FEL Gun Test Stand (GTS)

from construction to beam operations

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for the FEL team

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Outline

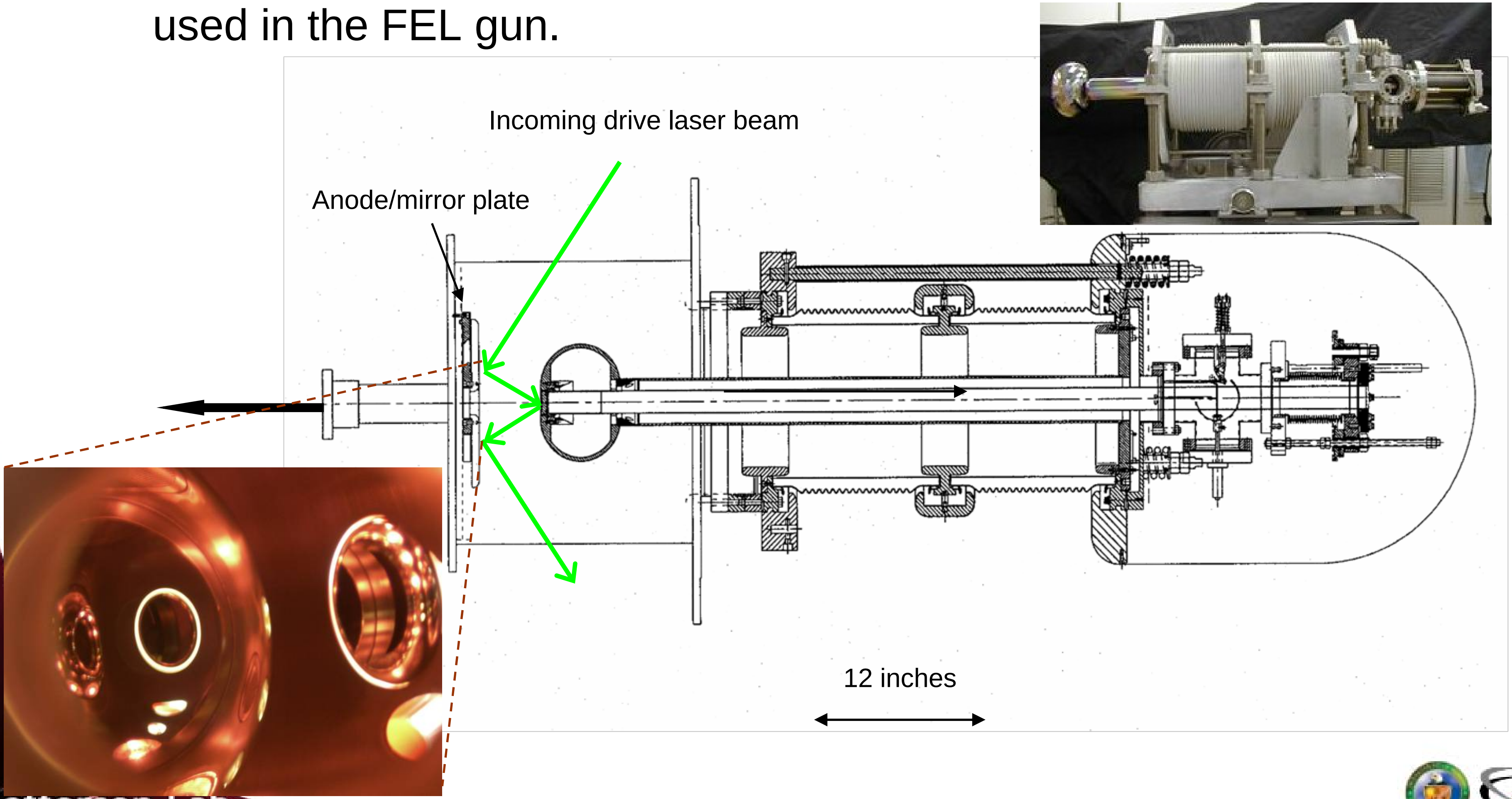
- The DC photocathode gun
- The enclosure and all other systems (HVPS, drive laser, beam line, instrumentation and control, etc…)
- Putting all the pieces together…at the same time
- Commissioning and operations
- Finally, electron beam!...but Surface Charge Limit comes along

The FEL Gun Test Stand (GTS) housing a copy of the Upgrade FEL DC photocathode gun has been built for

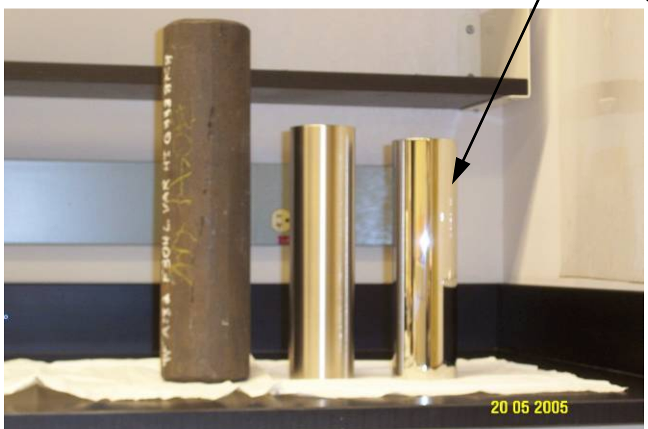
- Testing gun high voltage performance with coated electrodes for field emission suppression
- Dedicated operations for electron beam characterization at high charge
- Characterizing photocathode lifetime with improved methods and materials for better vacuum conditions
- A semi-load lock system for increased productivity during cathode change-out and for testing different cathode materials

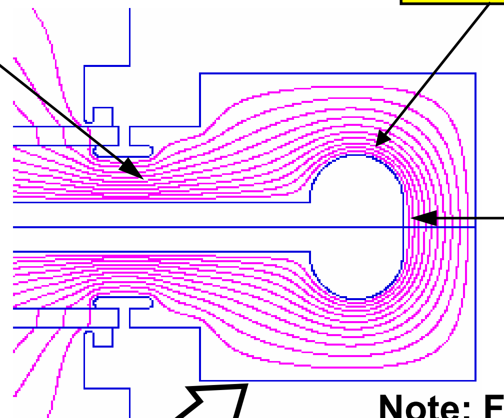
The FEL and the GTS guns are identical in design and dimensions except for two features:

1. The anode plate in the GTS gun is used as a mirror for reflecting off the drive laser and illuminating the photocathode at a 40 degree angle, instead of a mirror further downstream inside the beam line used in the FEL gun.

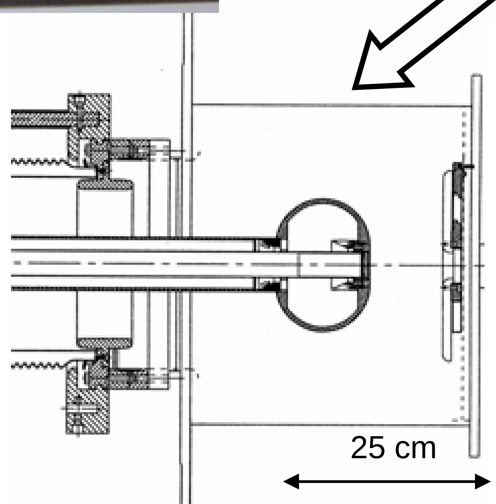


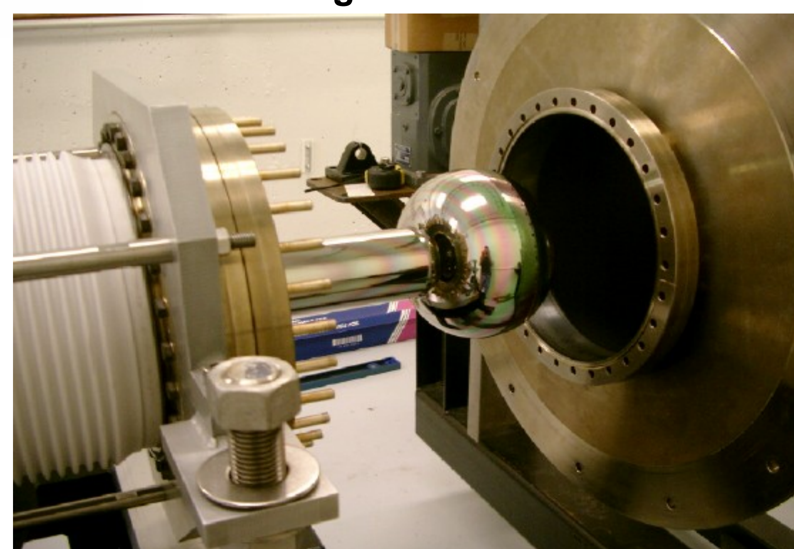
2. The electrodes in the GTS gun are coated with a field emission suppression film. The support tube electrode starts as a single block of cross-forged, vacuum arc re-melt stainless steel. Then it is machined, hand-polished, cleaned and plasma-sputtering coated



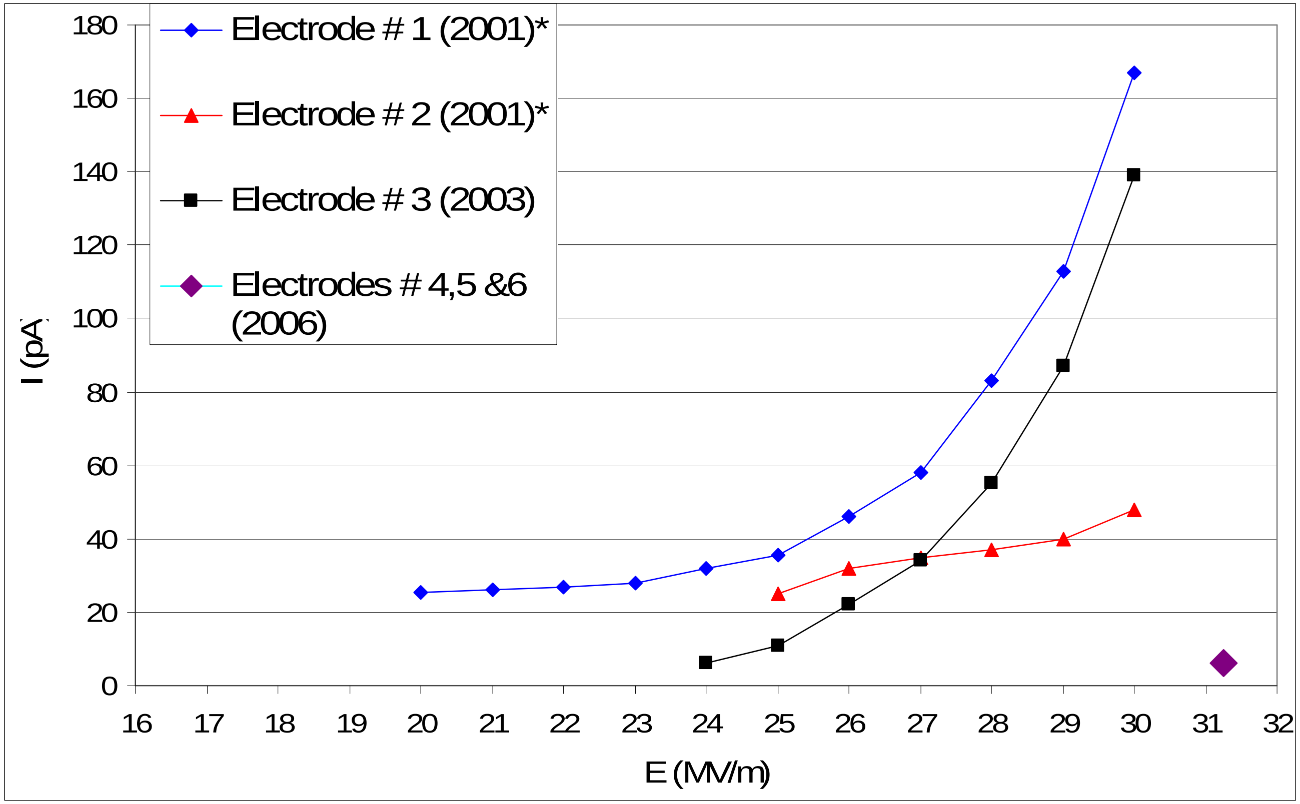


Note: Field strengths calculated for 500 kV





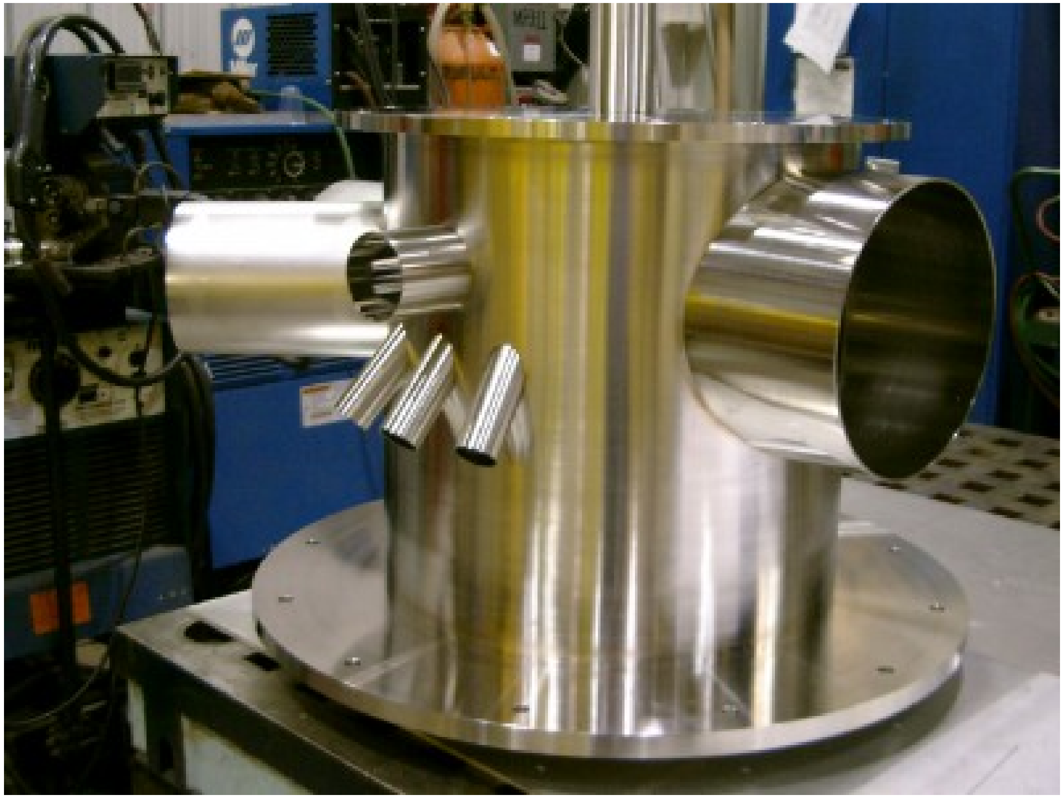
SiOxNy films§ have demonstrated field emission suppression by more than 5 orders of magnitude compared to bare polished stainless steel electrodes (27 µA at 16 MV/m)*



§ N. D. Theodore et al., IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 34, NO. 4, AUGUST 2006, pp 1074-1079.

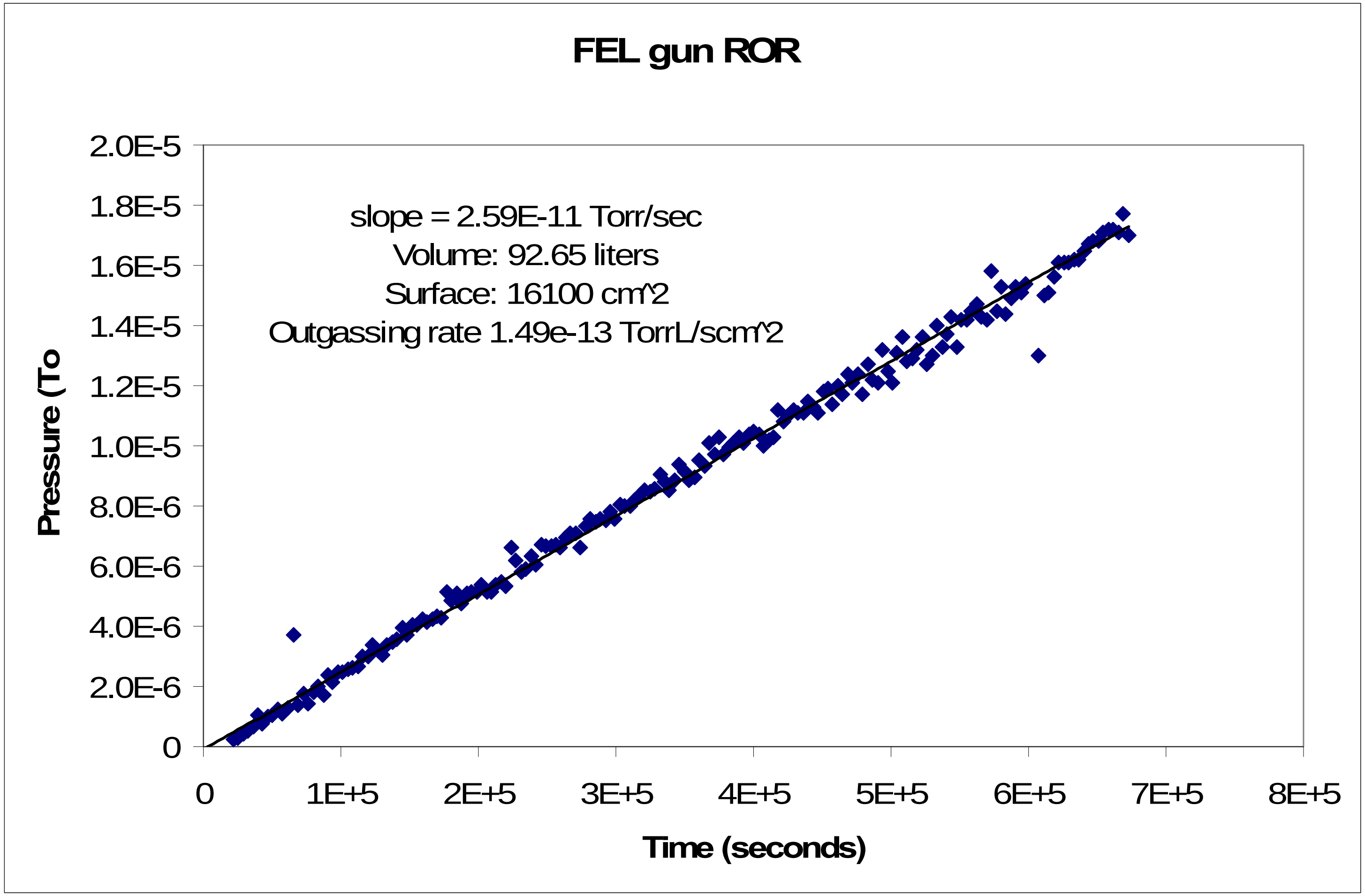
* C. Sinclair et al., Proceedings of the 2001 Particle Accelerator Conference, Chichago, pp.

The latest version of the gun chamber was machined out from a single ‘bead’ of vacuum arc re-melt, cross forged 316 LN Stainless Steel for low out-gassing rate



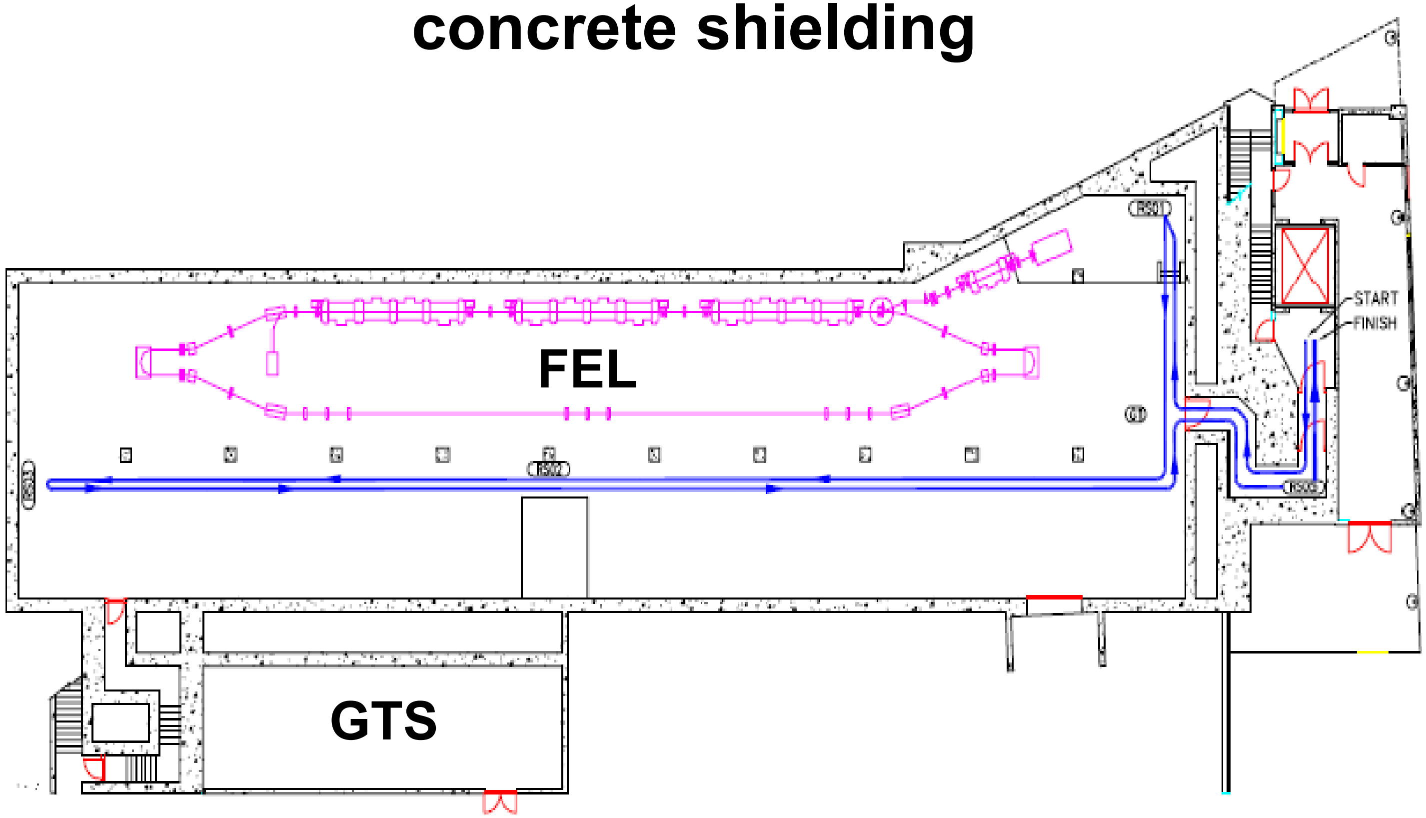
The chamber was vacuum fired in-house at 400 Celsius for 160 hours to desorb hydrogen from the walls

Phil Adderley and Marcy Stutzman reported the lowest Hydrogen out-gassing rate ever to be measured at JLab after the vacuum firing



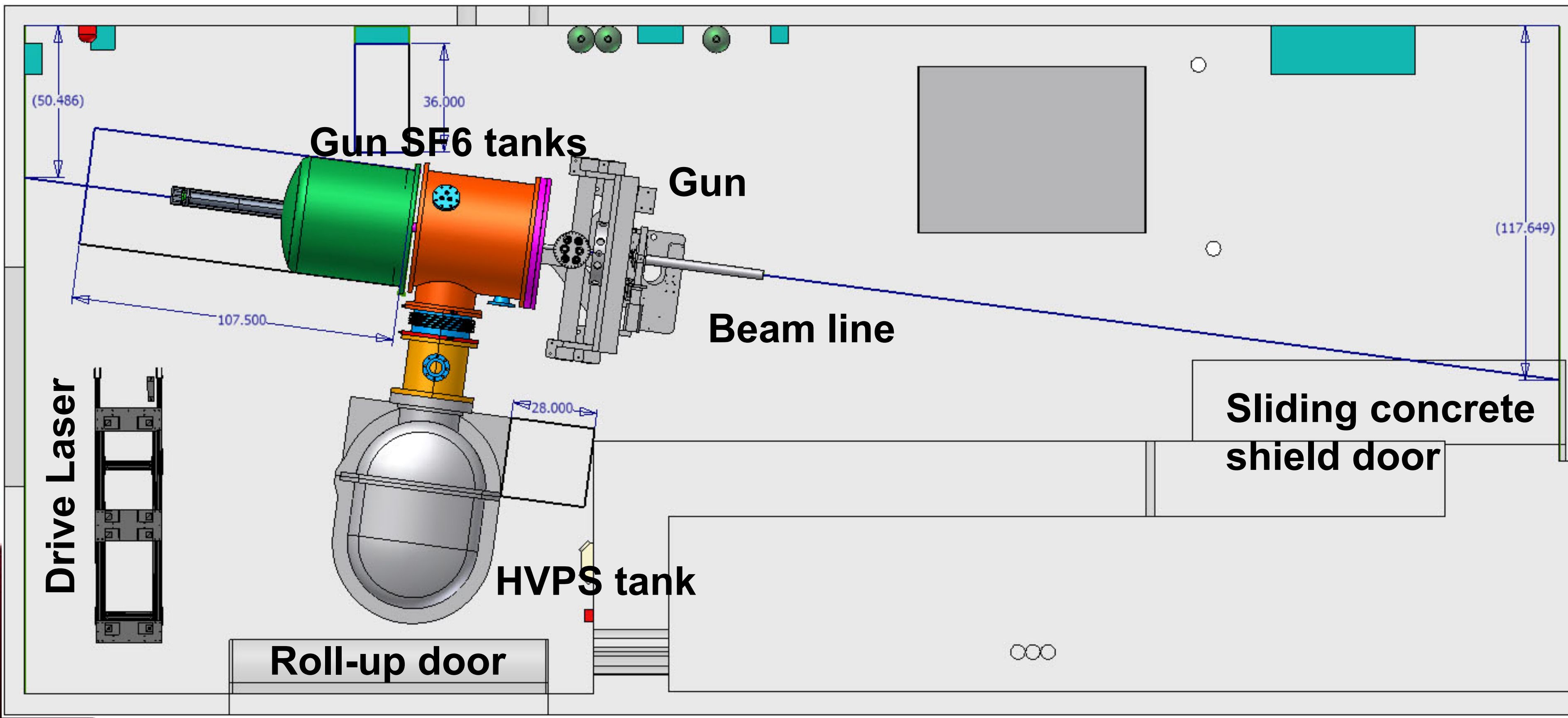
The gun assembly was done in a clean room over the ARC building. It was transported to the GTS in September 2006 and attached to a temporary vacuum chamber


The GTS enclosure was built from the FEL mechanical and HVAC room adjacent to the vault by adding concrete shielding



FEL FACILITY SWEEP DIAGRAM

The GTS enclosure, which had to be fitted with PSS/LPSS, lighting, electrical power, LCW, Nitrogen lines, is not very large…



… and filled up very quickly with the gun, the HVPS tanks, the drive laser, the beam line, and everything else that had to be installed in parallel with the gun attachment to its final vacuum chamber inside a clean room

‘Some’ rigging and ingenuity were in order to bring the high voltage power supply tank, the gun, and the rest of the equipment into the GTS thorough the roll-up door

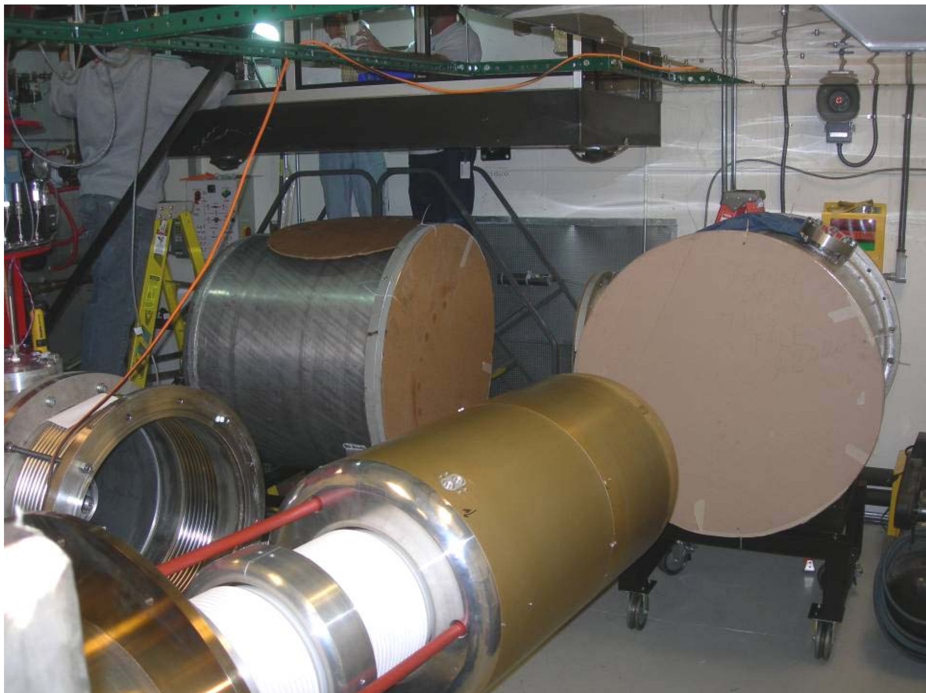
The old IR Demo 500 kV, 5 mA DC high voltage power supply (HVPS) was refurbished and re-assembled in the GTS for powering up the gun


Ferrari 308 GTS

Note: any resemblance in color is mere coincidence

The gun SF6 tanks were made in-house. Great accomplishment for the JLab machine shop achieving the aluminum welding certification

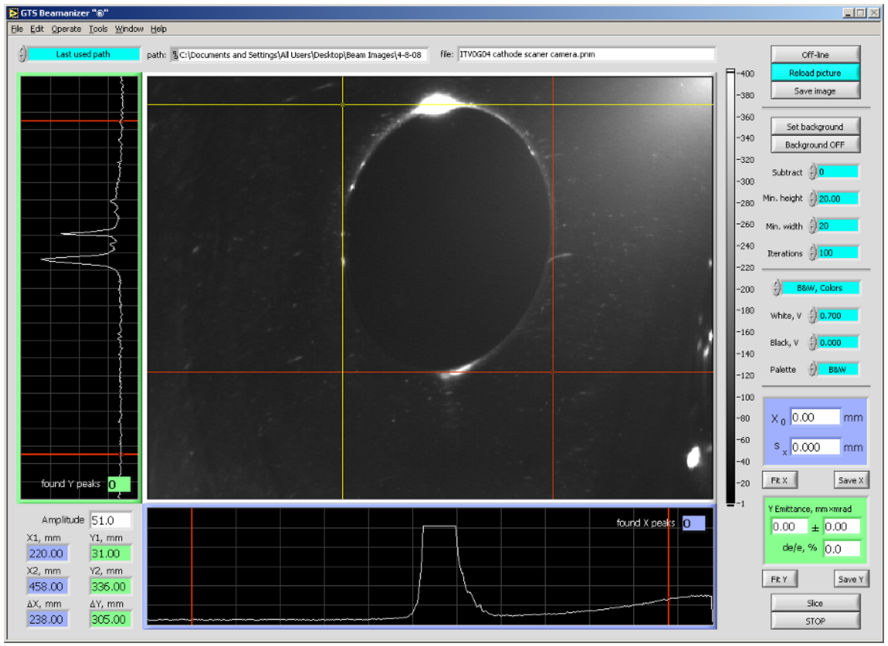
The Drive Laser table had to be hung up from the ceiling to provide more room for the gun tanks…and the people working around the gun



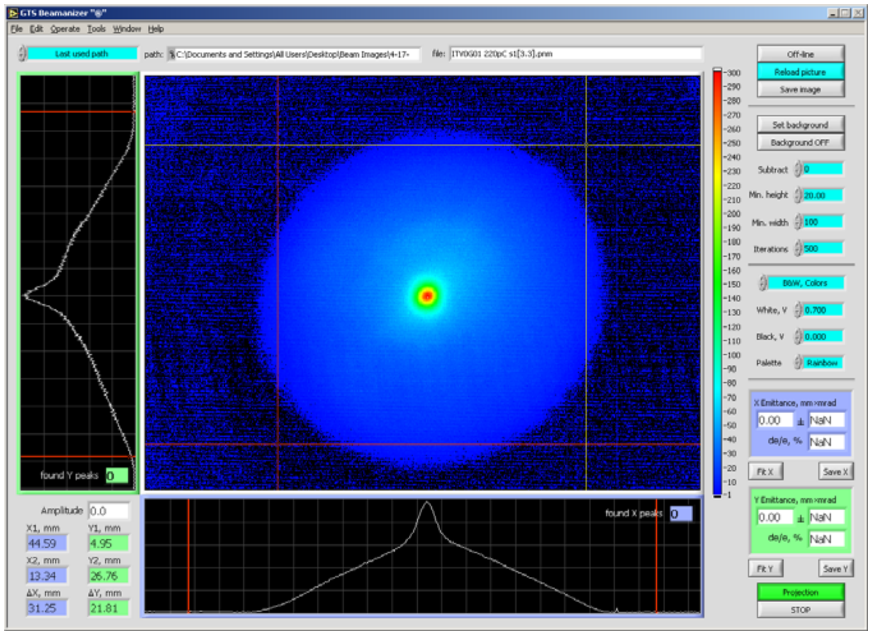
A new transfer system for moving the SF6 from the gun and HVPS to the storage bag was designed and built with pneumatic valves and electronic controls

The Personnel Safety System/Laser Personnel Safety System and all of the Instrumentation and Controls were customized for the GTS

Cameras and viewers were installed and with specially developed software provided excellent images of the cathode, the electron beam and the laser spot

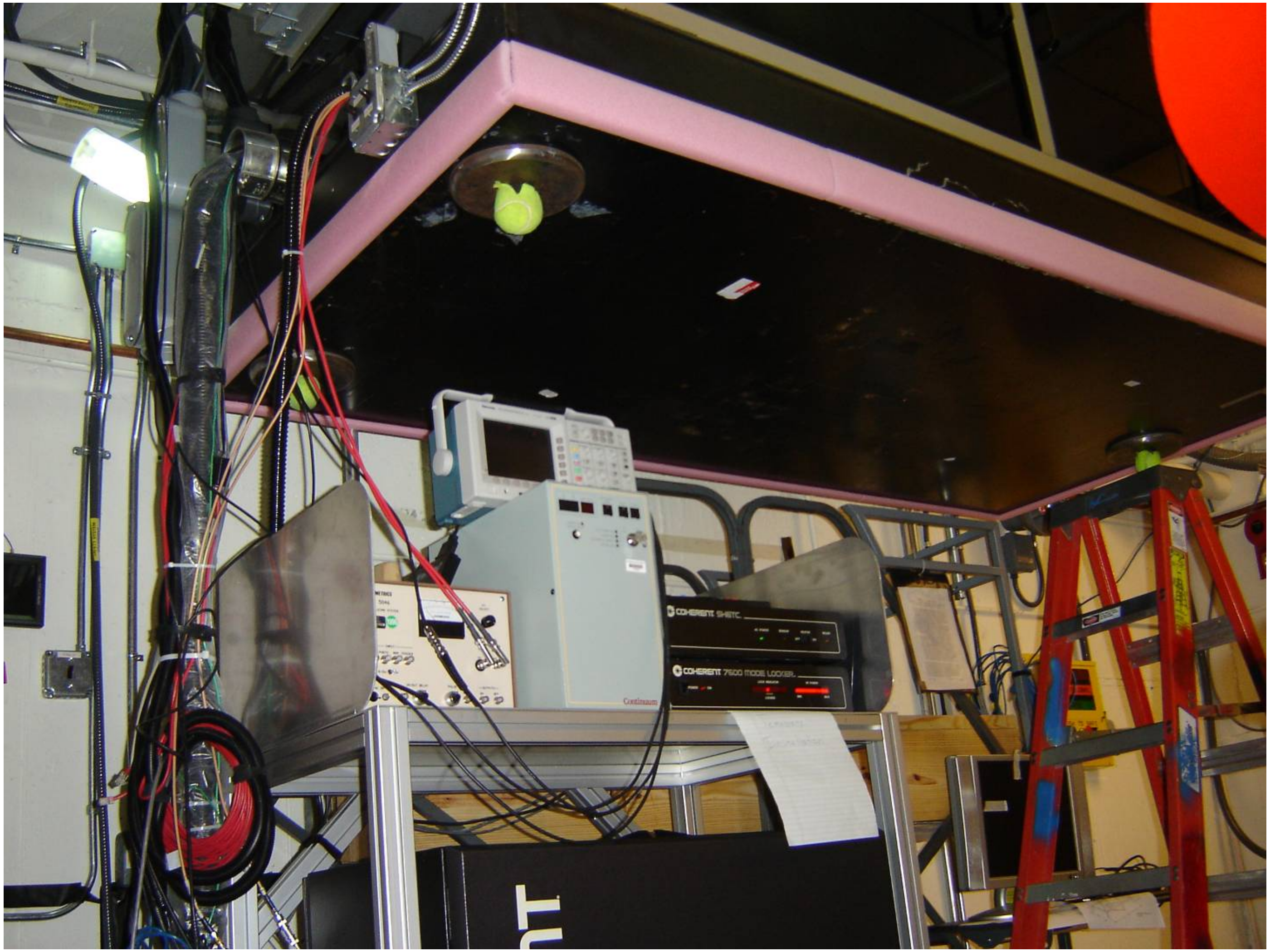


Picture of the 25 inch diameter GaAs wafer

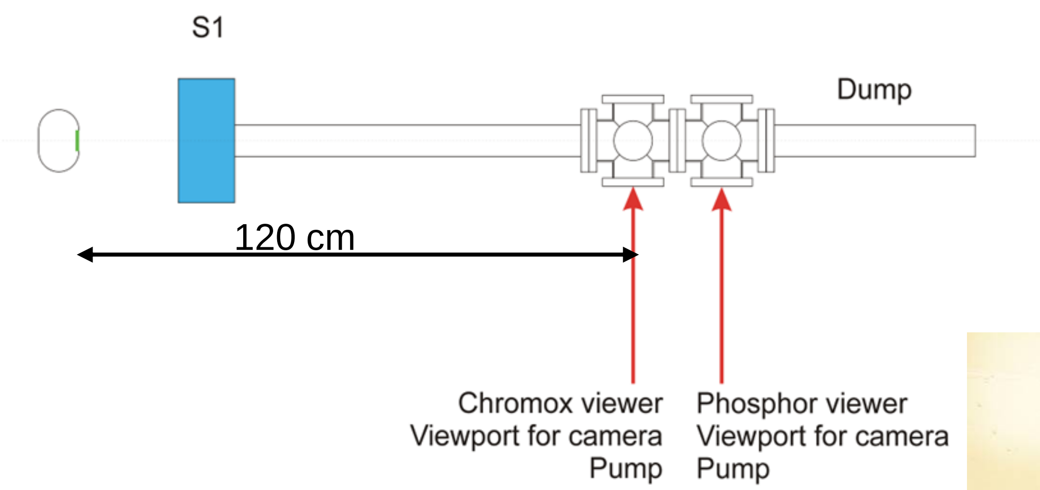


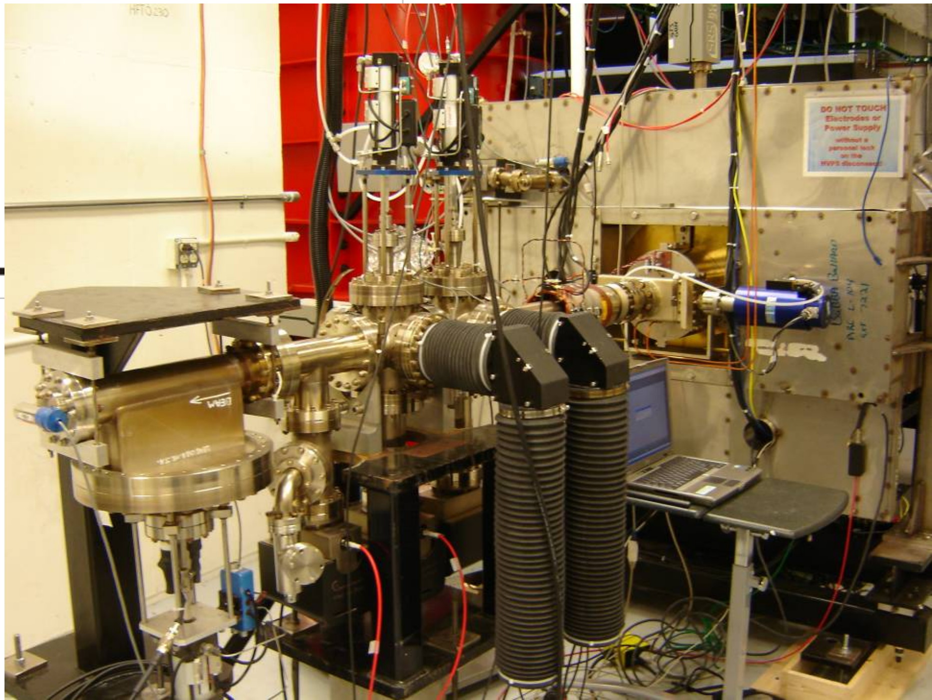
Electron beam image on a viewer screen

The FEL Antares drive laser was modified, installed, commissioned and finally operated for producing electron beam



The beam line is very basic now, but will be improved with multi-slits and a kicker cavity for longitudinal beam profile measurements





Before commissioning

- Performed Hazard Analysis (Radiation, ODH, EHS&Q, etc)
- Wrote Operating Safety Procedure
- Each system owner wrote Standard Operating Procedures (Drive Laser, SF6 transfer system, HVPS, PSS/LPSS, Concrete shield door, etc)
- Performed hot checkout of all systems

Drive Laser commissioning

- Mounting optical table on ceiling
- Designing and installing laser hutch with HEPA filter
- Installing electrical power and water cooling for the power supply
- Design and installation of transport system
- Due to 40 degree angle of incidence on cathode, the transport system was designed to produce a flat wave front at the cathode surface
- Plenty of energy per pulse, about 100 micro-Joules
- LPSS had to be fully functional before drive laser commissioning

High voltage conditioning

Date	Event
12/06/2007	Started HV operations, achieved 85 kV
12/07/2007	Started 3-shift operations **with marvelous staffing response from the FEL team**, achieved 130 kV
02/01/2008	Achieved 485 kV, punched-through ceramic insulator
02/08/2008	Fixed leak but re-opened at 485 kV
02/28/2008	Ensured gun performance at 460 kV. Declared HV conditioning done

– **It took 22 days, or 528 hours, to go from 130kV to 485kV, that's ~0.75 kV per hour**
– In contrast, the FEL gun took about 80 man-hours to condition to 420 kV with the slowest pace at 3 kV/hour
– Field emission suppression coating might have contributed to excessive gas desorption during high voltage conditioning compared to FEL bare electrodes
– Conditioning was slowed down by resistor breaking down, HVPS control chassis problems, PSS radiation detector malfunction, …

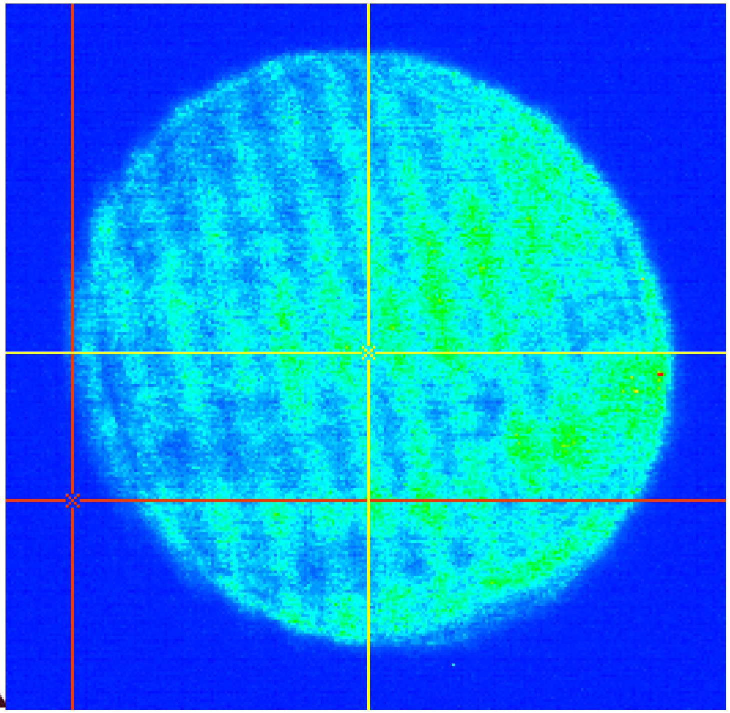
Operations

Date	Event
03/05/2008	First cathode ~ 2% QE but with very poor lifetime
03/13/2008	Conditioned cathode 250kV, first attempt for beam failed (magnet trim rack was off)
03/14/2008	First beam at 300kV, 110 pC with 1.5 μJ
03/24/2008	Beam at 325 kV, 150 pC with 25 μJ
03/26/2008	Beam at 350kV, 600 pC with 25 μJ of drive laser energy
04/01/2008	Second cathode ~ 5% QE
04/02/2008	Beam at 350kV, 600 pC with 0.5 μJ of drive laser energy
04/09/2008	Beam at 325kV, 1000pC with 2.5 μJ of drive laser energy (pico-amper-meter was clipping measurement at 600 pC)
05/06/2008	Third cathode, achieved 15% QE after realizing anode/mirror absorbs 50% of incident laser light

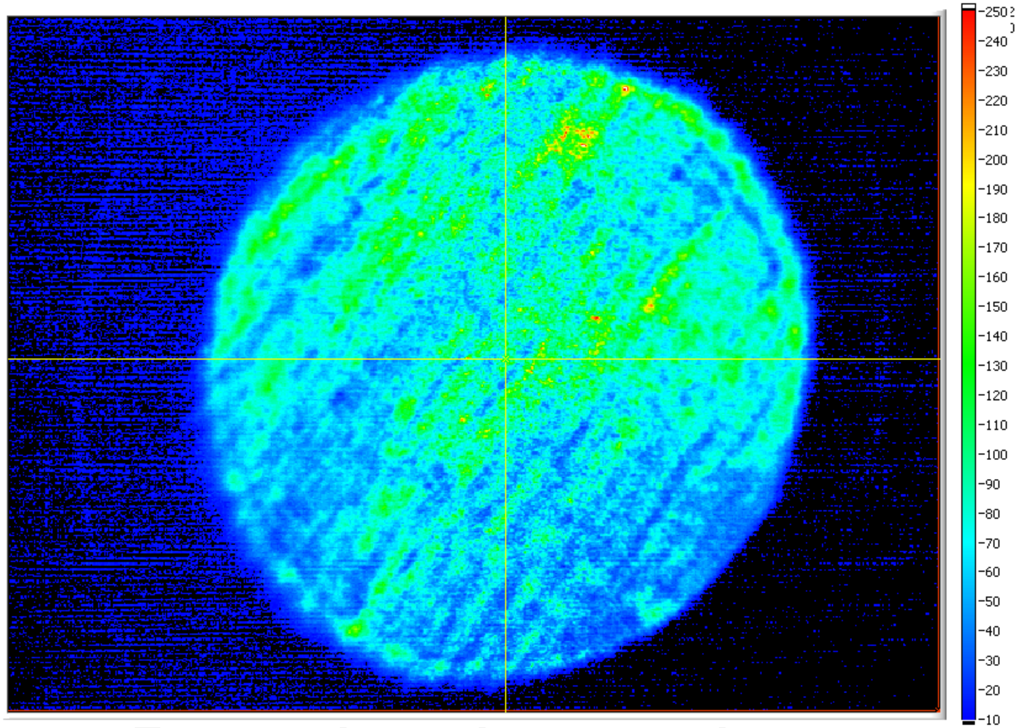
Got beam, but why all that laser energy per pulse to get it out from the cathode?

- If the cathode is 1% QE, then the energy per pulse needed to produce 1 nC is 0.25 μJ
- Even if QE is 0.1%, laser energy should only be 2.5 μJ
- But we needed 2.5 μJ instead with a 1% QE cathode!
- Are they QE measurements orders of magnitude off?

We checked the QE scanner measurements by mapping the cathode QE with the electron beam on a viewer. To eliminate space charge effect, the cathode was illuminated with a DC laser at very low fluence. QE measurements for both the DC and the scanner lasers were within 10% of each other

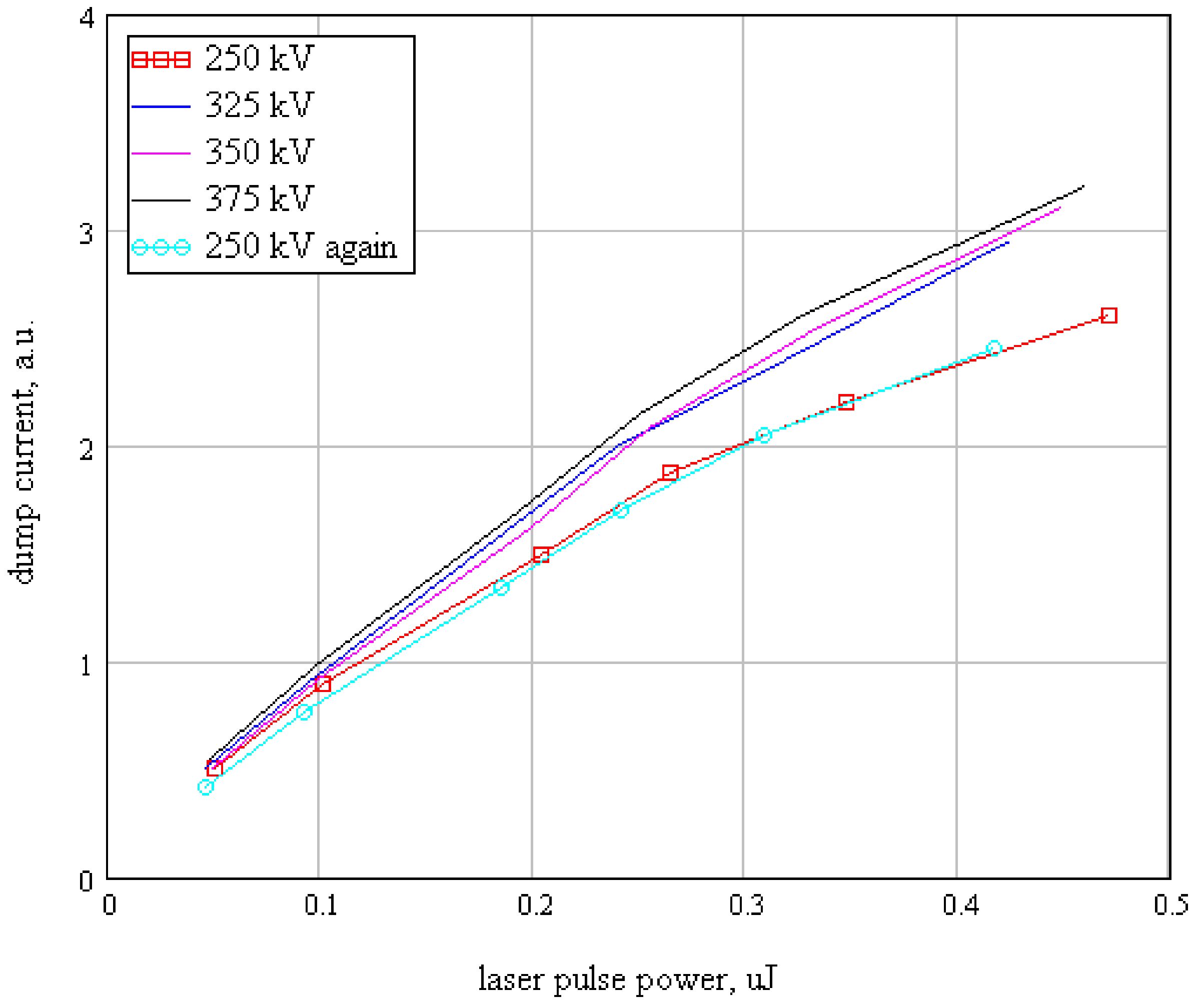


Picture of the laser beam spot on the cathode



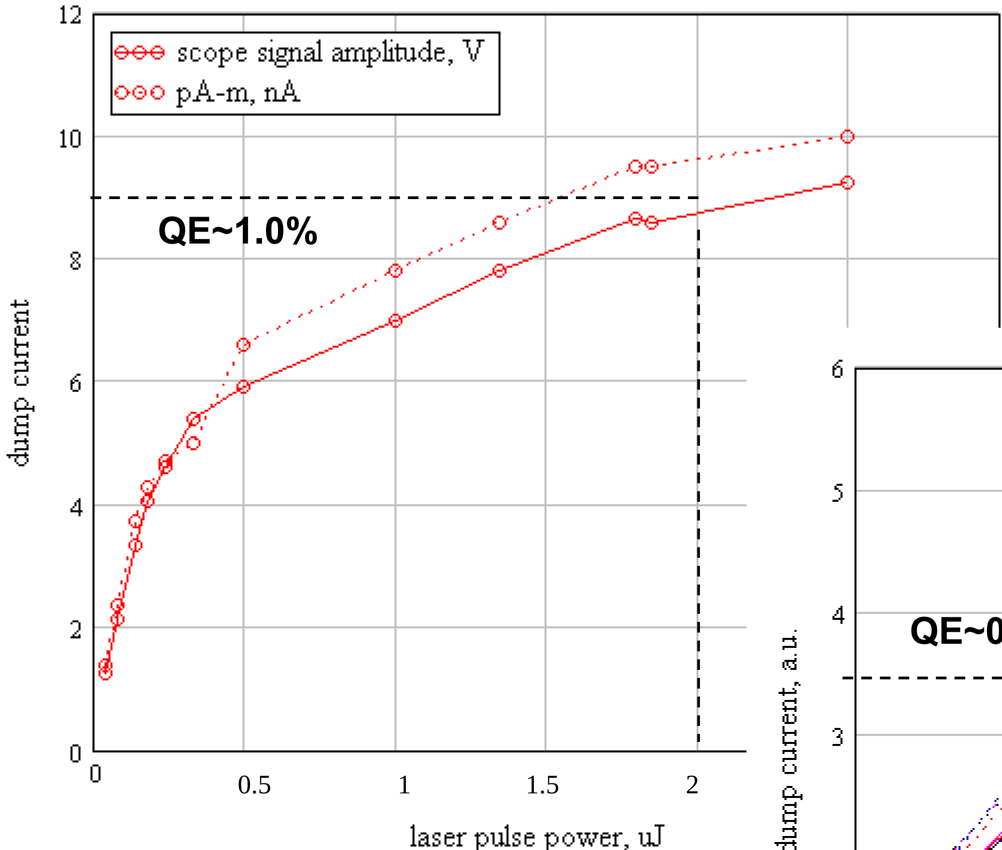
Electron beam image on the viewer screen mapping the laser beam spot on the cathode

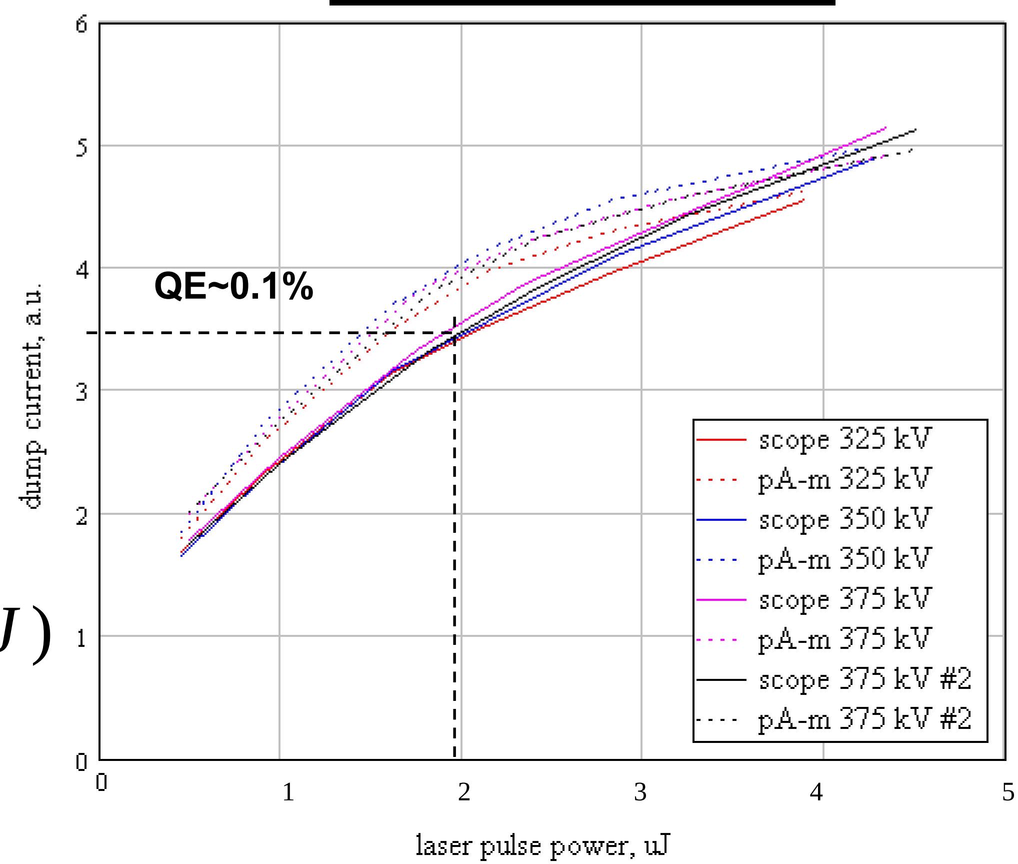
Is it space charge limit, $I=KV^{3/2}$?
No, there is no dependence on voltage over 250kV



But it is Surface Charge Limit

When the photocathode is excited with high densities of light (near the bandgap), the total photoemitted charge is **not proportional to the light intensity**





$$Q(nC) = \frac{QE(\%) \cdot \lambda}{124} \cdot E(\mu J)$$

Is there a way to lessen the SCL effect on GaAs photocathodes?

- We are preparing to take more data as a function of Quantum Efficiency

- The drive laser transport system is also being modified to change the spot size on the cathode and take data as a function of illuminated area

- Literature on surface charge limit suggest to increase the dopant density (nominal is Zn@10^{19}/cm$^{3)}$. This is something that could be tested once the semi-load-lock system is installed

Finally

- What was not accomplished
  - Improve vacuum conditions due to large leak on 14-inch flange
  - Install and operate semi-load-lock system
  - Install Brewster windows and Molybdenum anode plate with reflective coating for enhanced reflectivity
  - Operate gun at 500 kV due to punch-through ceramic leak at 485kV
  - Measure beam emittance and longitudinal profile

- What is next
  - Study SCL as a function of laser spot size and QE
  - Install and commission multi-slit and kicker cavity
  - Replace damaged ceramic with improved version (bulk resistivity)
  - Install and commission semi-load-lock system
  - Demonstrate reliable gun operation at 500kV
  - Study SCL on GaAs with higher dopant density???

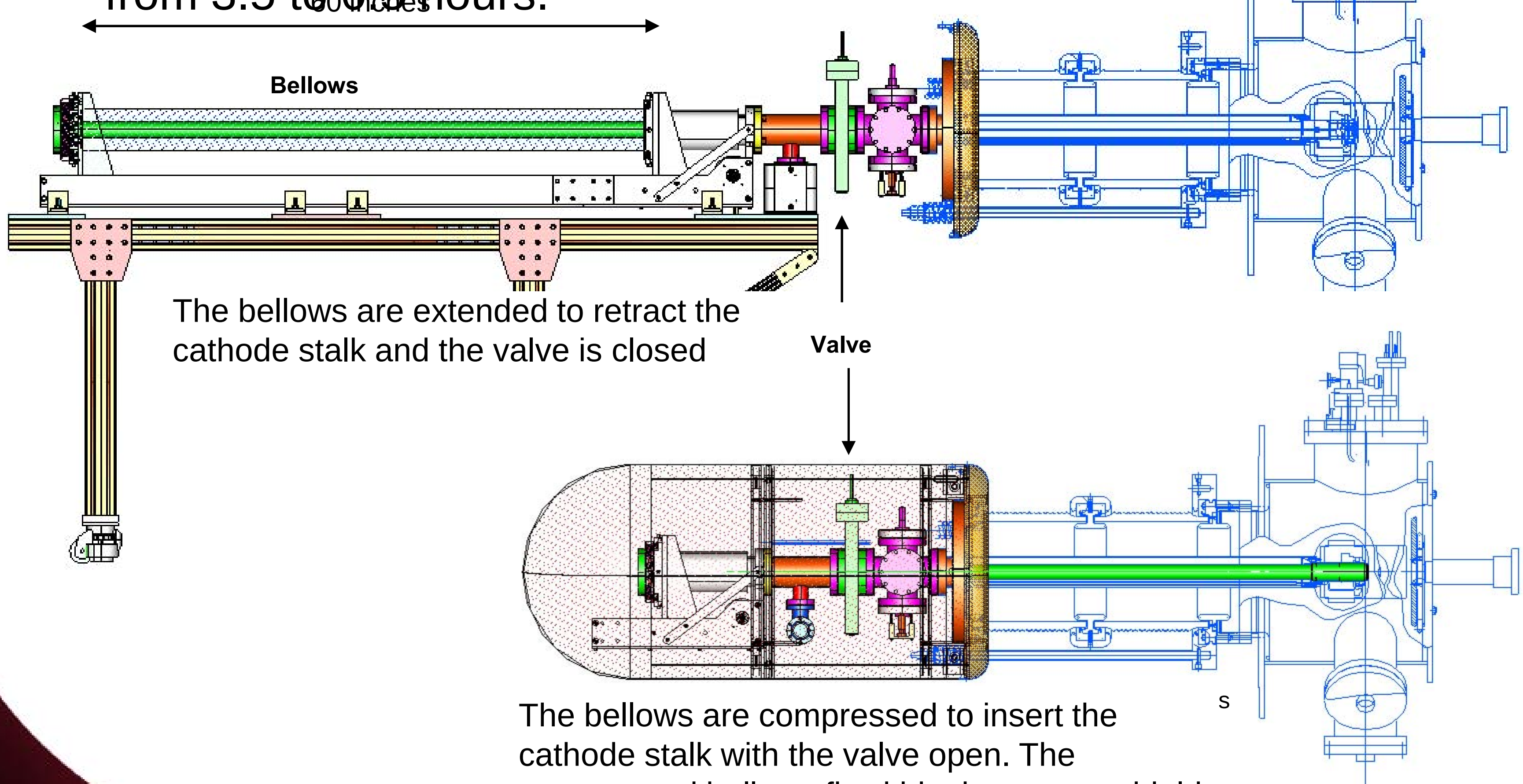
The GTS is the result of a fantastic team effort. Congratulations to all!!

- The entire FEL team
- The Safety Systems Group
- Radiation Control Group
- Vacuum Group
- Installation Group
- Survey and Alignment Group
- ESH&Q Division

Backup

Semi-load-lock

- A design of a semi-load lock system for replacing cathodes without perturbing the gun chamber vacuum has been completed and fabrication awarded to McAllister Inc. This system will also allow re-cesiation without opening the SF6 tank, shortening the process from 3.5 to 0.5 hours.



The bellows are extended to retract the cathode stalk and the valve is closed

The bellows are compressed to insert the cathode stalk with the valve open. The compressed bellows fit within the corona shield

High voltage conditioning