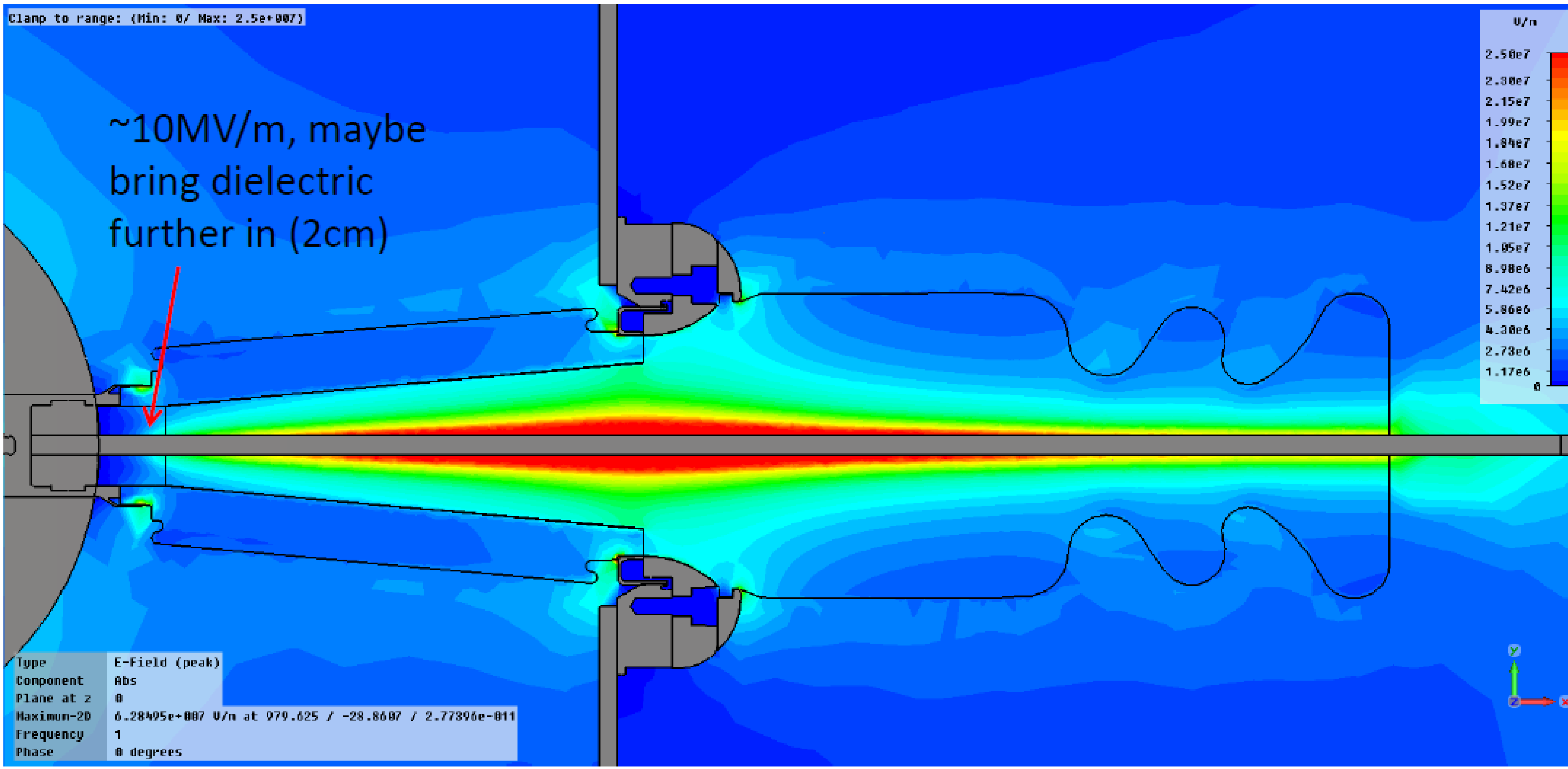


Learn to apply high voltage without breakdown, dielectric plug inside insulator,
Then address the field emission problems inside the gun

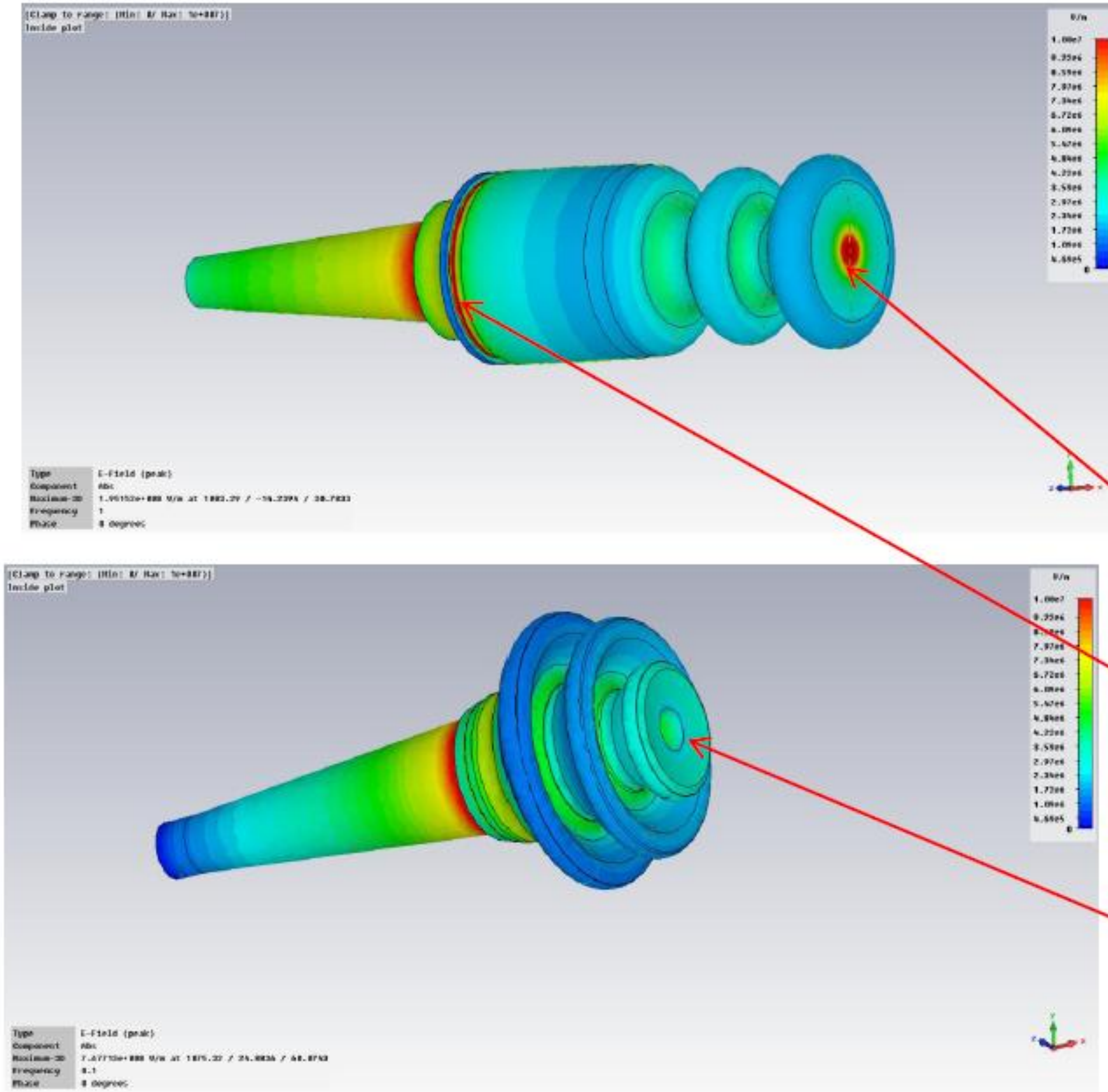
Electrostatic Modeling



Electrostatic Modeling



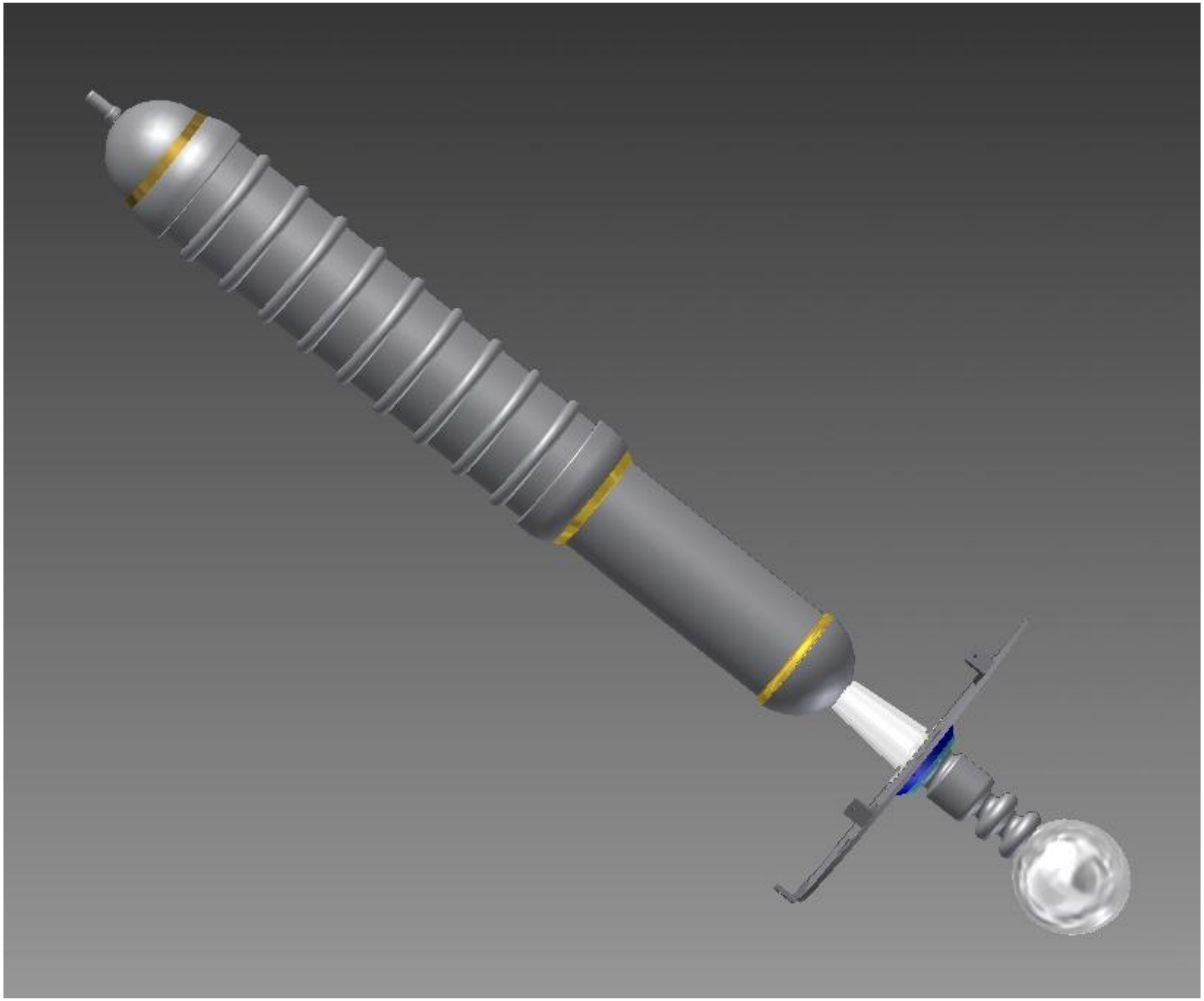
Electrostatic Modeling



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

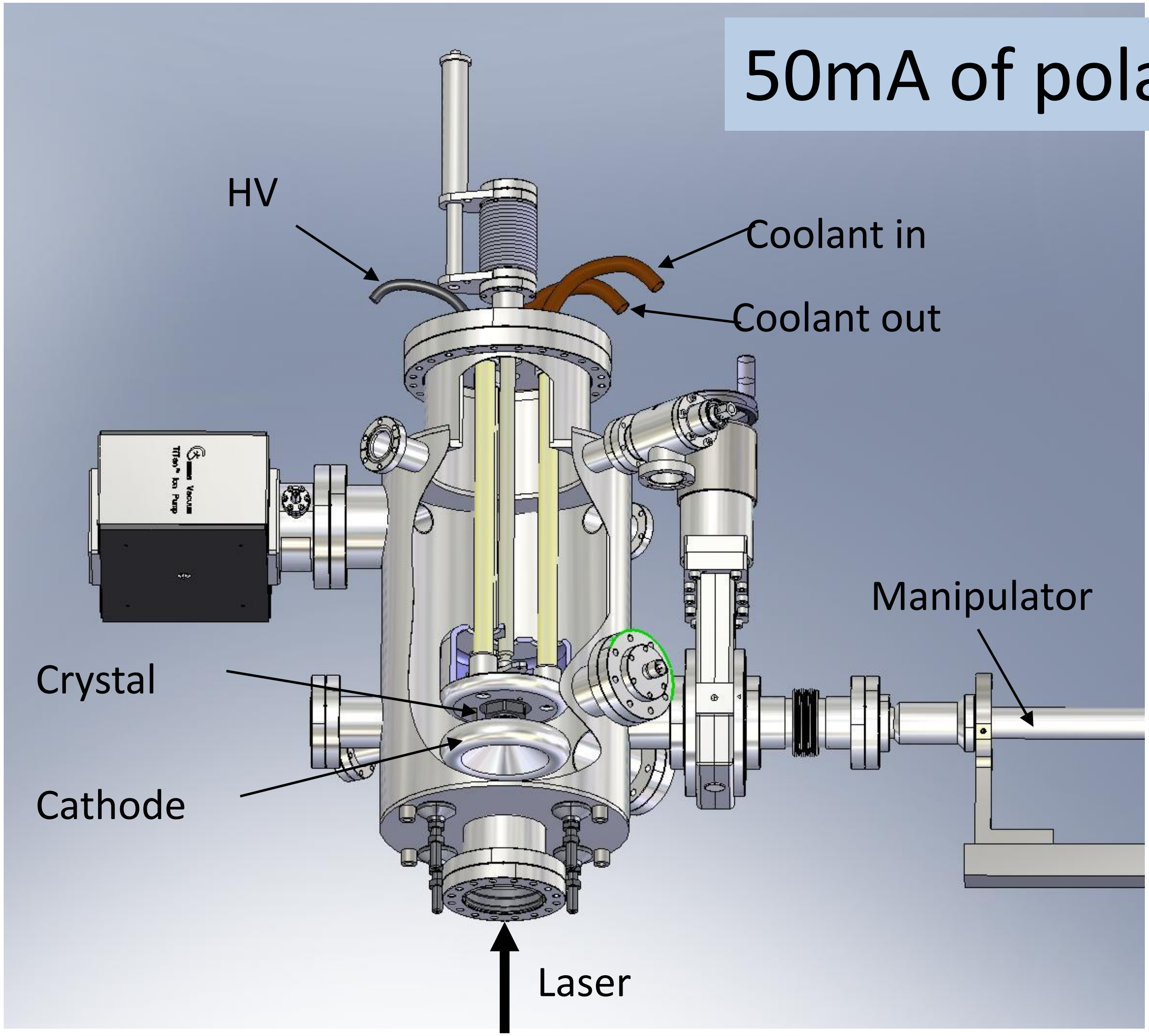
Dielectric is curved, and the placement/shape of the HV connection is different. For FEL I tried to 'shield' triple points.

What the heck is this?



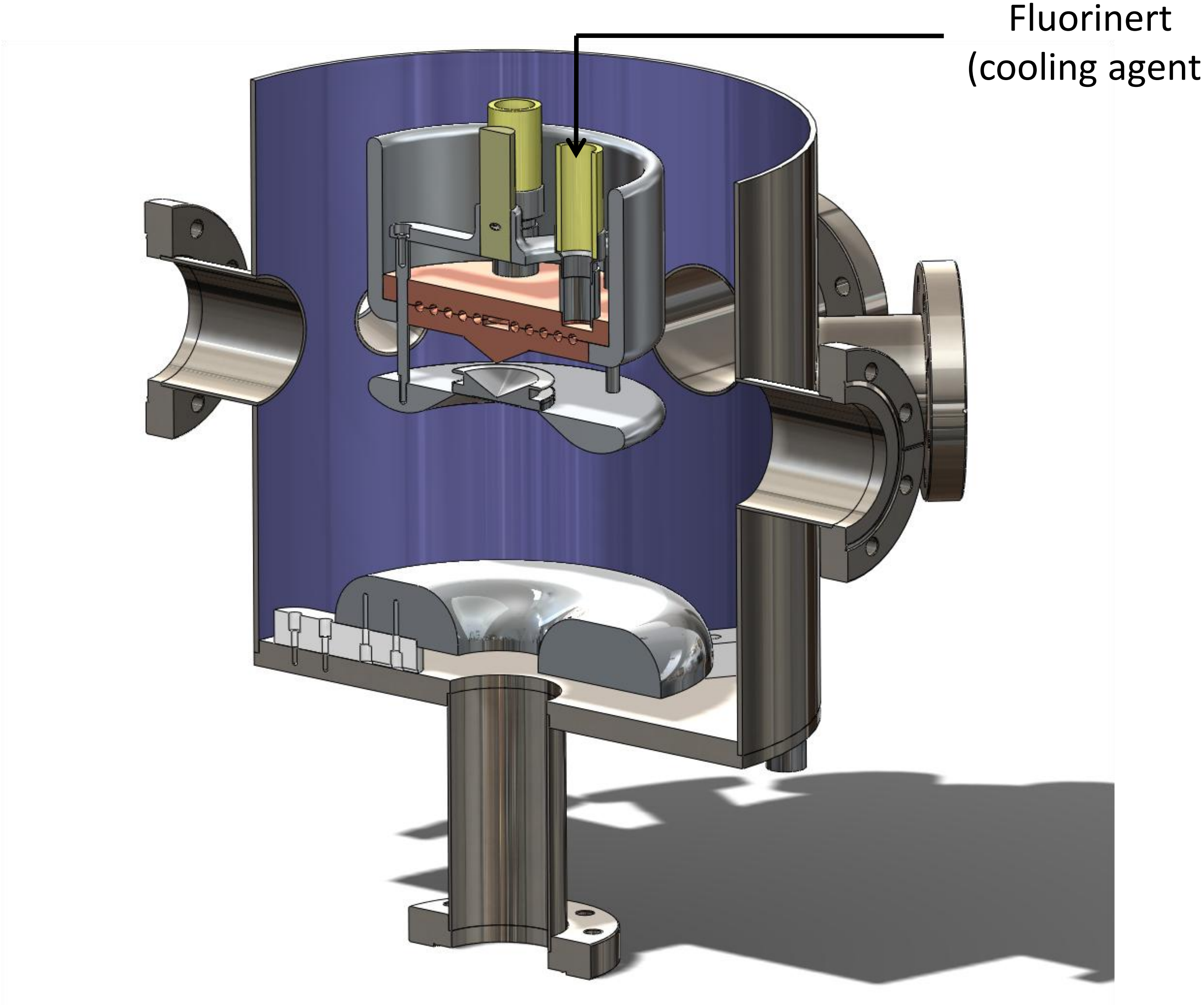
MIT-Bates eRHIC Polarized e-Source

50mA of polarized beam



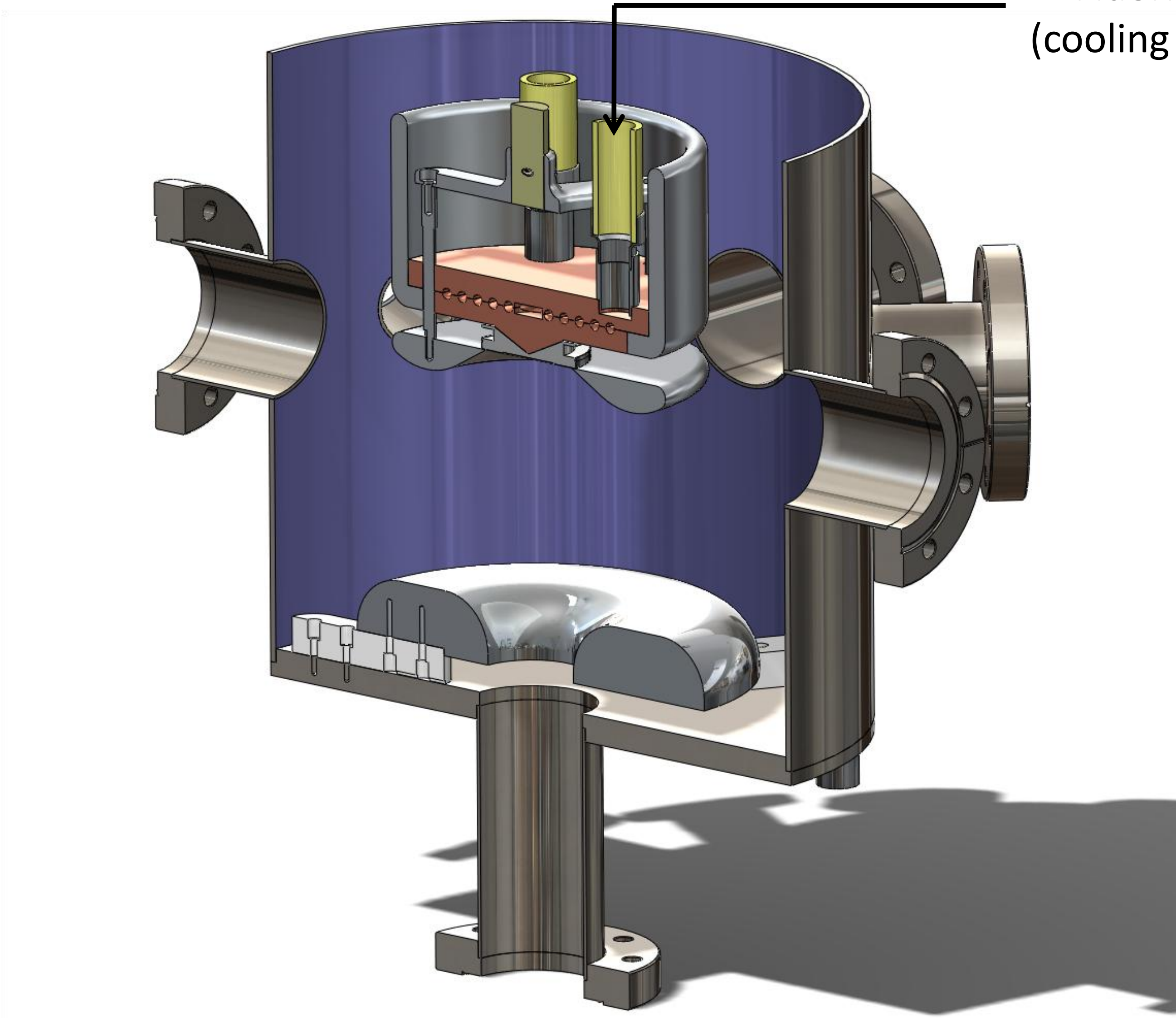
Courtesy Evgeni Tsentalovich, MIT Bates

Cathode – anode assembly



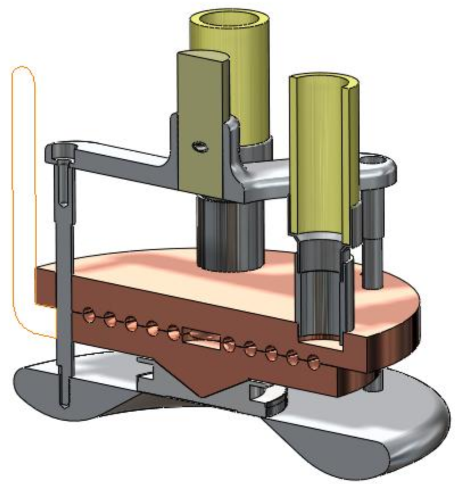
Courtesy Evgeni Tsentalovich, MIT Bates

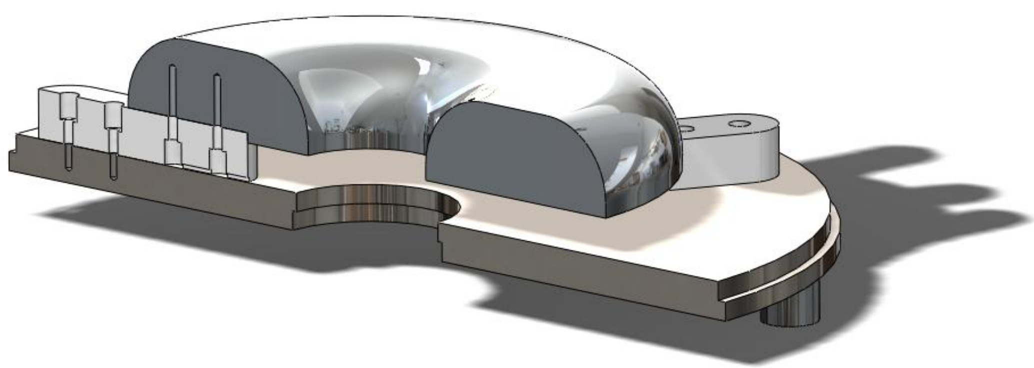
Cathode – anode assembly



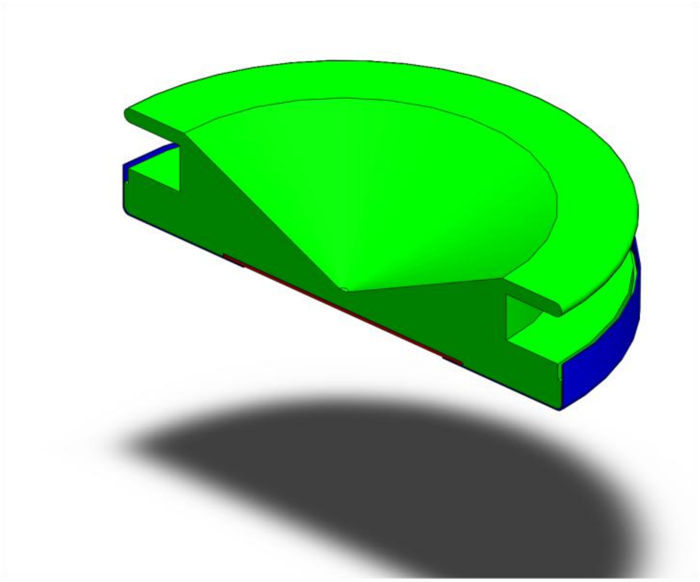
Courtesy Evgeni Tsentalovich, MIT Bates

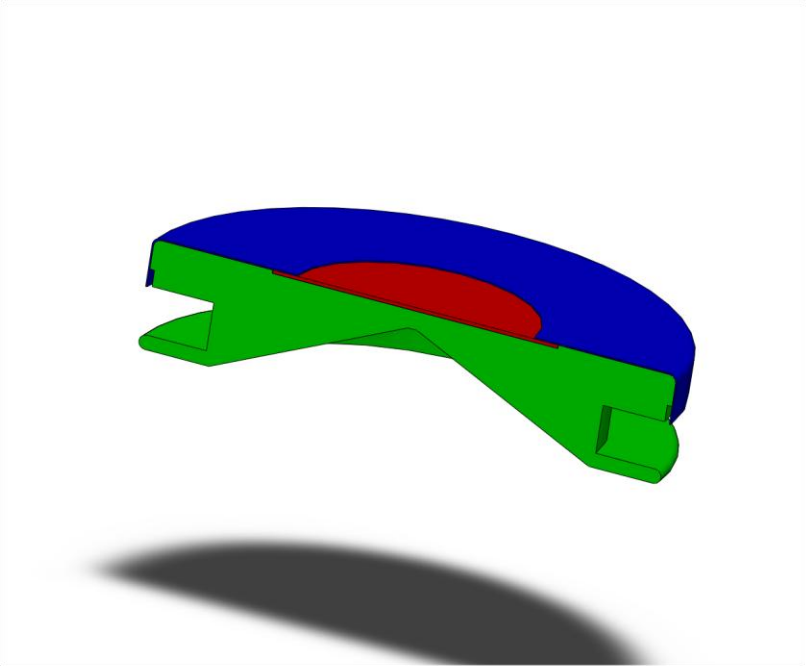
Cathode – anode assembly

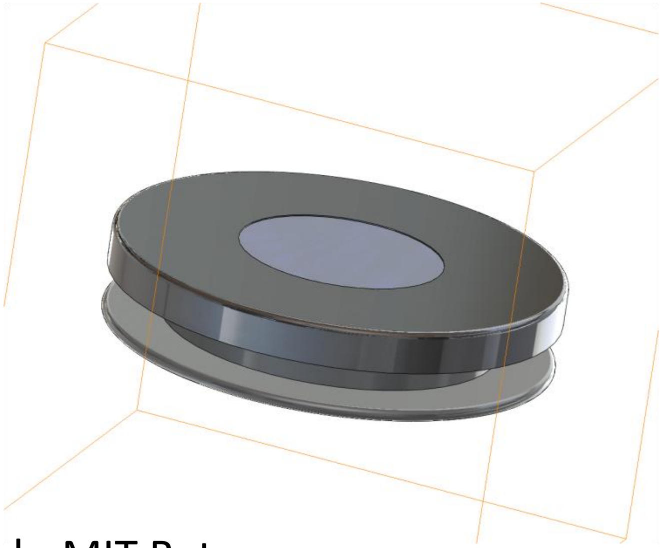




Pack with a crystal

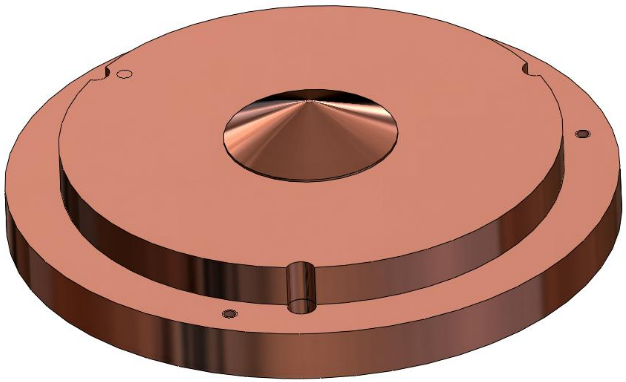


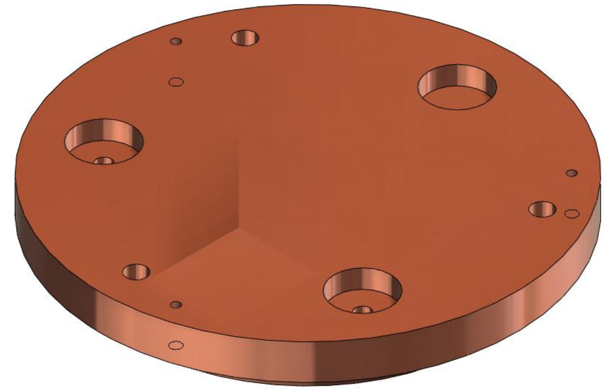


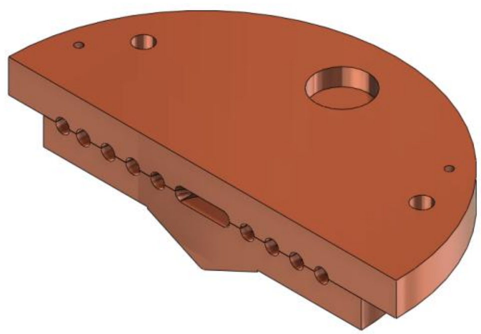


Courtesy Evgeni Tsentalovich, MIT Bates

Heat exchanger

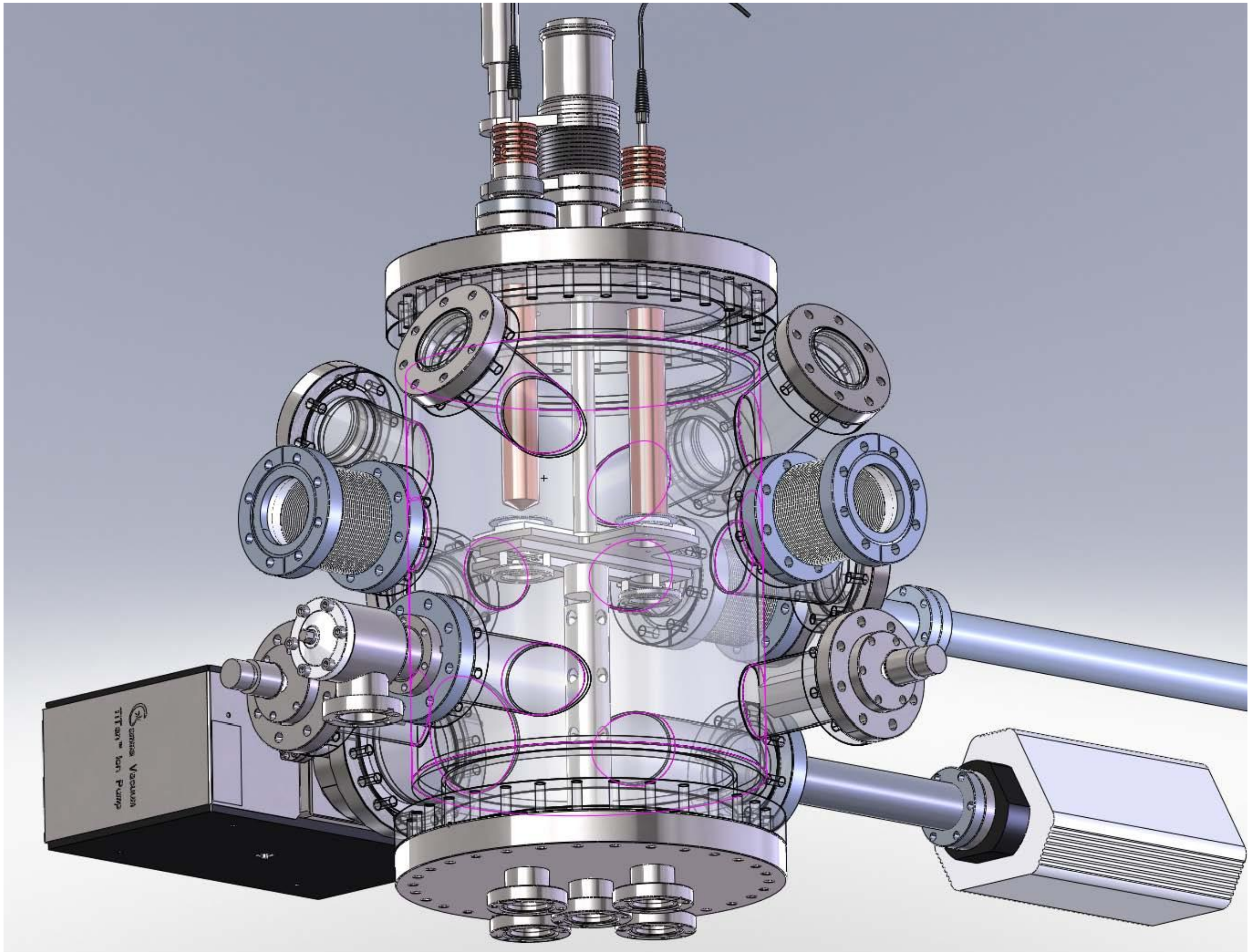






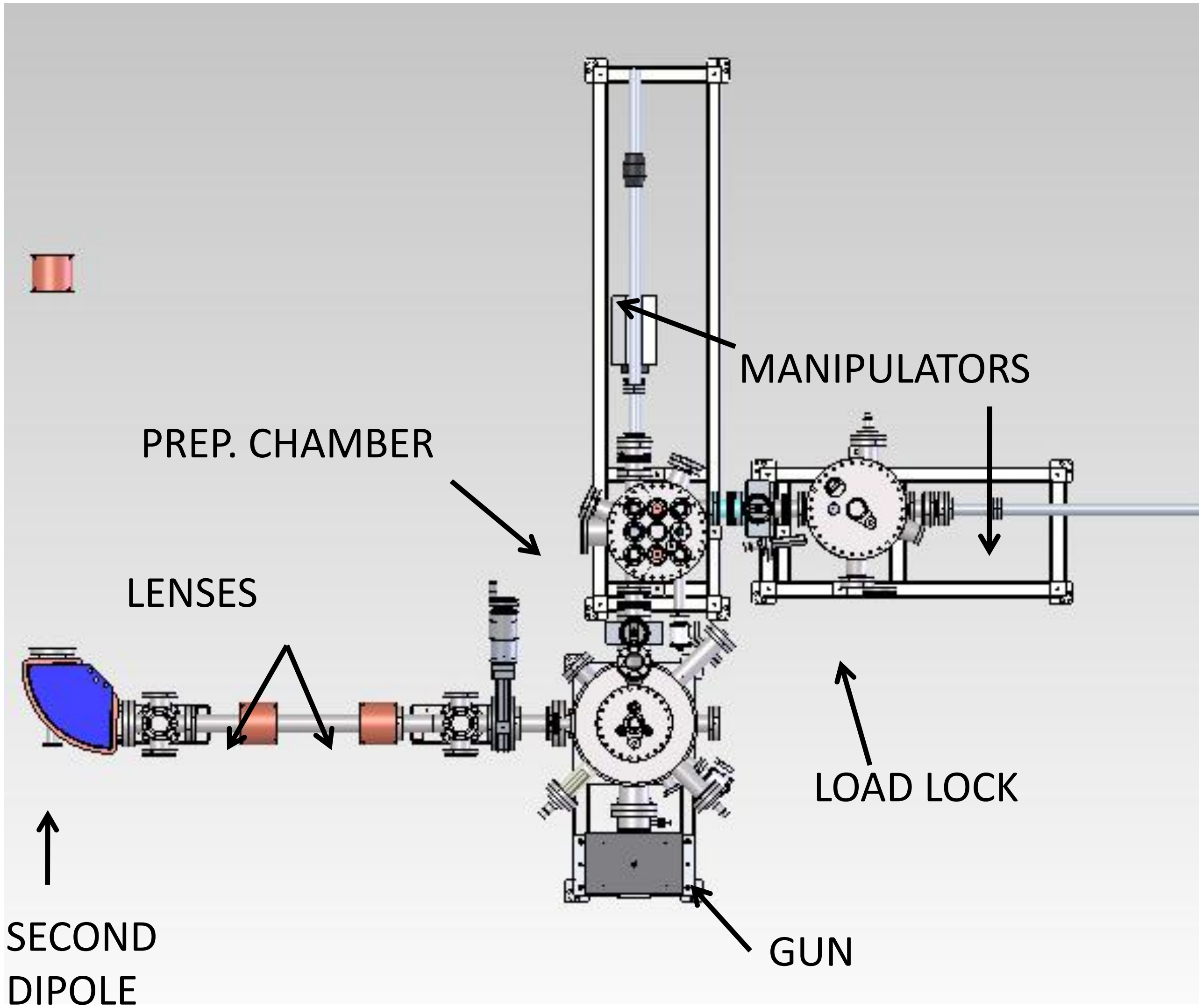
Courtesy Evgeni Tsentalovich, MIT Bates

Preparation chamber



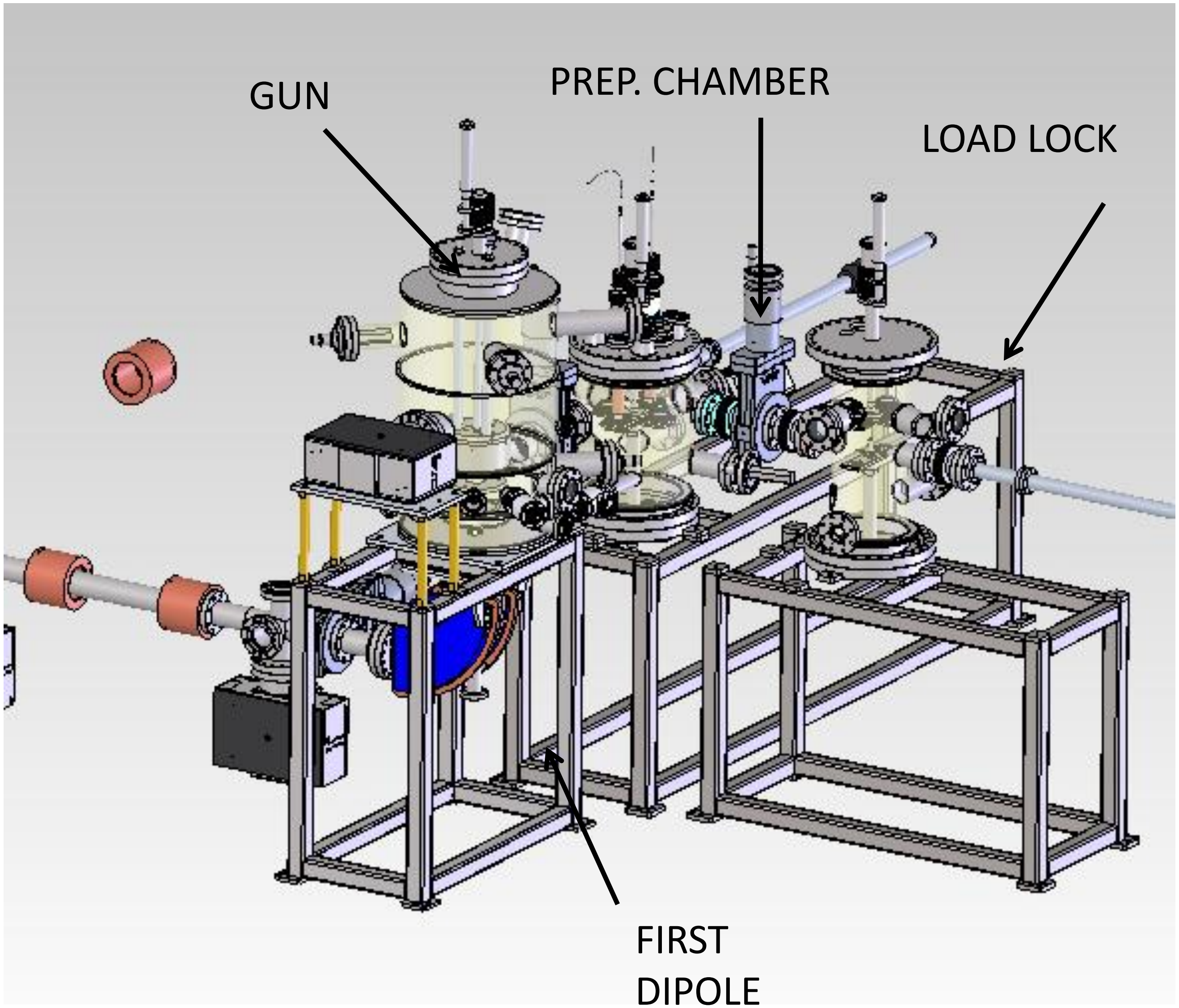
Courtesy Evgeni Tsentalovich, MIT Bates

General assembly – top view

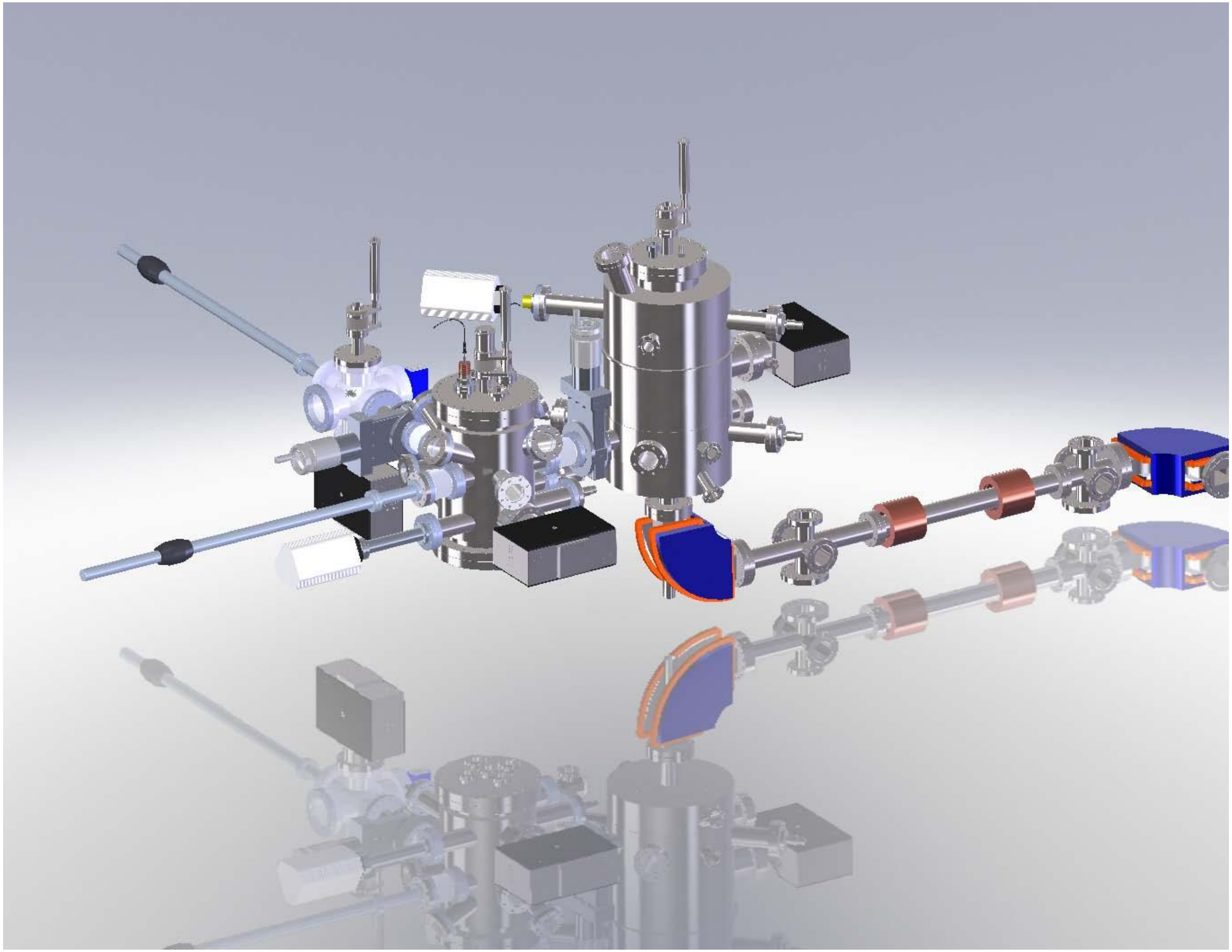


Courtesy Evgeni Tsentalovich, MIT Bates

General assembly – top view



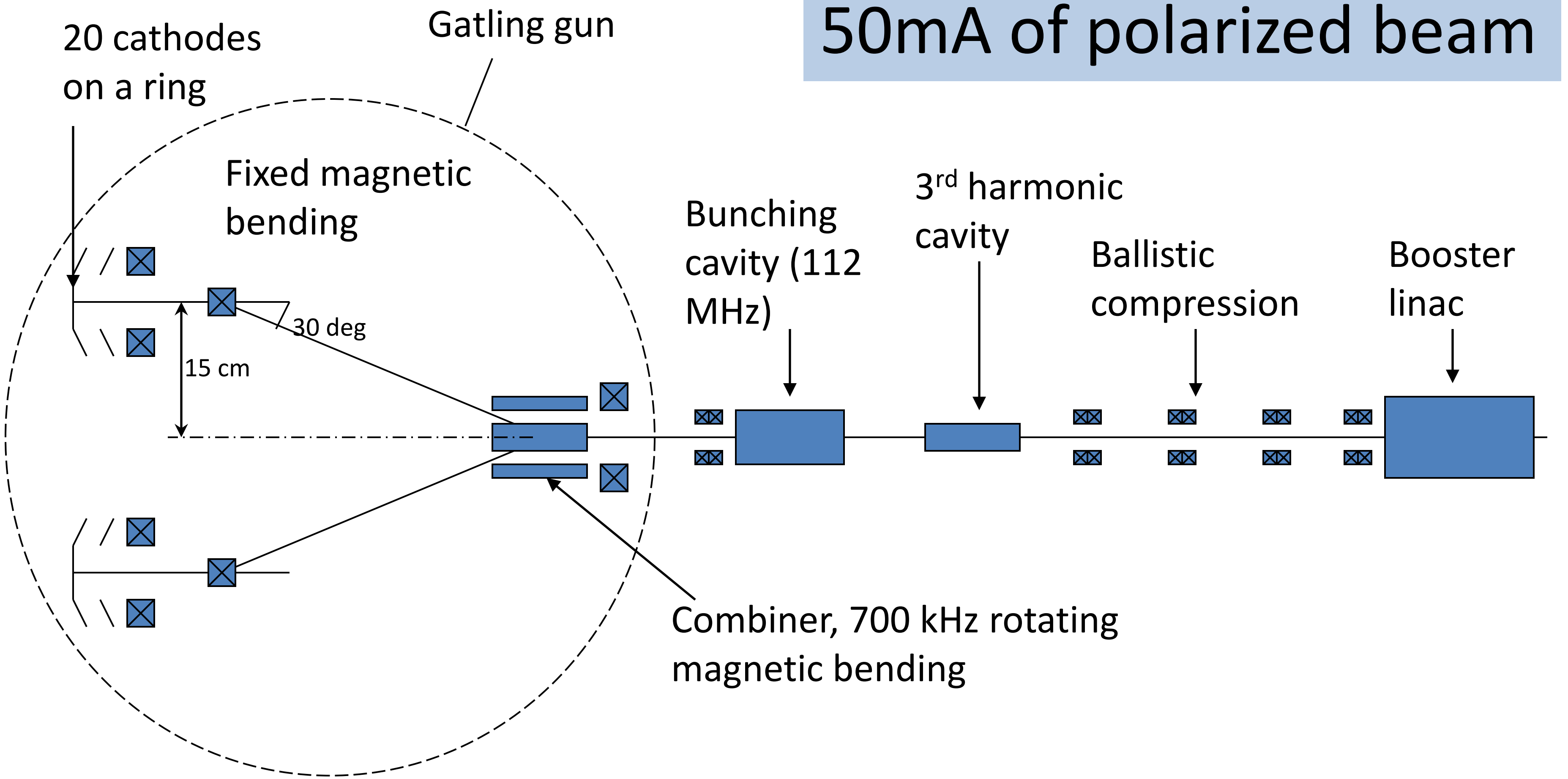
Courtesy Evgeni Tsentalovich, MIT Bates



Courtesy Evgeni Tsentalovich, MIT Bates

BNL eRHIC "Gatling gun"

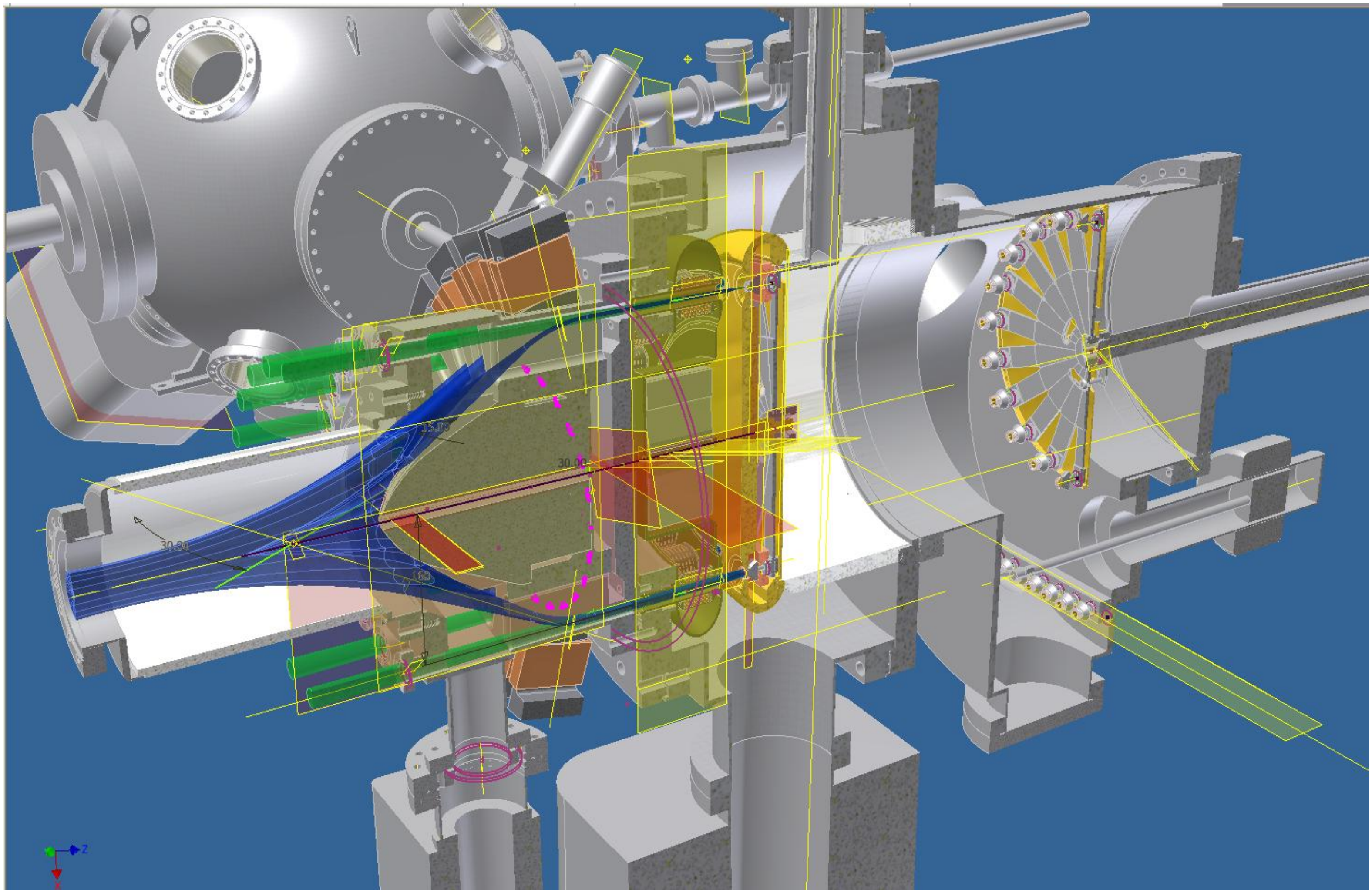
50mA of polarized beam



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

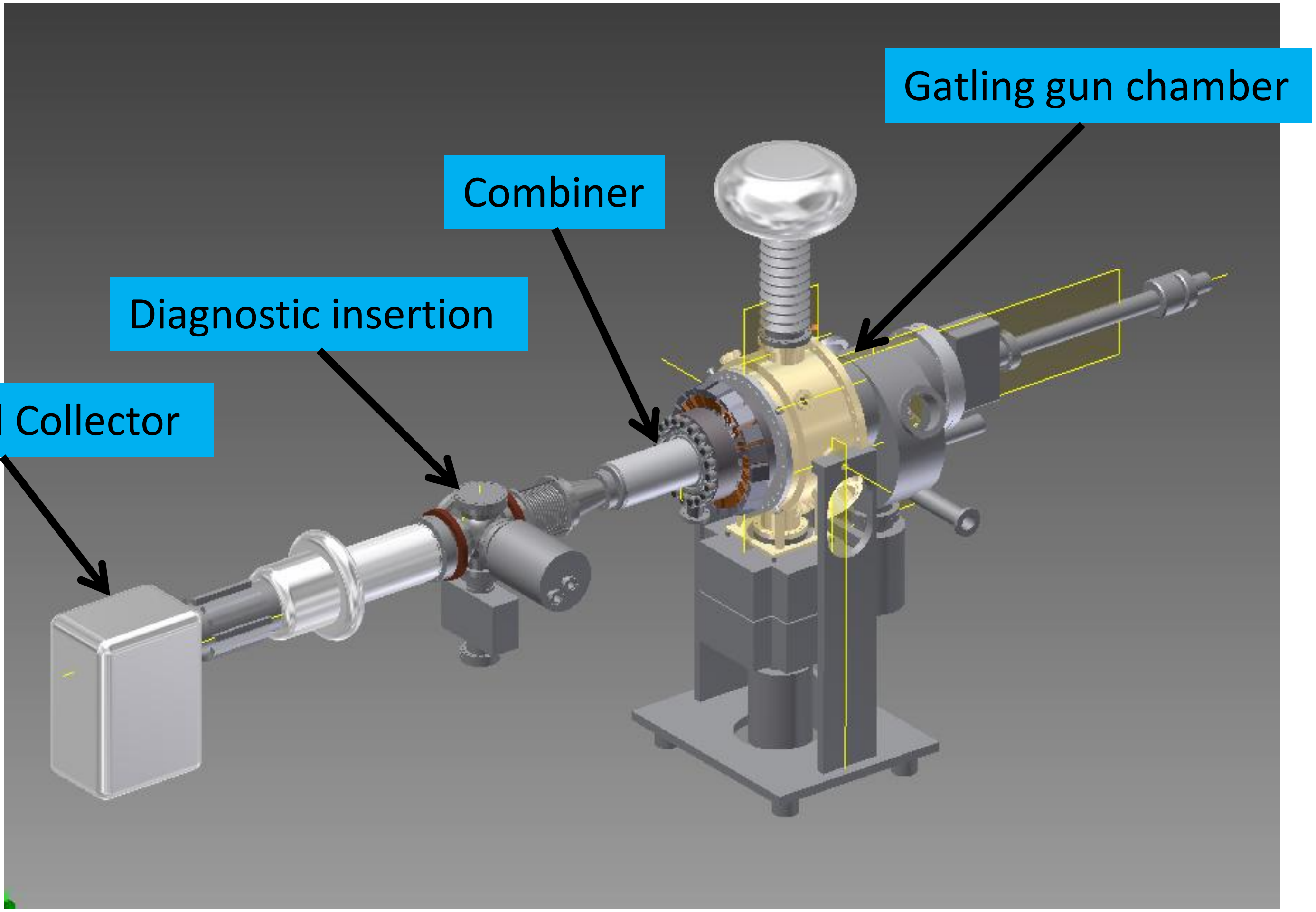
BNL "Gatling gun"



Green indicates Laser, Blue indicates electron beam paths

Courtesy X. Chang, BNL

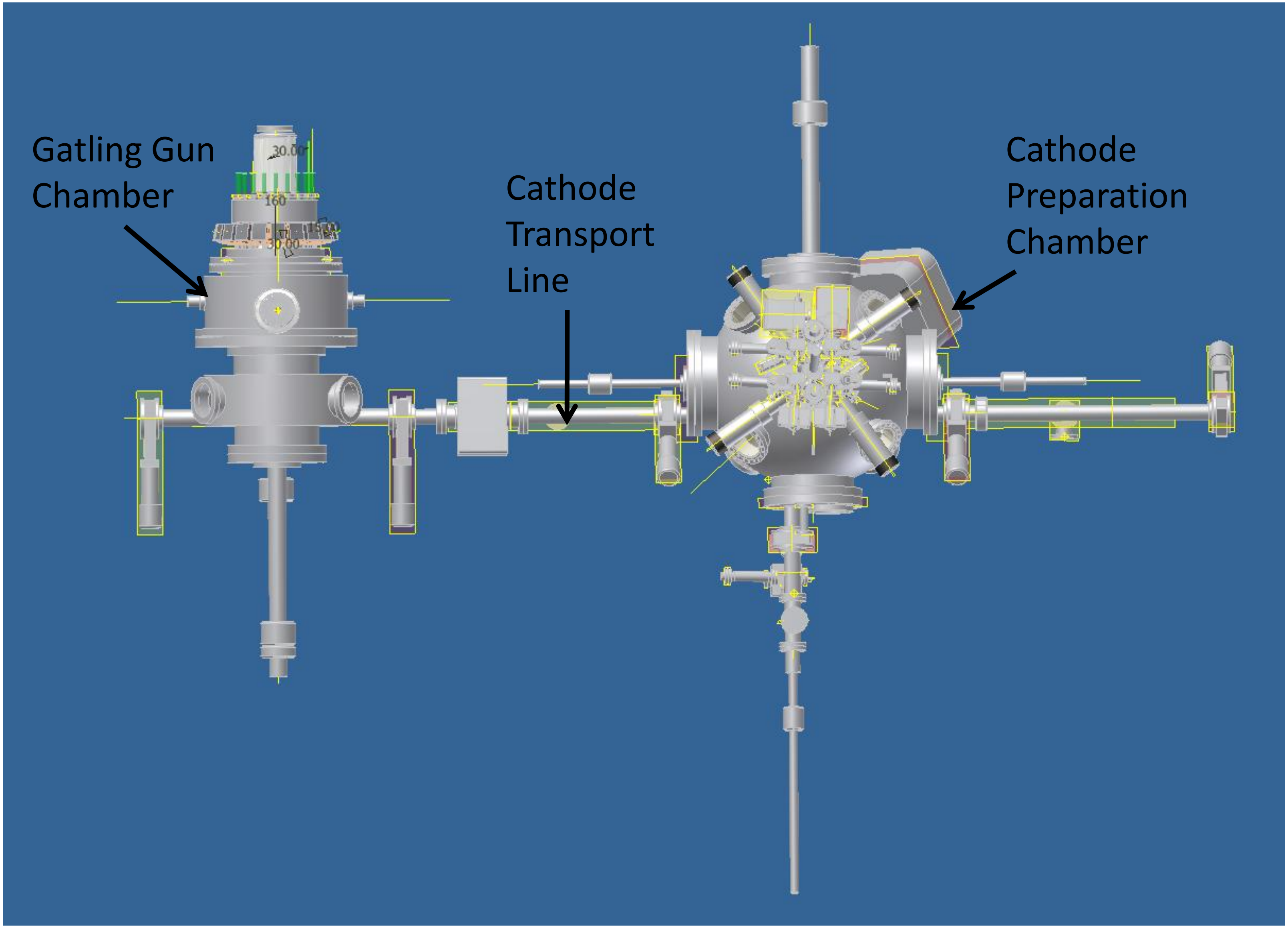
BNL "Gatling gun"



Depressed Collector can reduce the HV power supply current, reduce radiation.

Courtesy X. Chang, BNL

BNL “Gatling gun”



Courtesy X. Chang, BNL