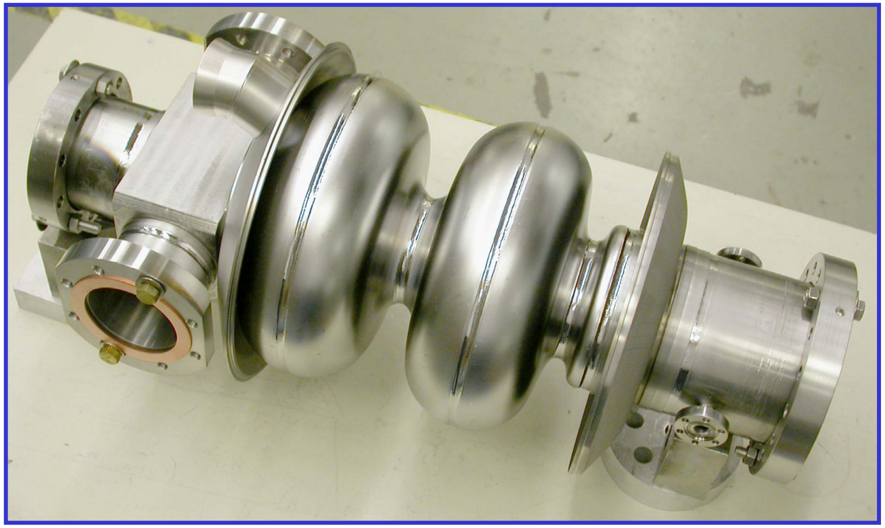
The ERL Injector Project at Cornell University

Bruce Dunham
Cornell University



Contributors

- Ivan Bazarov
- Maury Tigner
- Sol Gruner
- Dave Rice
- Charles Sinclair
- Georg Hoffstaetter
- Hasan Padamsee
- Eric Chojnacki
- Matthias Liepe
- Sergey Belomestnykh
- Karl Smolenski
- Yulin Li
- Xianghong Liu
- Dimitre Ouzounov
- John Dobbins
- John Barley
- Richard Ehrlich
- Fay Hannon
- Richard Gallagher
- many others . . .

Outline

- Overview
- SRF/RF
- Cryogenics
- Photocathode Gun and Laser System
- Beamline
- Commissioning and Planning

Overview

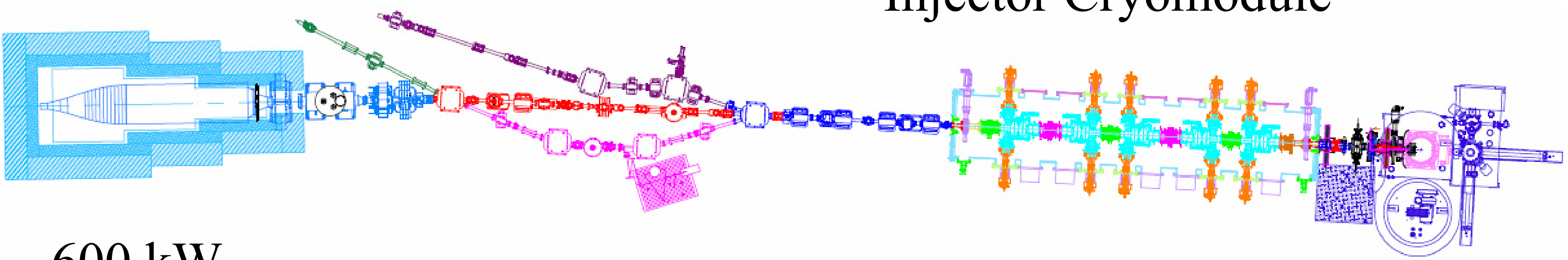
- **HV DC gun** based **photo**-injector
- up to **100 mA** average current, **5-15 MeV** beam energy
- norm. rms emittance **≤1 μm** at **77 pC**/bunch
- rms bunch length **0.6 mm**, energy spread **0.1%**

- Achieve gun voltage in excess of 500 kV
- Demonstrate photocathode longevity
- Cleanly couple 0.5 MW RF power into the beam without affecting its transverse emit.
- Control non-linear beam dynamics: over a dozen of sensitive parameters that need to be set *just right* to achieve the highest brightness
- Instrumentation and tune-up strategy
- Drive laser profile programming (both temporal and spatial)

ERL Injector Layout

Diagnostic Beamlines

Injector Cryomodule

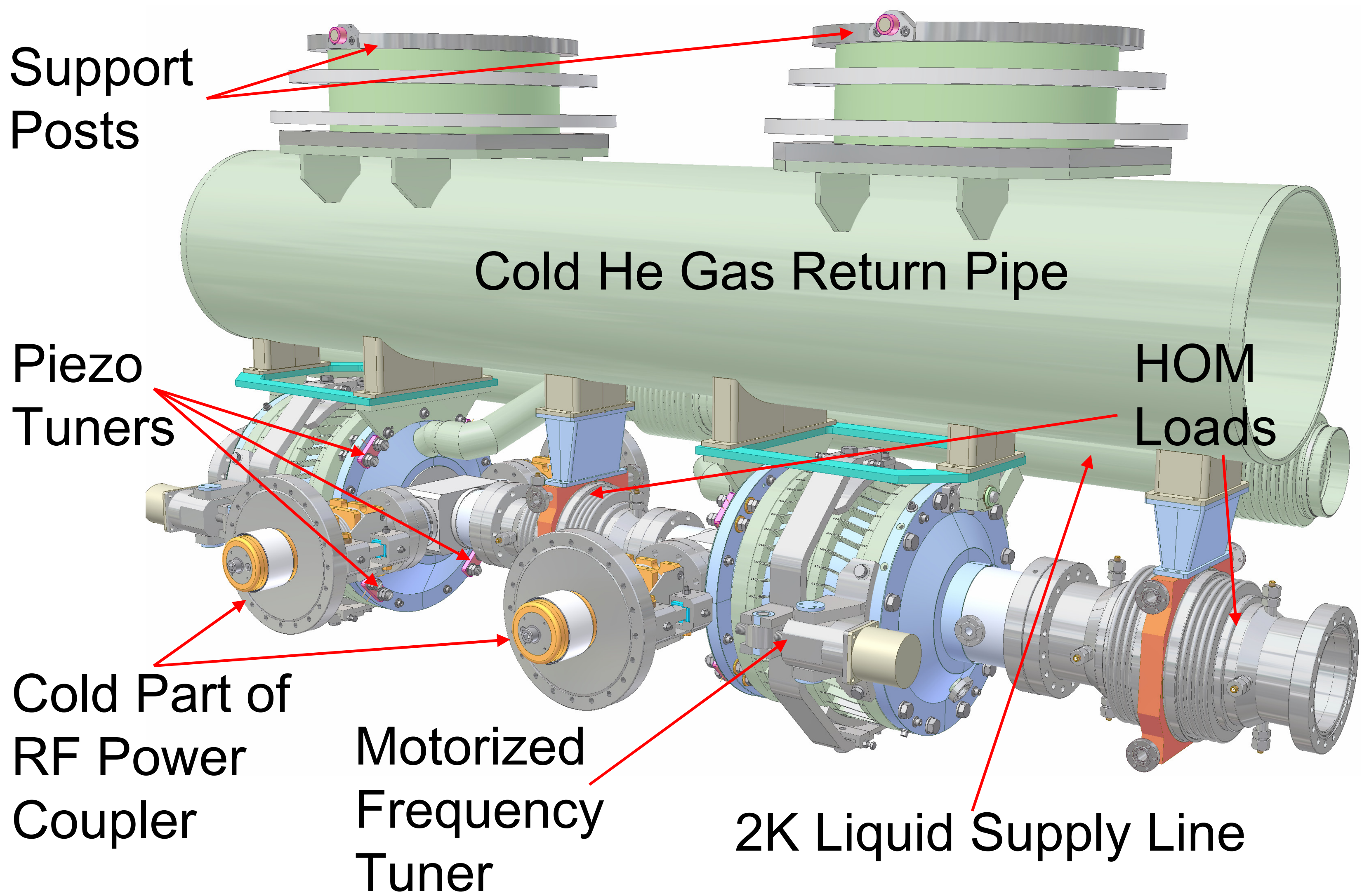


600 kW
Dump

Photocathode Gun

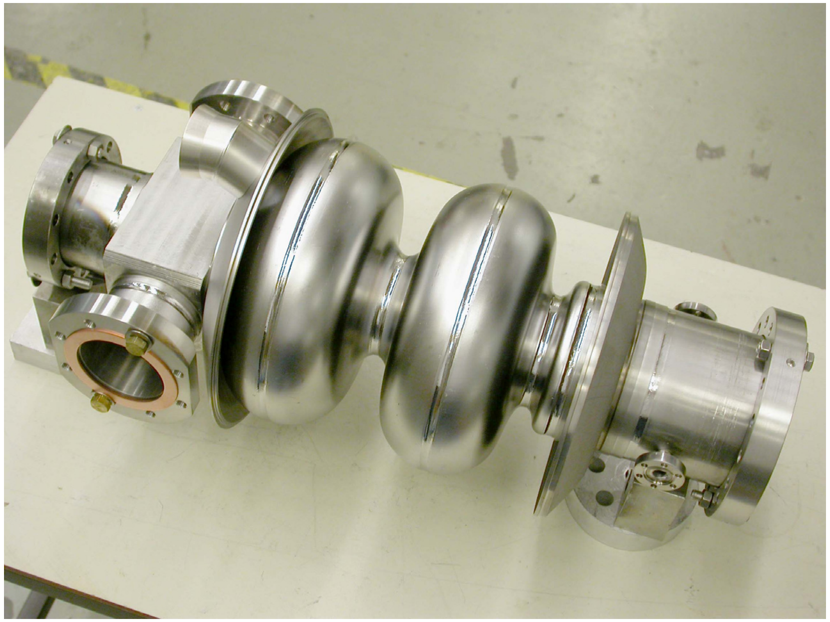
SRF and RF Systems

Injector Cryomodule



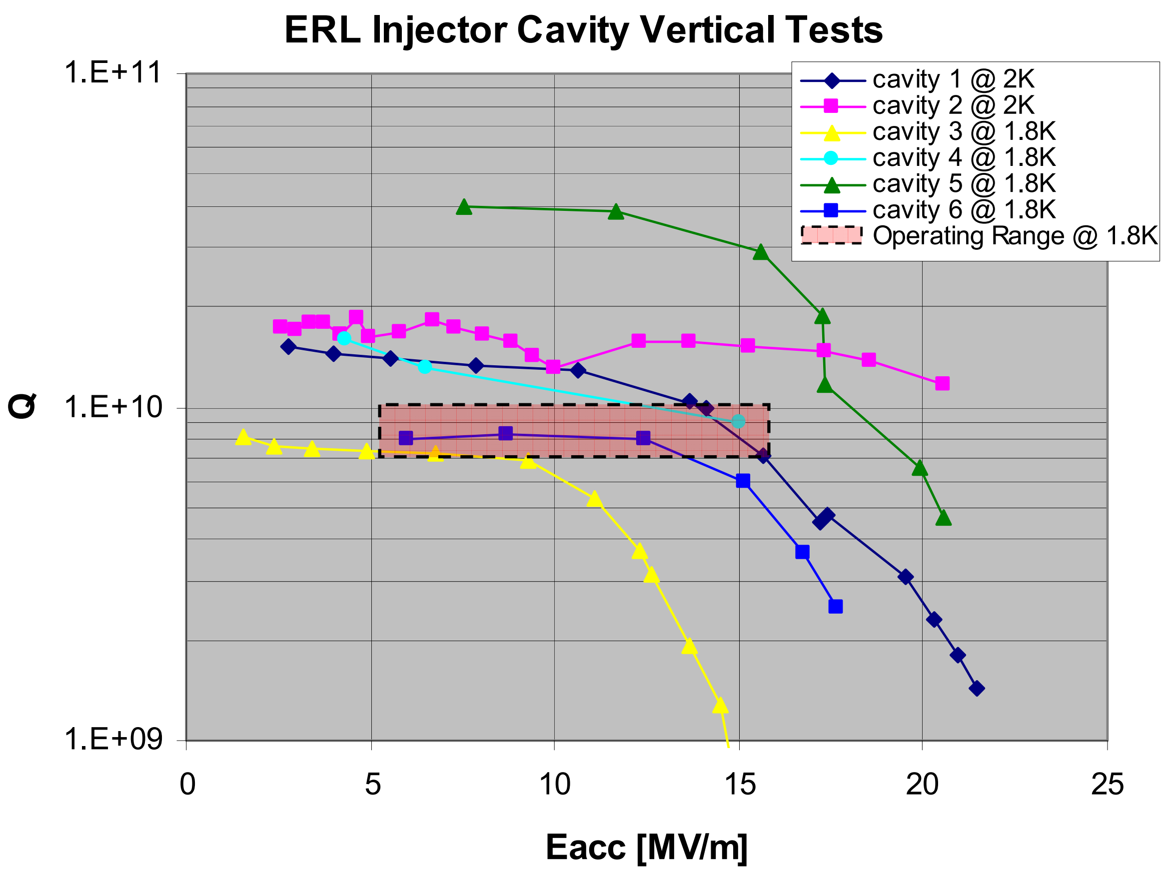
2 Cell Cavity

Frequency	1300 MHz
Cells per cavity	2
R/Q	222 Ω
Voltage	1-3 MV
Gradient	5-15 MV/m
Q_o @ 2K	$>10^{10}$
Q_{ext}	$4.6\cdot10^4 – 4.1\cdot10^5$
Active length	0.218 m
Total length	0.536 m



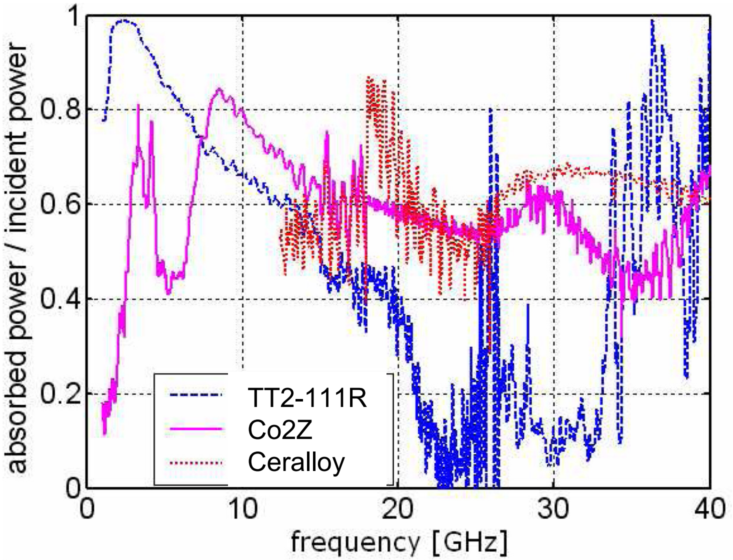
- 5 cavities tested, all meet specs, E > 15 MV/m (most E > 20 MV/m) , Q > 10^{10} @ 2K
- Only BCP, no 800C treatment
- Two tested for H disease, no H disease

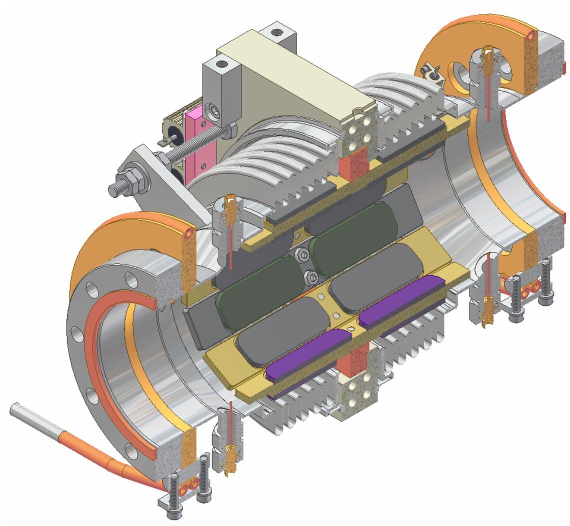
Cavity Performance

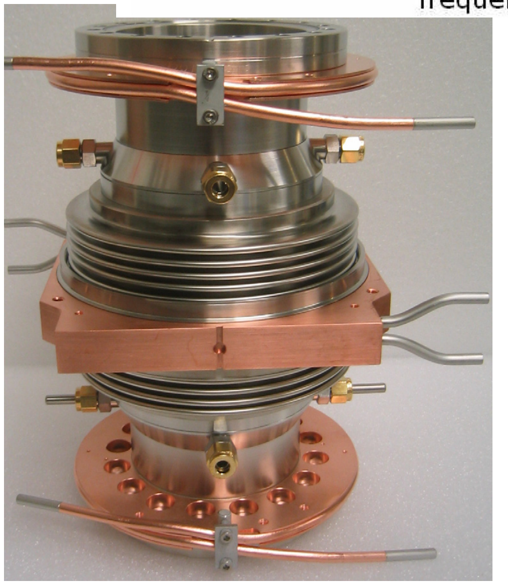


HOM Loads

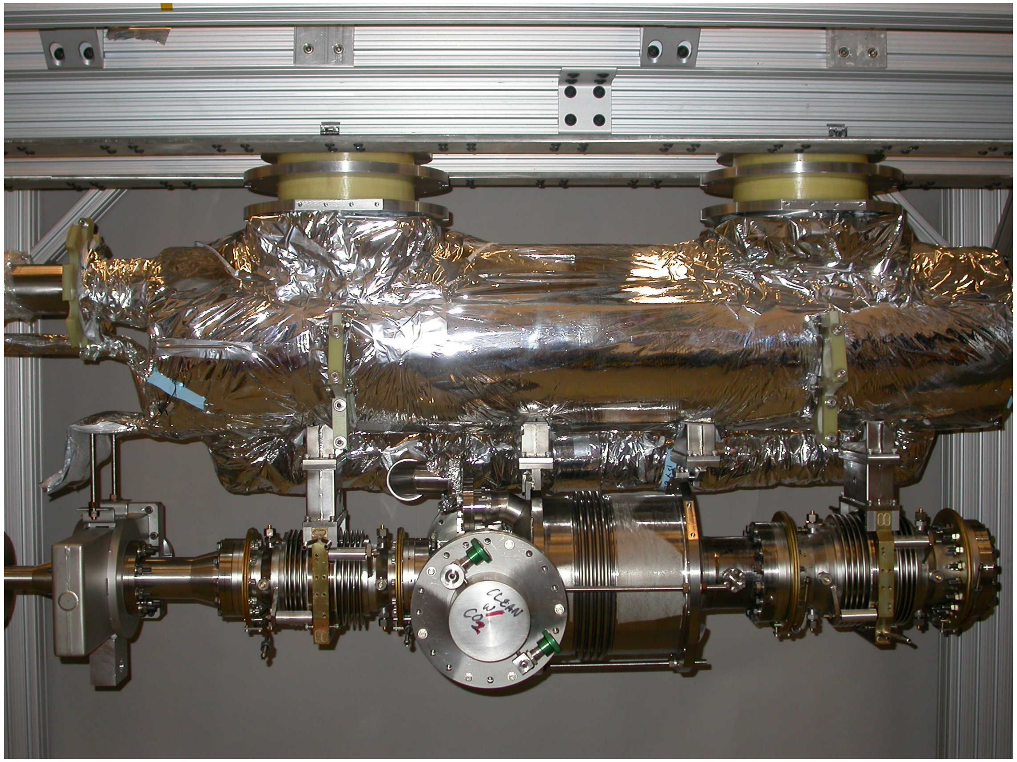
Total # loads	3 @ 78mm + 3 @ 106mm
Power per load	26 W (200 W max)
HOM frequency range	1.4 – **100 GHz**
Operating temperature	80 K
Coolant	He Gas
RF absorbing tiles	TT2, Co2Z, Ceralloy

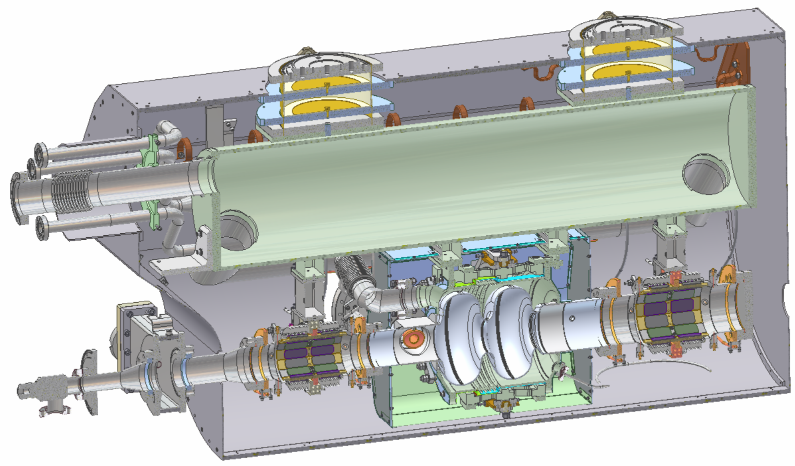




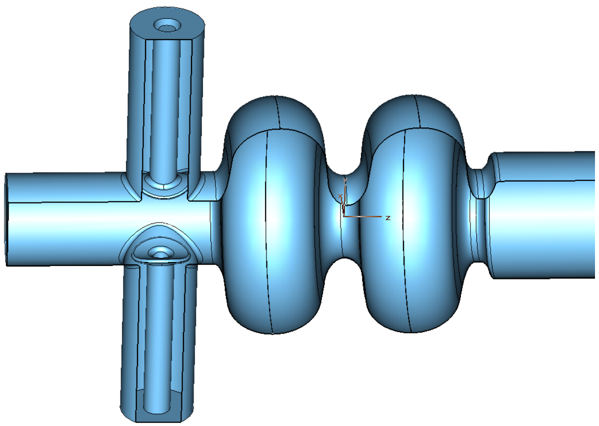


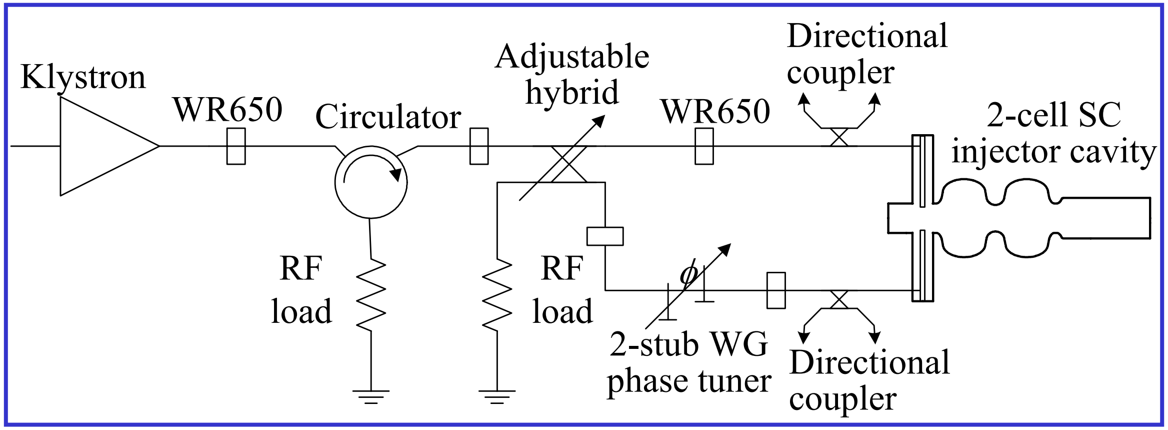
Horizontal Cavity Test





RF Coupler Requirements





Frequency	**1300 MHz**
Bandwidth	**±10 MHz**
Max. power transfer to matched load	**75 kW**
Number of ceramic windows	**2**
Cold coax. line impedance	**60 Ohm**
Warm coax. line impedance	**46 Ohm**
Coax. line OD	**62 mm**
Q_{ext} range	**$9.2 \cdot 10^4$ to $8.2 \cdot 10^5$**
Antenna stroke	**> 15 mm**
Heat leak to 2 K	**< 0.2 W**
Heat leak to 5 K	**< 3 W**
Heat leak to 80 K	**< 75 W**

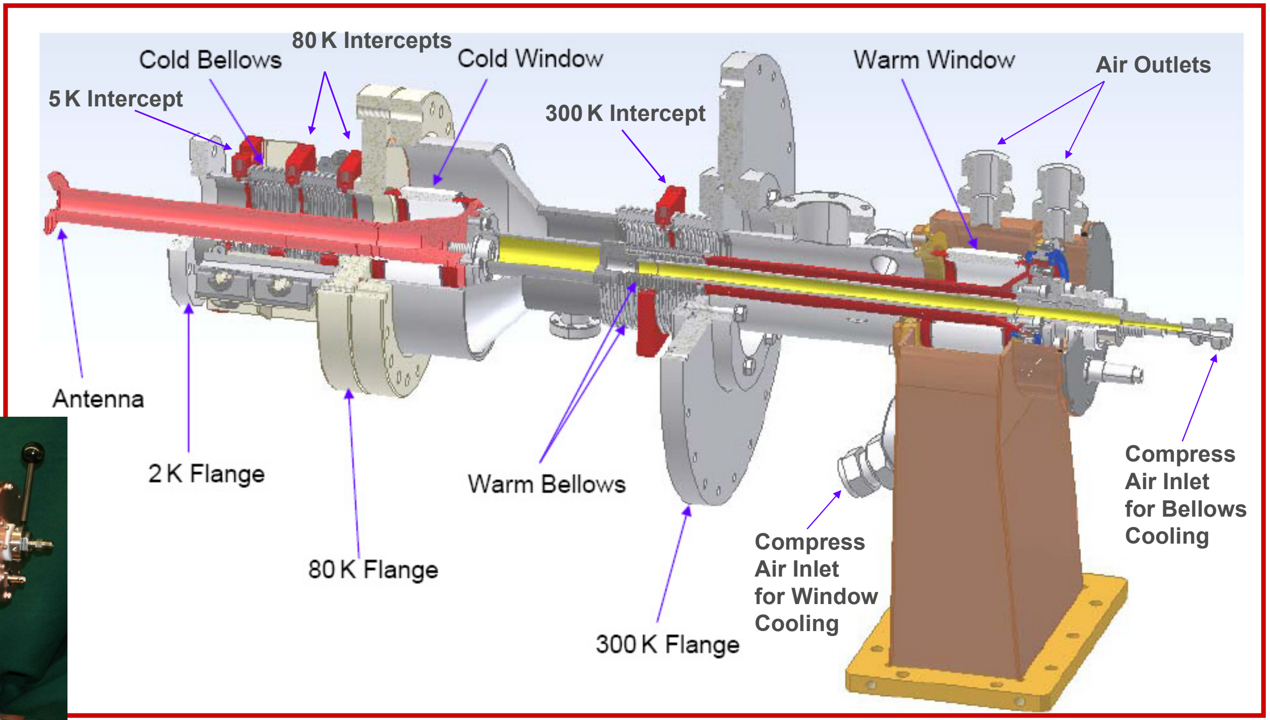
Twin coupler:

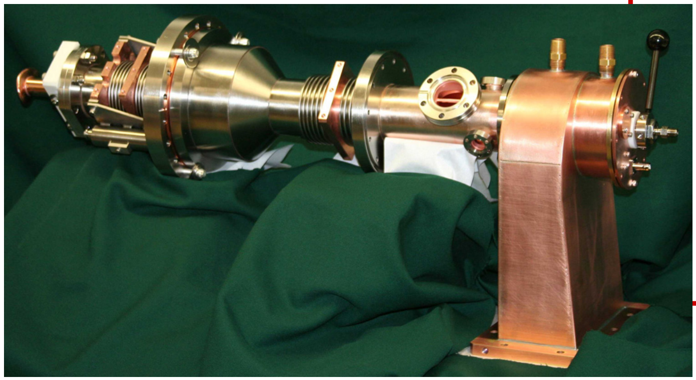
- Deliver 100 kW CW RF power to beam
- Provide strong and variable coupling
- Minimize transverse kick to beam
- Minimize cryogenic heat leaks
- "Multipacting-free" geometry

Coupler design highlights

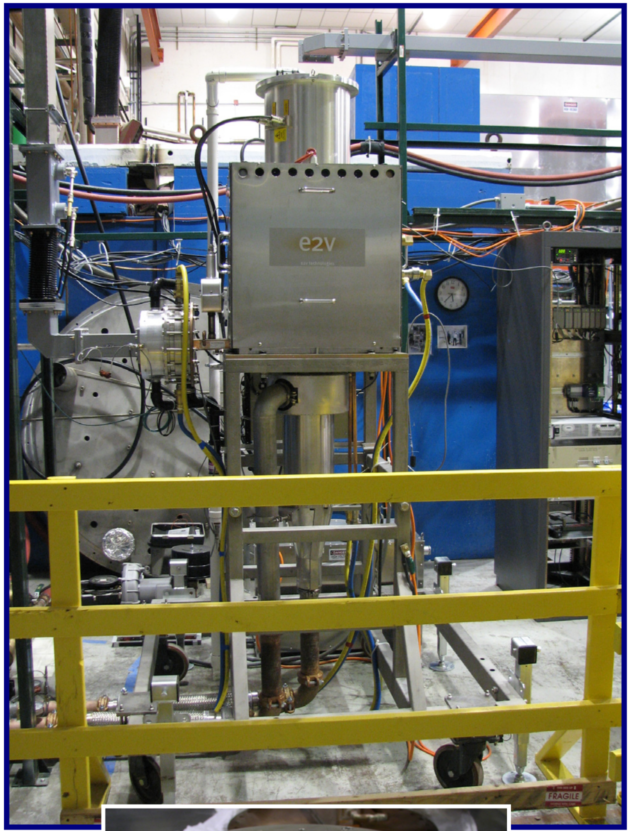
Design features:

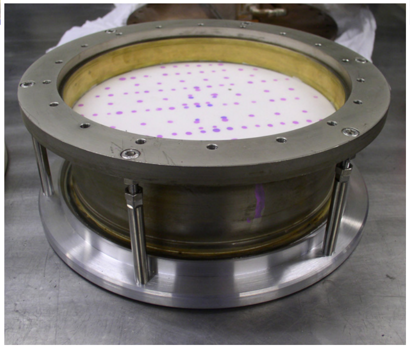
- The cold part was completely redesigned using a 62 mm, 60 Ohm coaxial line for stronger coupling, better power handling and avoiding multipacting
- Antenna tip was enlarged and shaped for stronger coupling
- "Cold" window was enlarged to the size of "warm" window
- Outer conductor bellows design was improved for better cooling (added heat intercepts)
- Air cooling of the warm inner conductor bellows was added



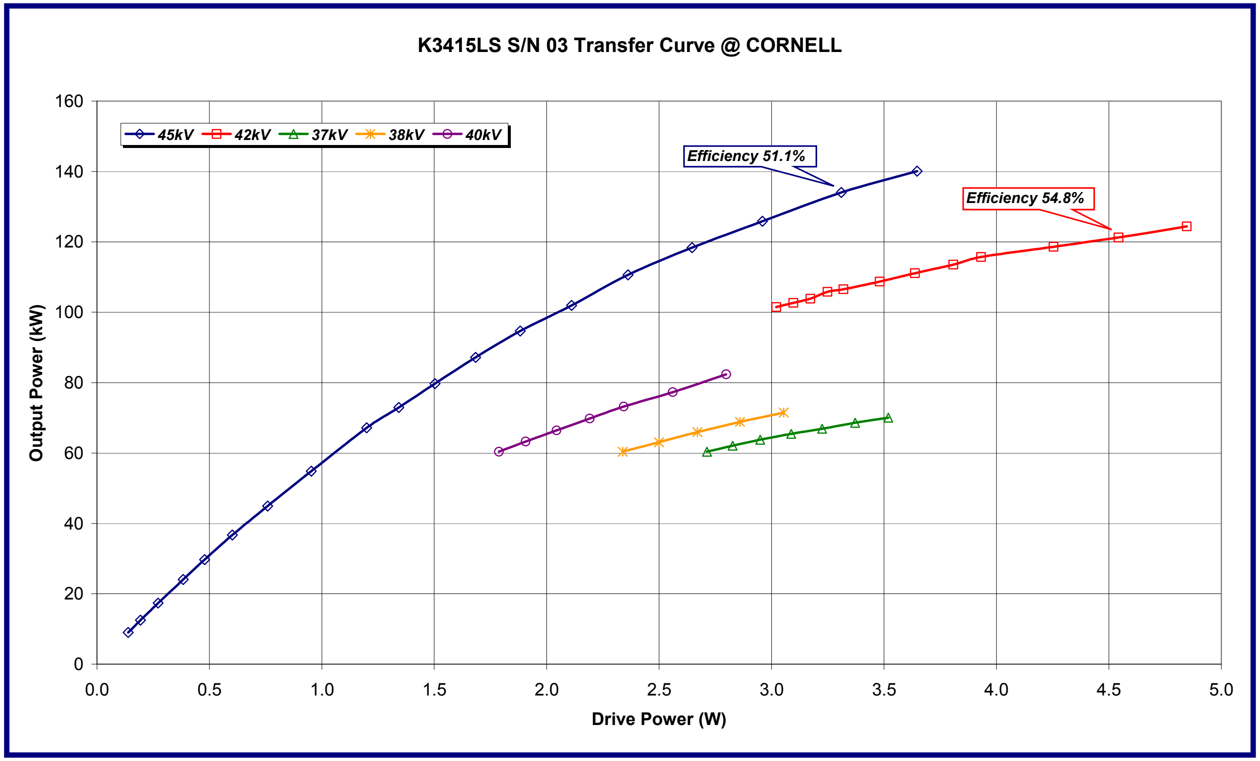


ERL injector klystron

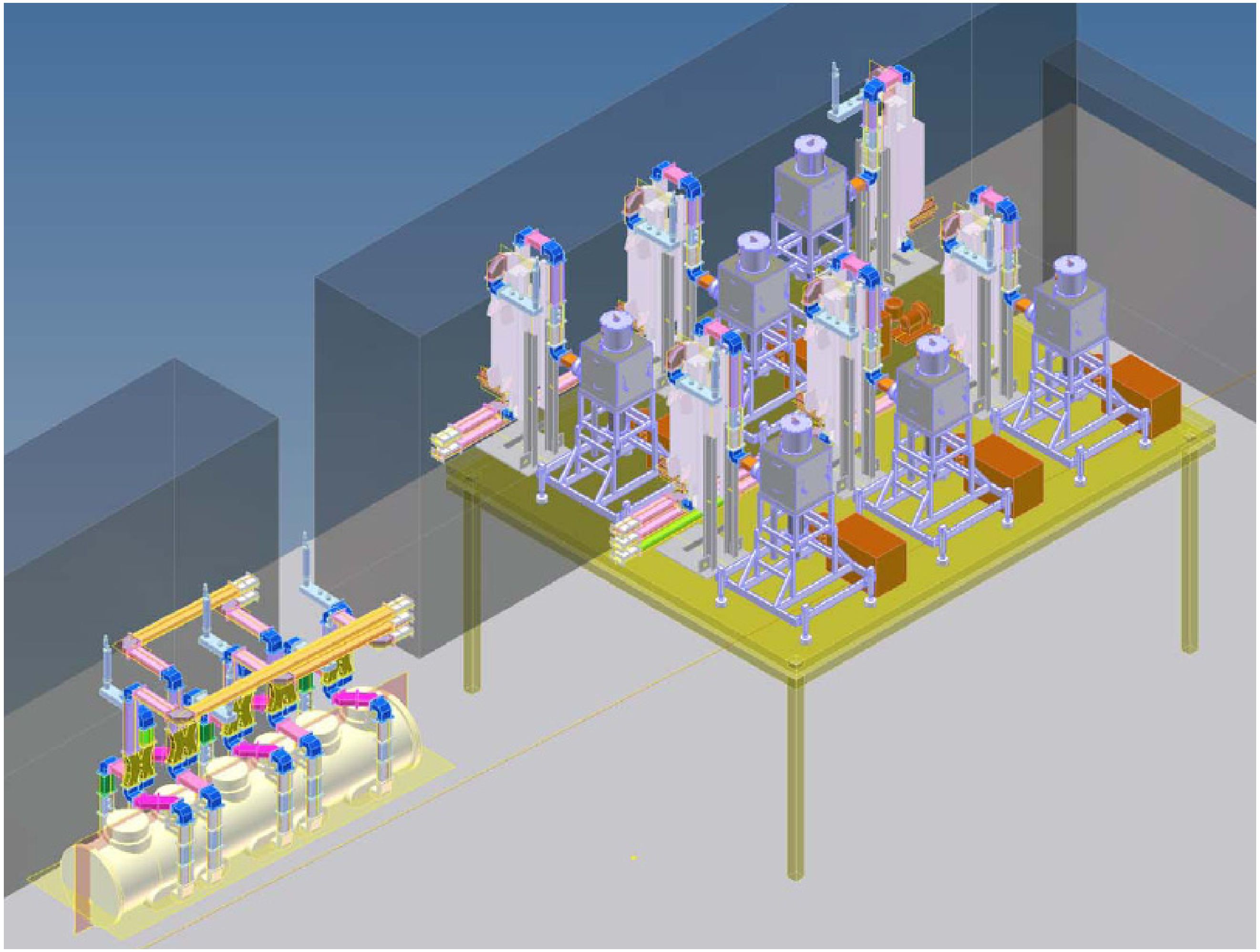




- **e2v designed a high CW power klystron.**
- **Parameters of this 7-cavity tube: max. beam voltage 45 kV, current 5.87 A, full power collector, at max. output power of 135 kW the efficiency is >50%, gain >45 dB, bandwidth is >±2 MHz @ 1 dB and >±3 MHz @ 3 dB.**
- **The first tube (SN03) was delivered and successfully tested at Cornell on March 6 – 8.**
- **Transfer curves were measured for several HV settings.**



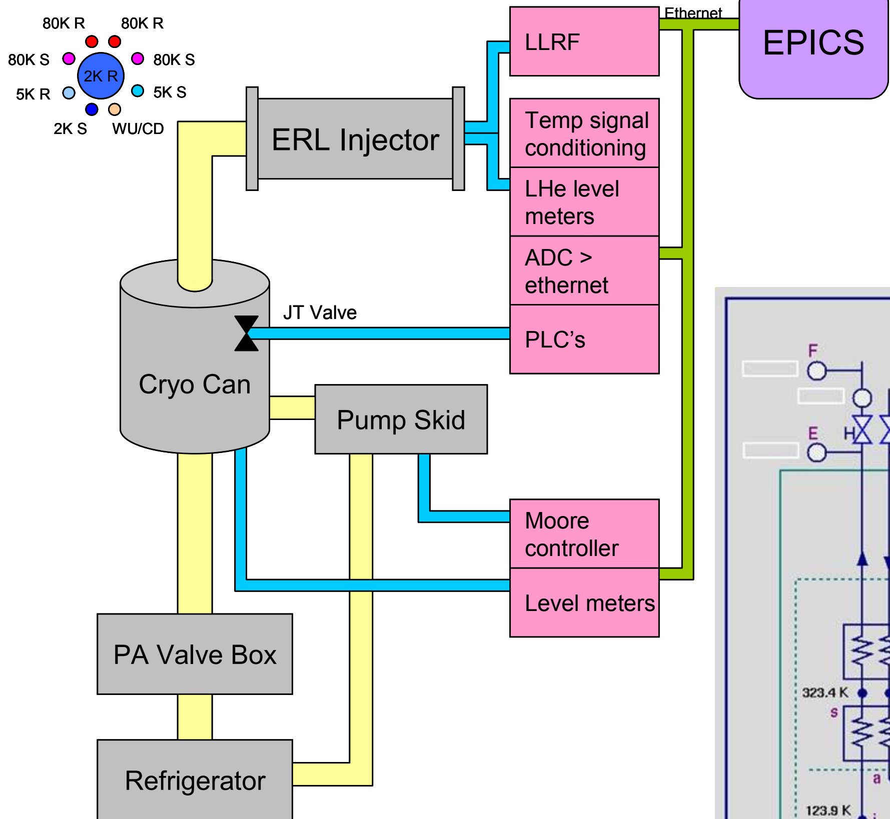
RF Power Distribution

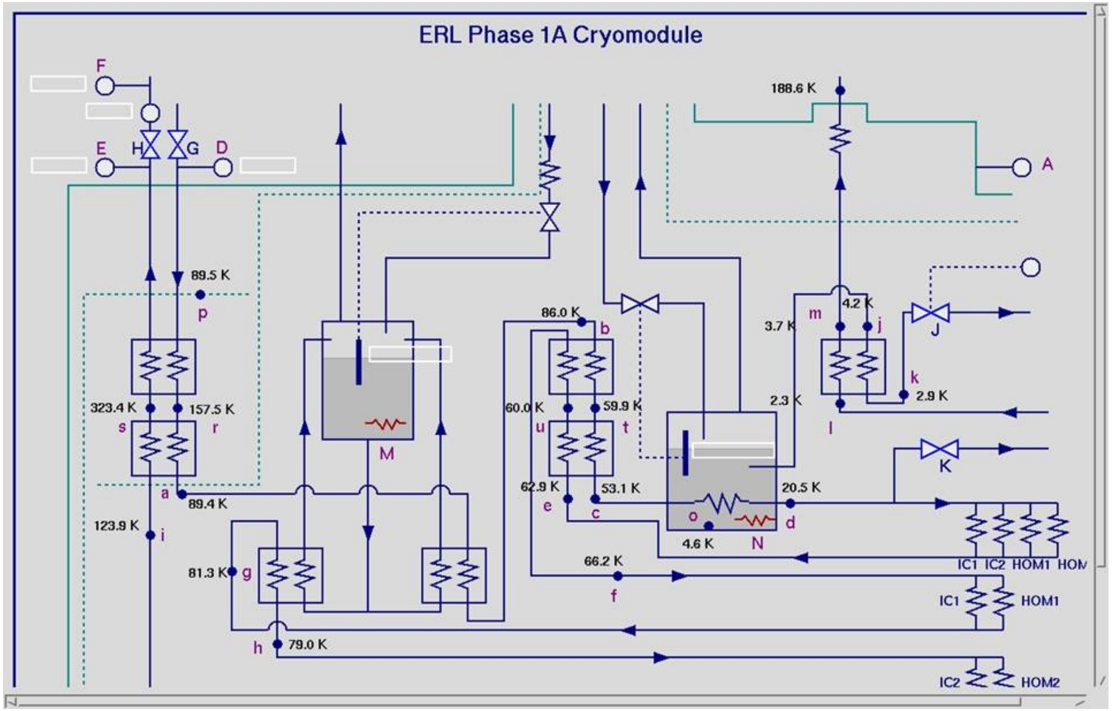


Cryogenic System

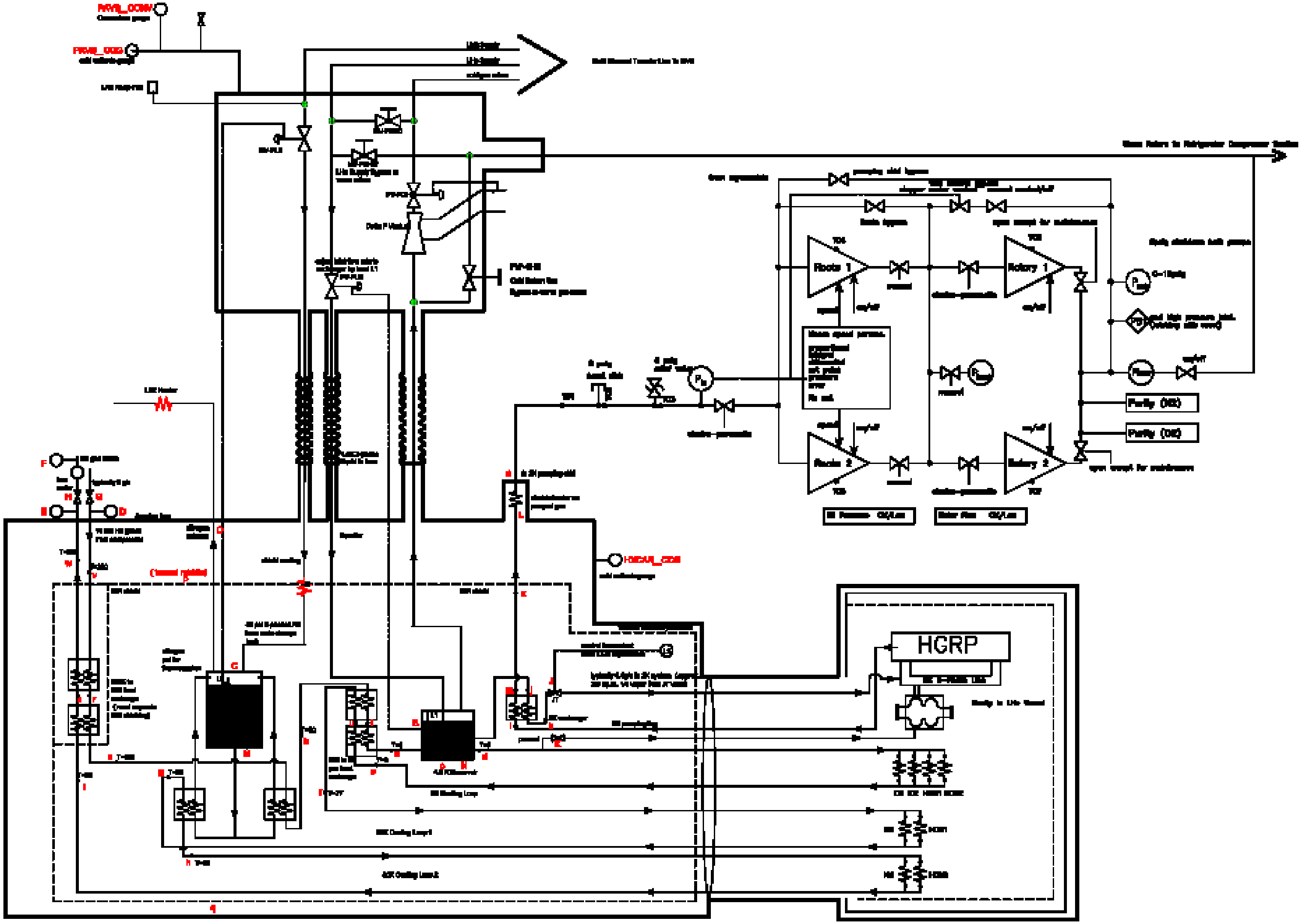
Cryo – First cold test

2K Cavity	25 W
5K Coupler + HOM Load	68 W
80 K Coupler	696 W





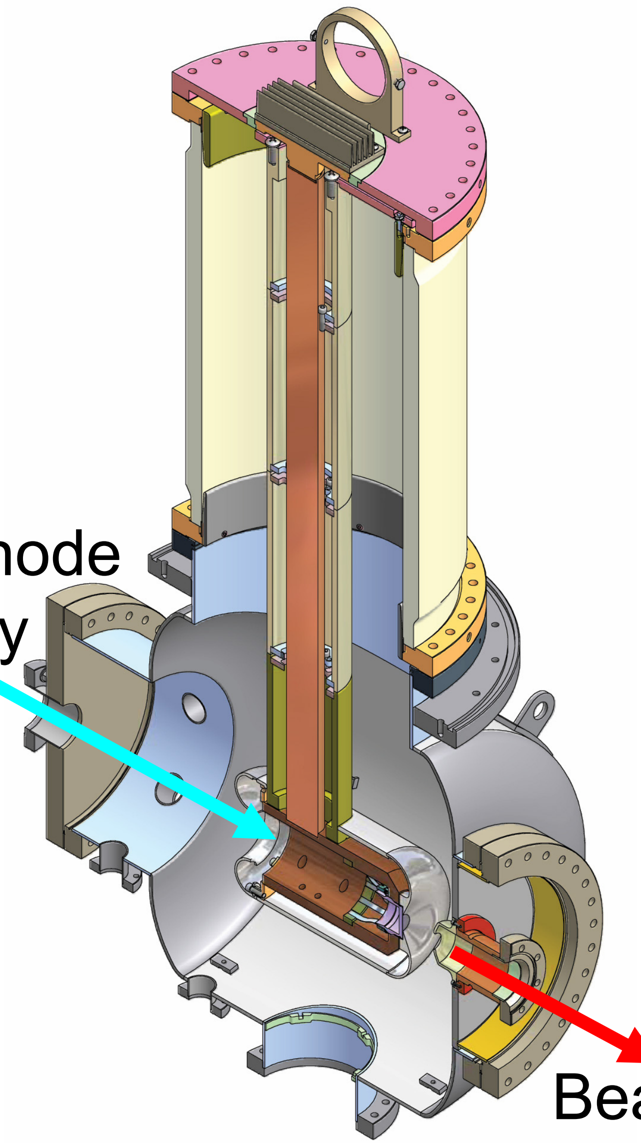
Cryogenics Block Diagram

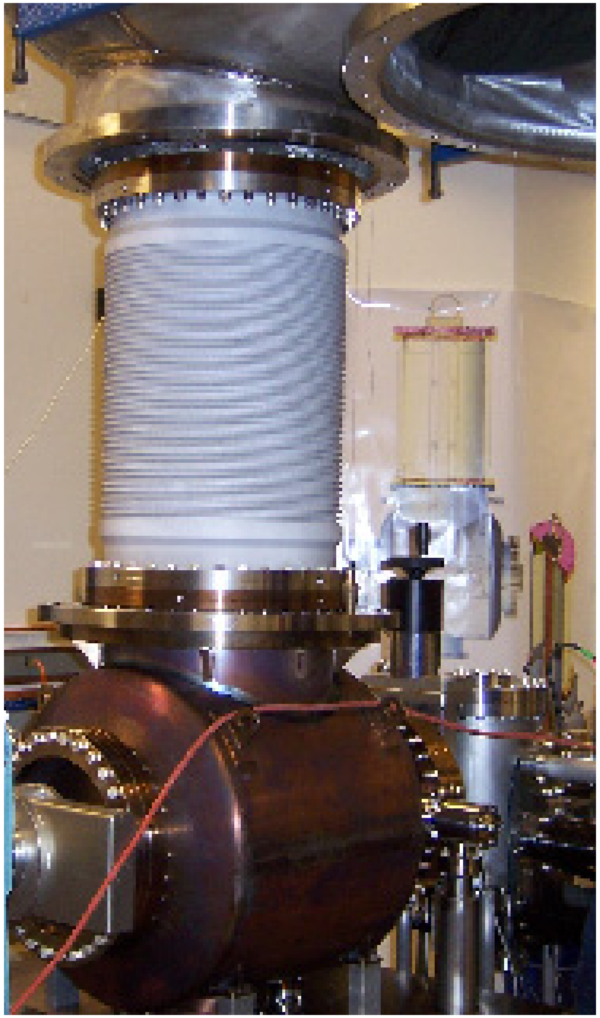


Revised Cooling Scheme for the 2006 Horizontal Test. Provides He gas cooling for both 5K and 80K loads.
Uses plate heat exchangers for gas/gas exchange and He/LN2 loads, finned tube HX for 4.5K. Uses thermosyphon control for LN2 flow. Orientation of exchangers is to remind us that bottom end should be cold end.
For 2008 testing, flow rates will be 5 times larger.

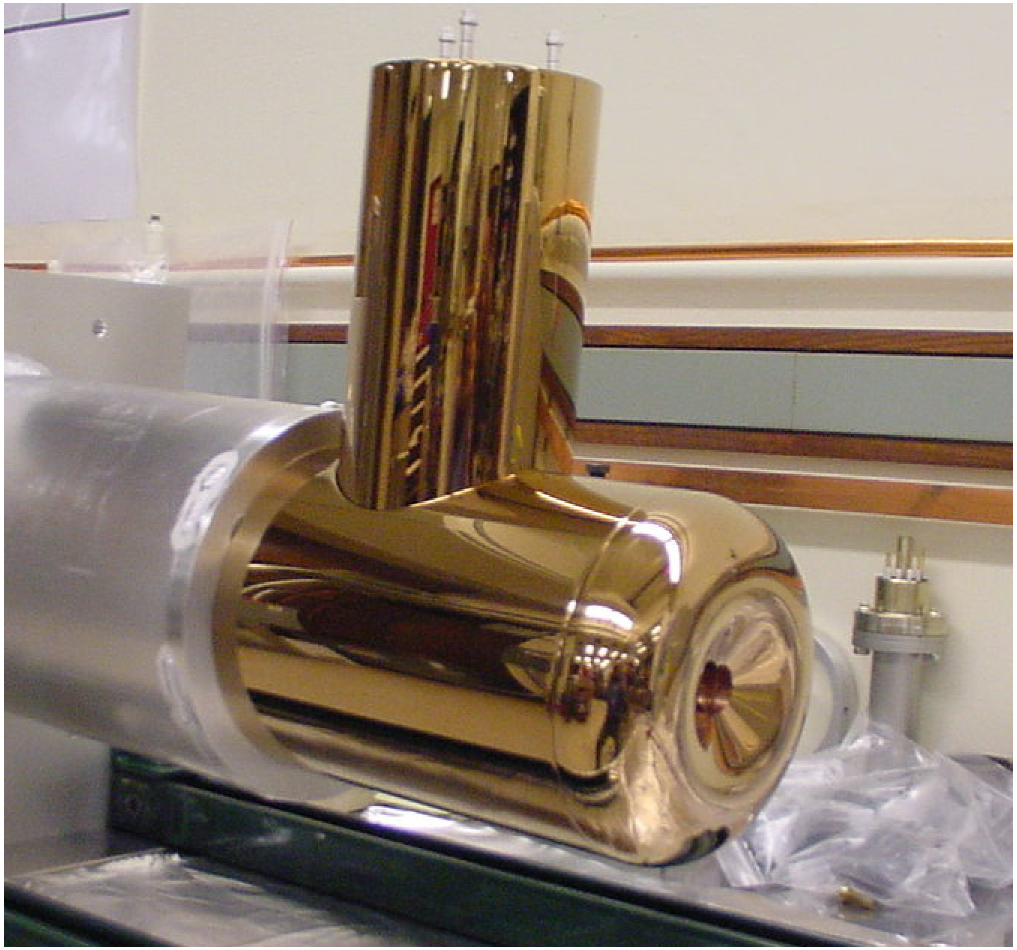
Photocathode Gun and Laser System

750 kV Gun





Gun Focusing Electrode



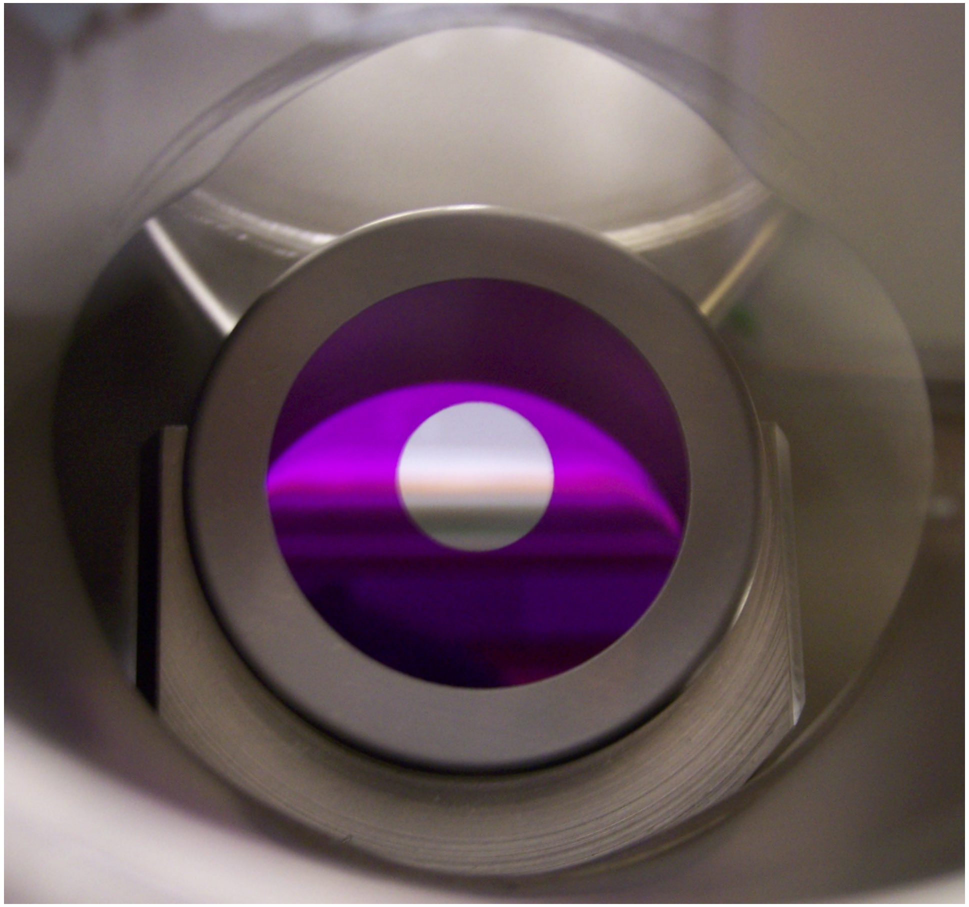
All electrodes can be assembled without touching any high voltage surfac

750 kV Power Supply

750 kV, 100 mA DC supply

Supplied by Kaiser Systems, Inc in Beverly, MA

GaAs Photocathode

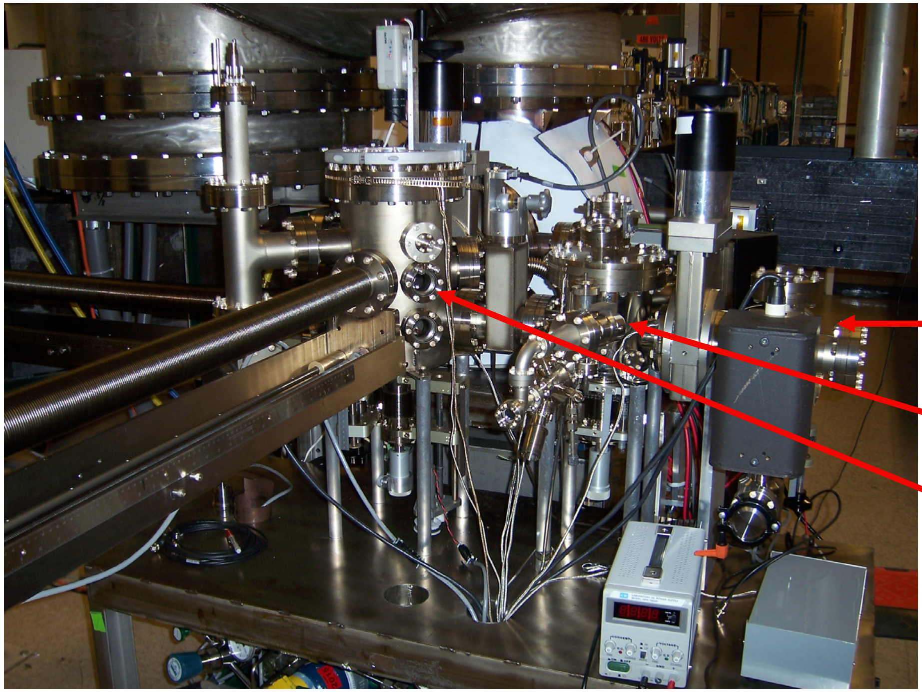


This photo shows the GaAs cathode used in the photoemission electron gun.

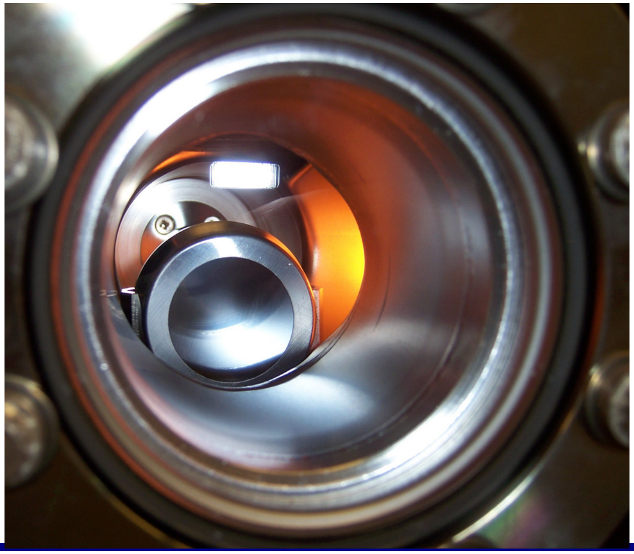
The silver circle at the center is the active electron emission area when exposed to light.

The purple annulus around this is also GaAs, but has been covered with an oxide layer to prevent emission from scattered light. Any electrons that would have been emitted from this region can hit the vacuum vessel and degrade the cathode lifetime.

Load Lock System



- Load lock chamber with quick bakeout capability
- Heater chamber
- Cathode preparation and transfer chamber



Vacuum Performance

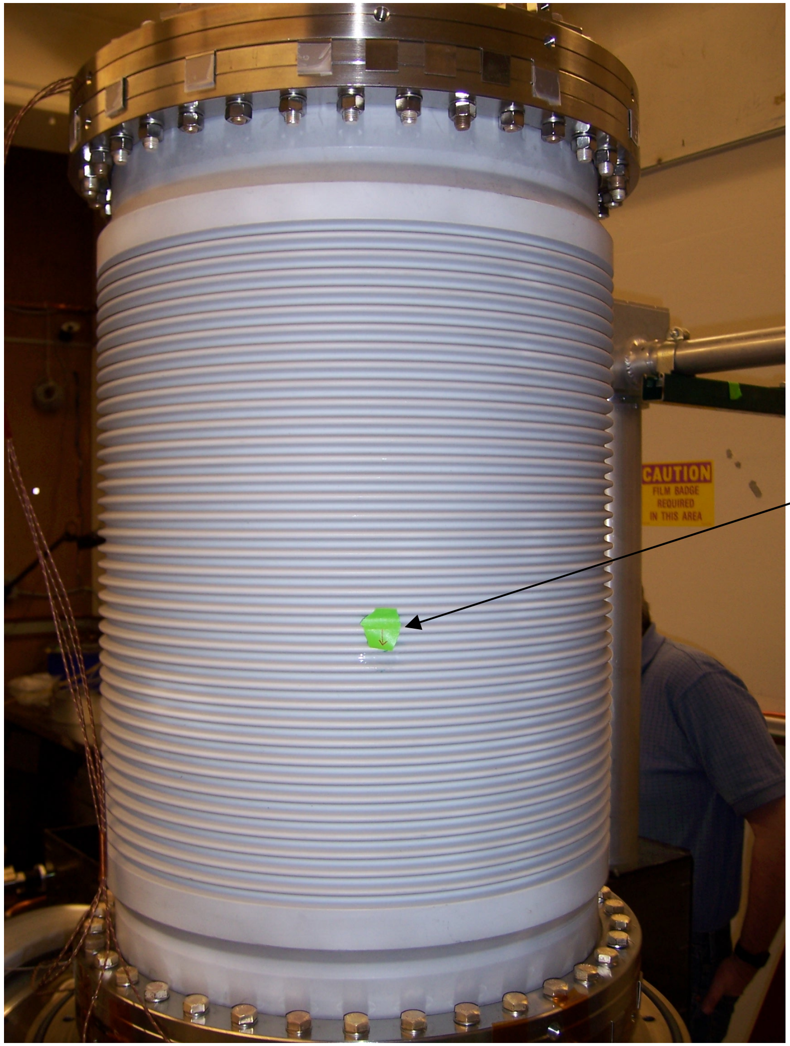
- Want XHV levels to reduce ion backbombardment (which is the key for long lifetime)
- Many getter pumps (12 strips, 20000 L/s)
- Stainless steel parts fired at 400C in air to reduce hydrogen outgassing (similar to LIGO)
- System vacuum bake to 150C

Extractor gauge readings as low as $5x10^{-12}$ Torr

HV processing

- For optimum emittance, need to operate between 500-600 kV
- So far, with limited attempts, we have only reached 330 kV
- What are the problems and how to solve them?

Ceramic Leak

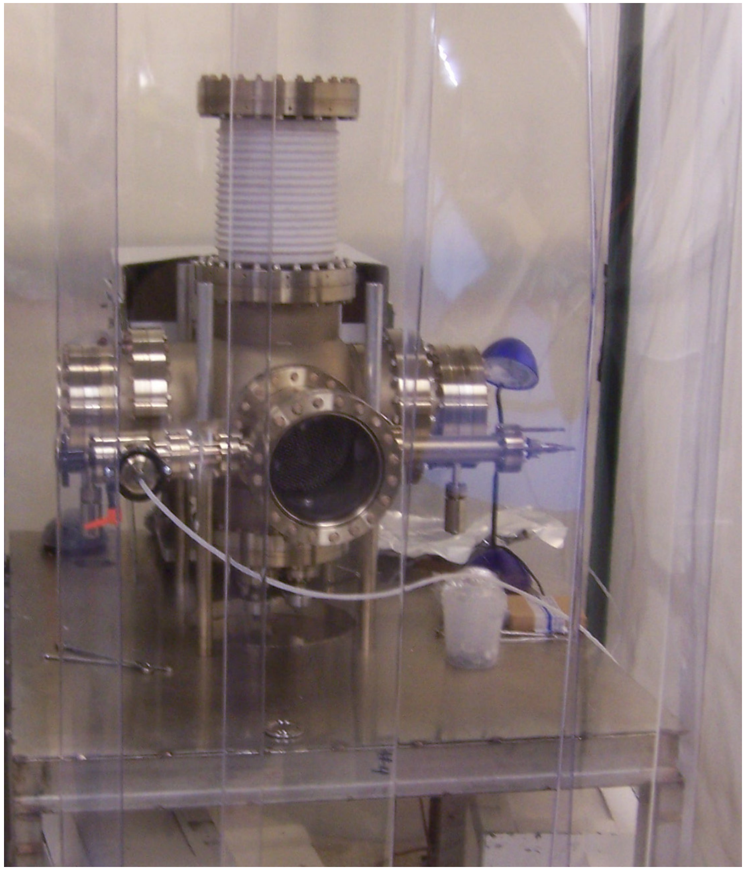


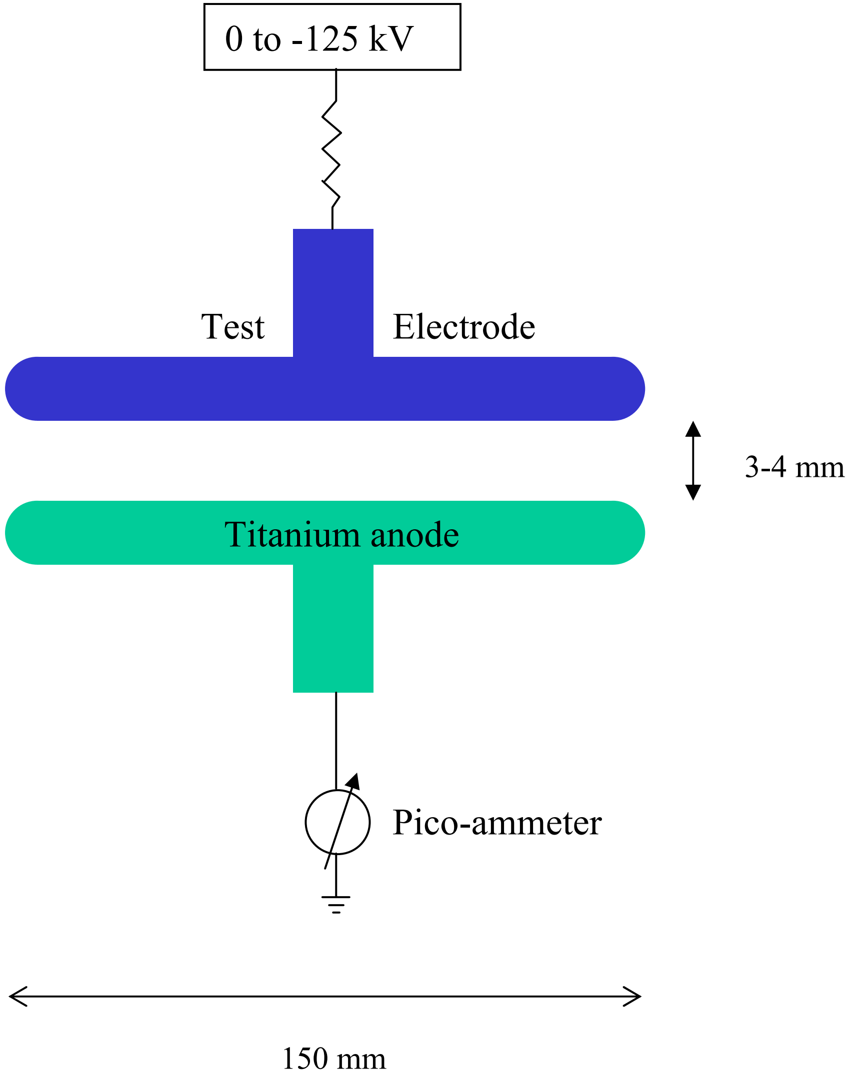
The resistive coating on this ceramic was not done well (R ~ 7000 G-Ohm)

Experienced a vacuum leak due to punch-through at 330kV

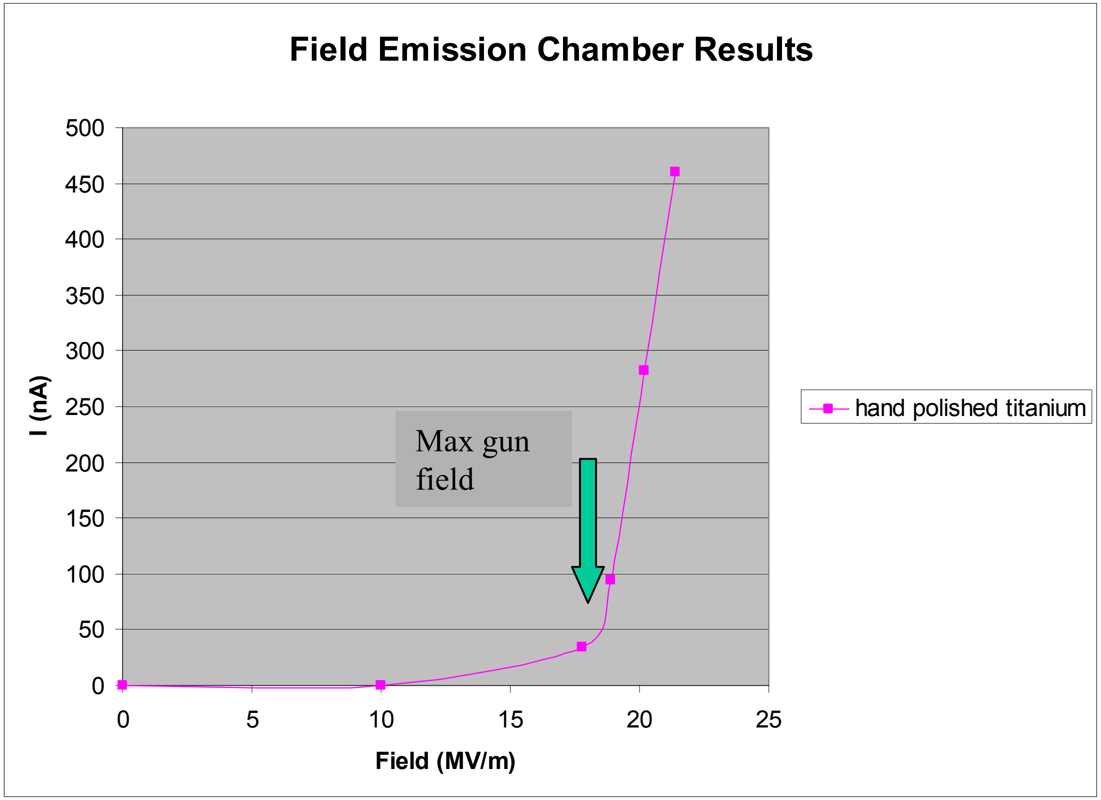
CPI is making a second ceramic with a better coating ~100 G-Ohm (due end of May)

HV Testing – Large Area Electrodes





Initial Results, continued



This titanium disk was hand polished and reached a field higher than the gun will see.

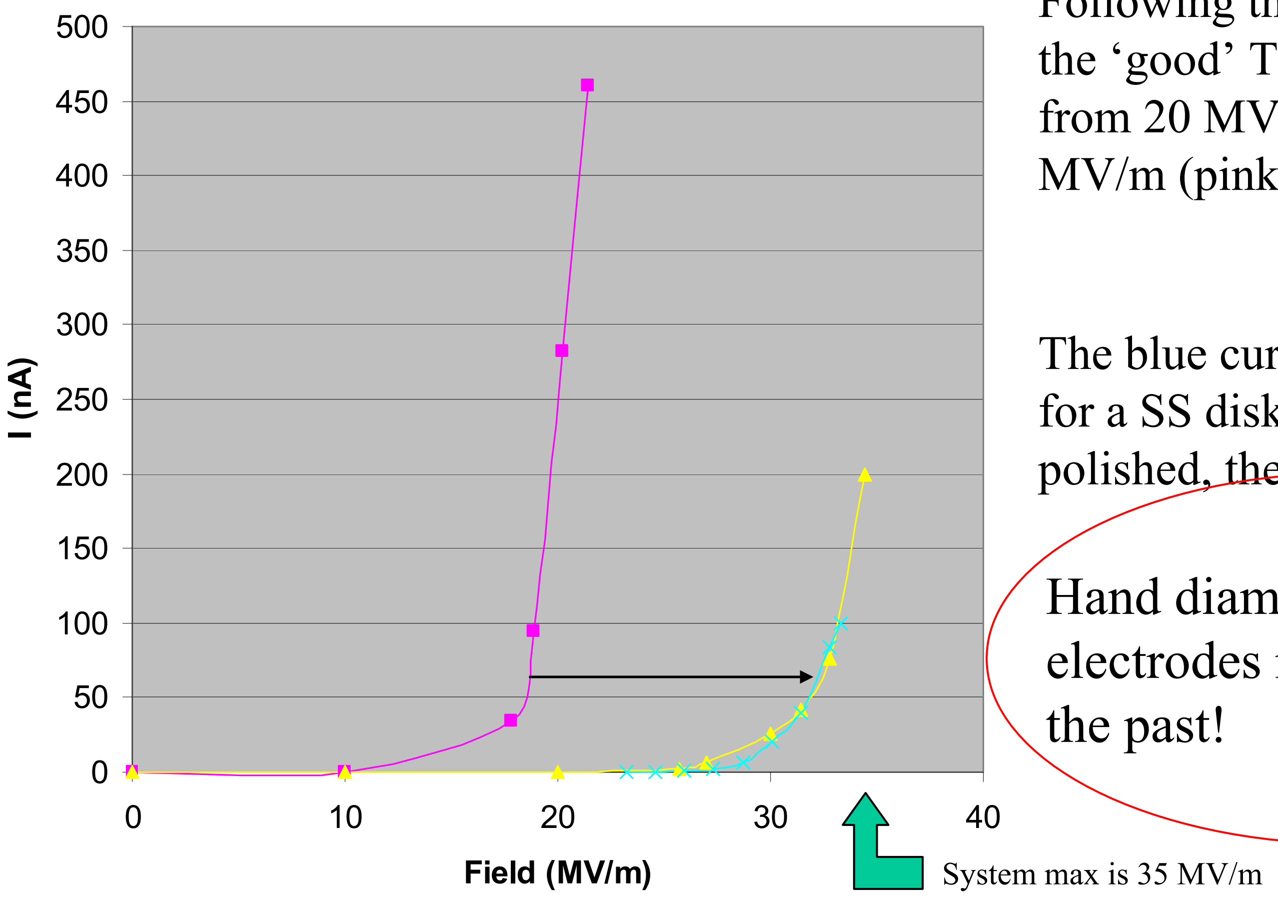
Should be okay for gun electrodes too, but the ‘technology’ does not transfer

SRF-like cleaning procedure

1. Either hand polish or electro-polish metal electrode
2. After hand polished, ultrasound in hot soap and water, rinse in DI water and store in DI water. After electro-polishing, store under DI water
3. Transfer to a clean room environment
4. Mount the sample on the HPR system – (high pressure rinse system)
5. HPR for 2 hours
6. Remove and let dry in the clean room
7. Store in a clean, sealed container until ready for installation
8. Remove from sealed container in a clean room
9. Final cleaning using a commercial sno-gun
10. Install in system

MYTH or FACT?: electro-polishing is bad for gun electrodes

“SRF-clean” results

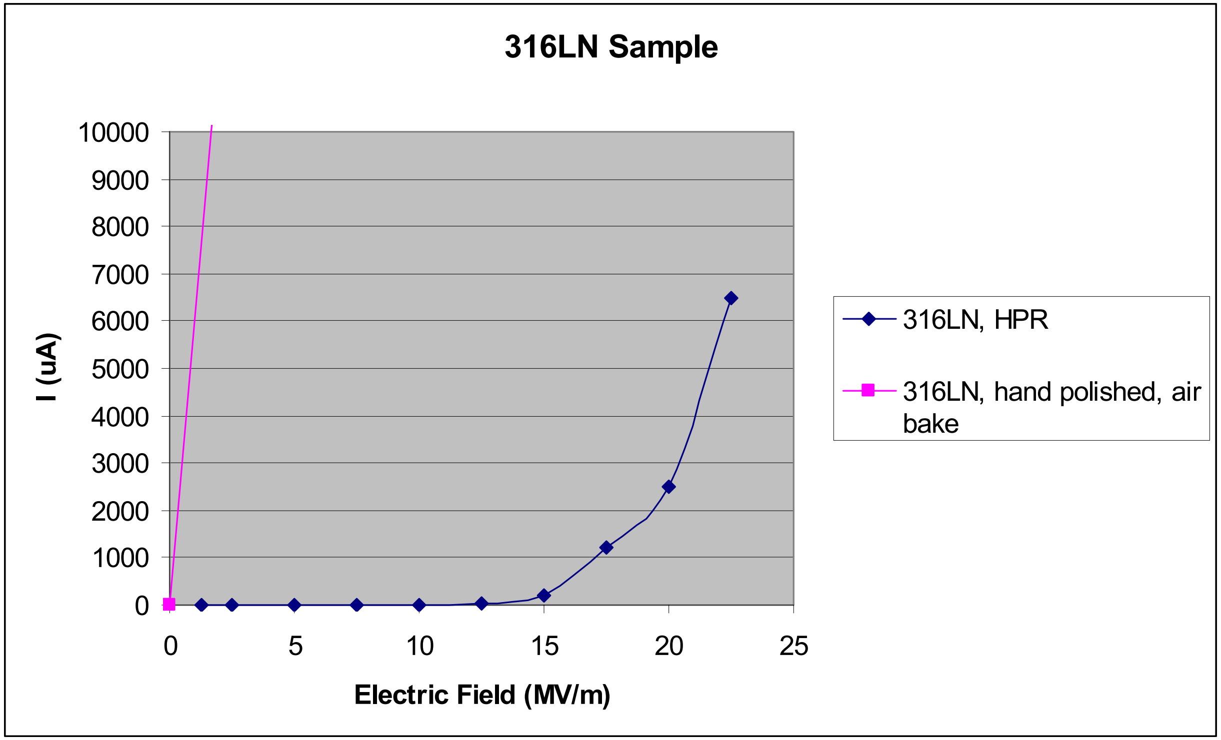


Following the new procedures, the ‘good’ Ti electrode improved from 20 MV/m to nearly 35 MV/m (pink to yellow curve)

The blue curve shows the results for a SS disk that was electro-polished, then ‘SRF-cleaned’

Hand diamond polishing of electrodes may be a thing of the past!

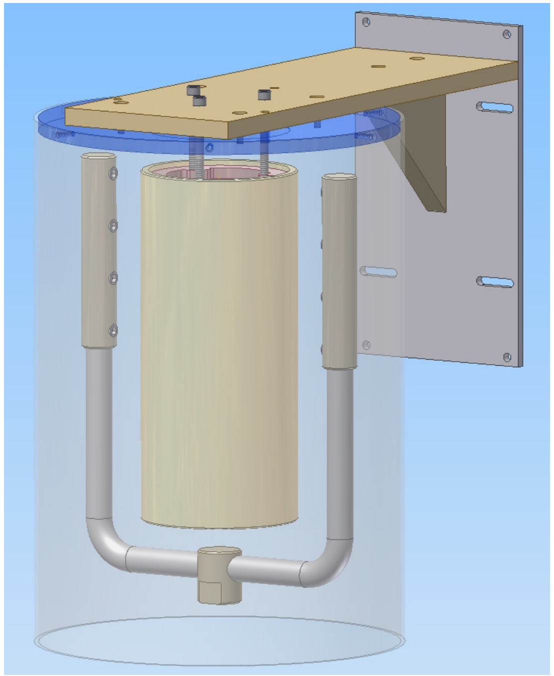
More HPR results . . .

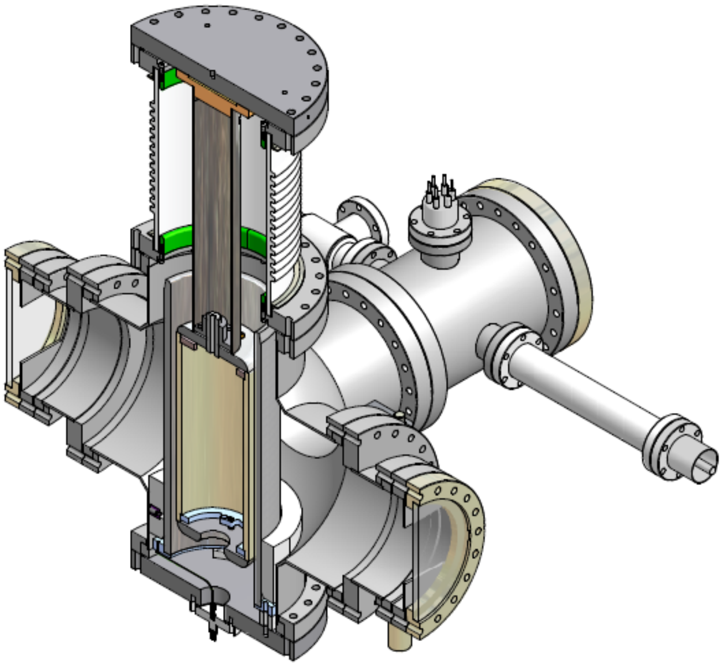


This cleaning method turned a really bad electrode into a ‘good’ one

HV Testing – Real Gun Parts

HPR equipment for large gun electrodes





Pre-test all gun parts *before* installing in the gun.

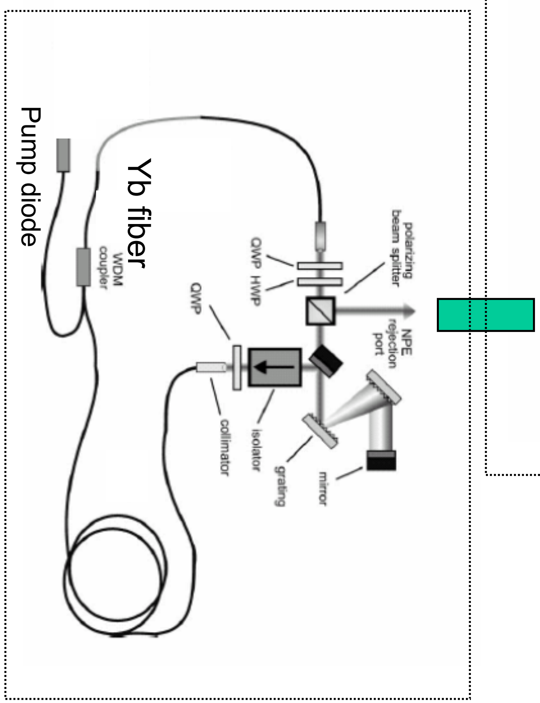
New Gun Assembly Procedure

1. Clean all electrodes per the 'SRF-clean' procedure
2. Pre-test all parts to the max field they will experience at 750kV
3. Enclose gun in portable clean room
4. Vent, maintaining a large nitrogen purge
5. Carefully remove old parts, wipe out any particles, wafer chips, etc
6. For each new part, clean with sno-cleaner before installing.
7. Pre-test all bolts and fasteners for particle generation before use (test on a bench with a particle counter). Avoid plated bolts unless you are sure they do not flake.
8. Do not use aluminum foil to cover parts or flanges – we have found tiny pieces of foil stuck to electrodes.
9. For surveying, cover all but one port at a time if possible. Use o-ring sealed covers instead of foil, or clear plastic wrap if you need to see through for alignment.
10. Pump out slowly to reduce the chance of stirring up dust that may be in the chamber or ion pumps.

The Laser System

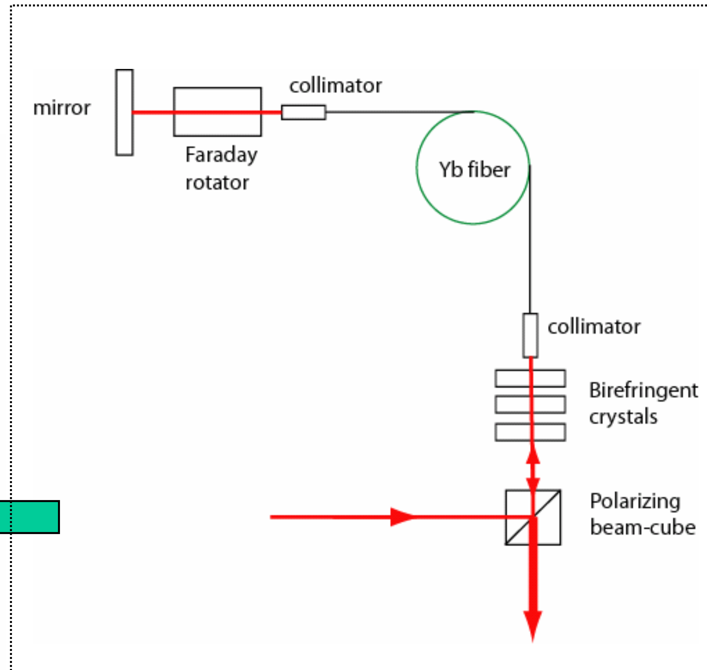
Fiber Laser Description – 50 MHz

Oscillator



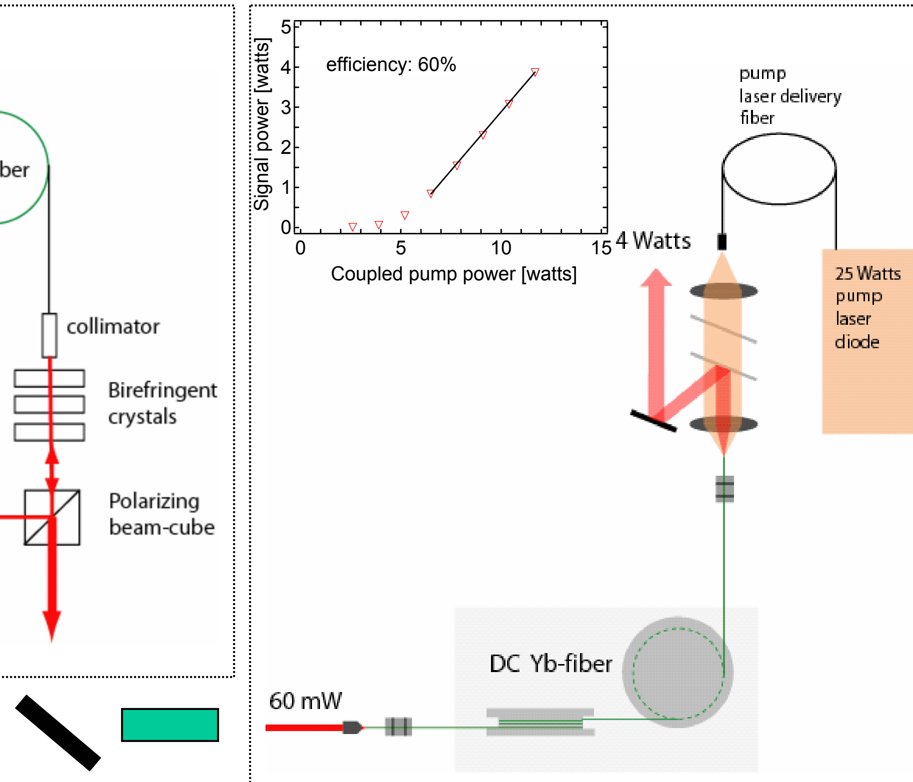
15 mW
300 pJ

Pre-Amplifier



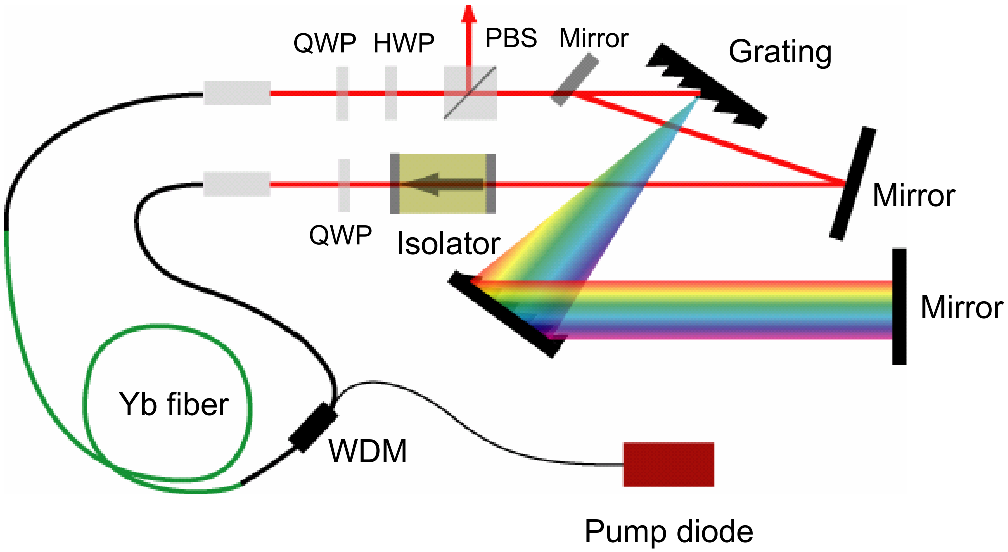
60 mW
1.2 nJ

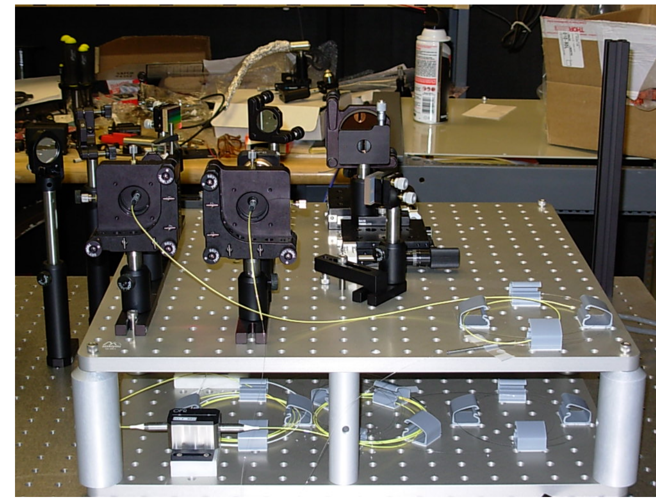
Amplifier



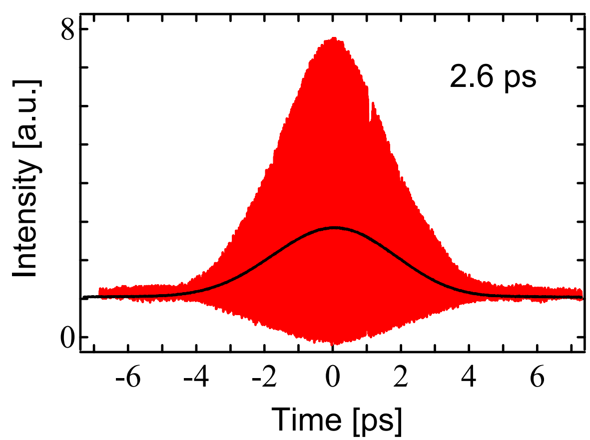
4 W
80 nJ

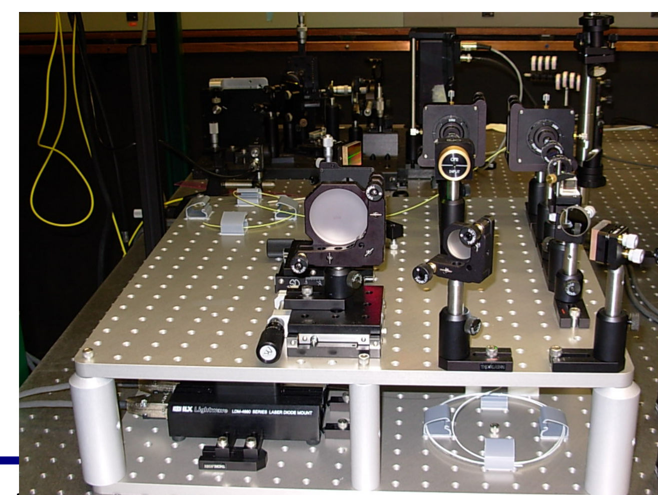
The 50 MHz Oscillator



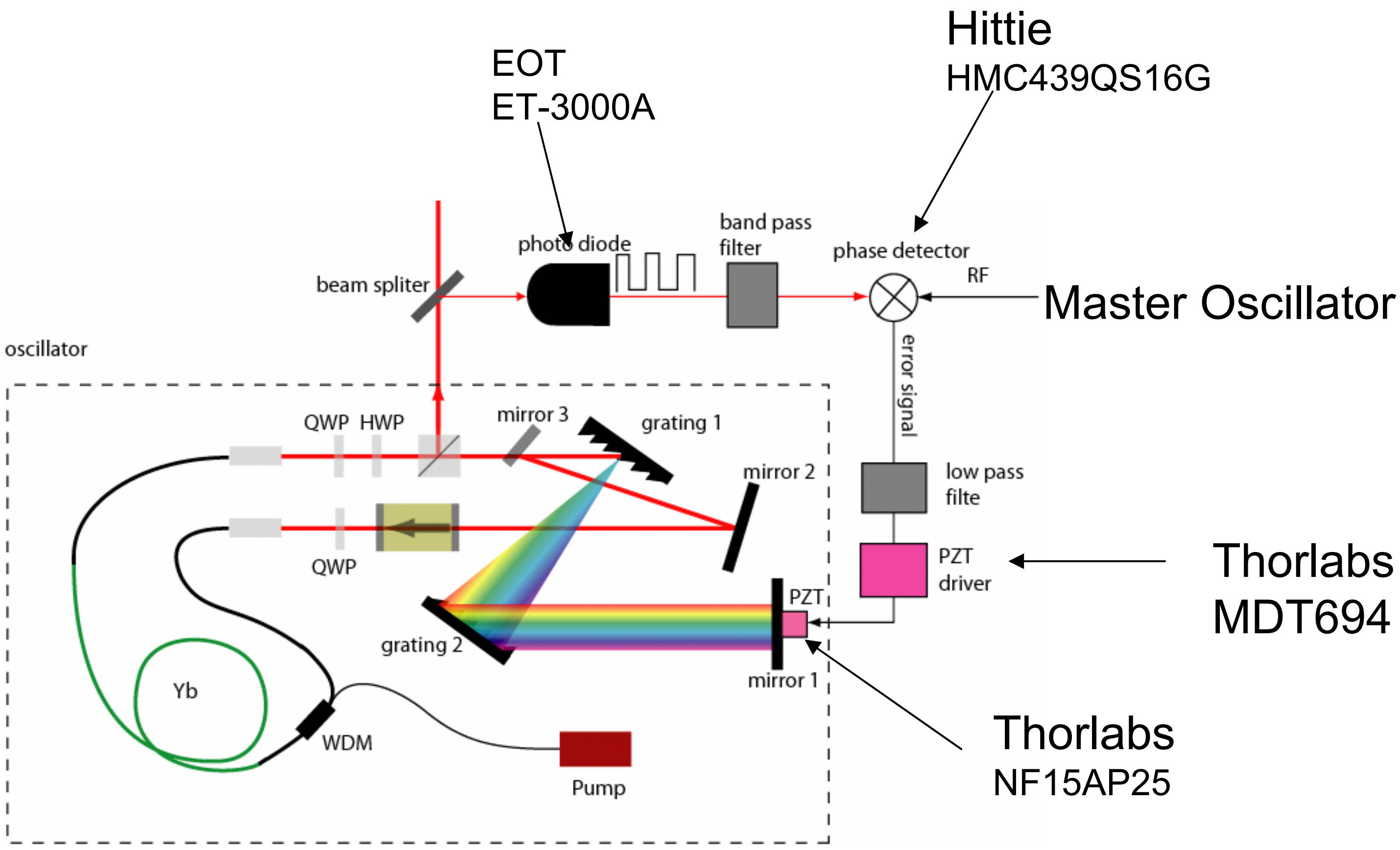


λ = 1040 nm
pulse duration ~ 2.5 ps
power ~ 15 mW
f_r ~ 50 MHz

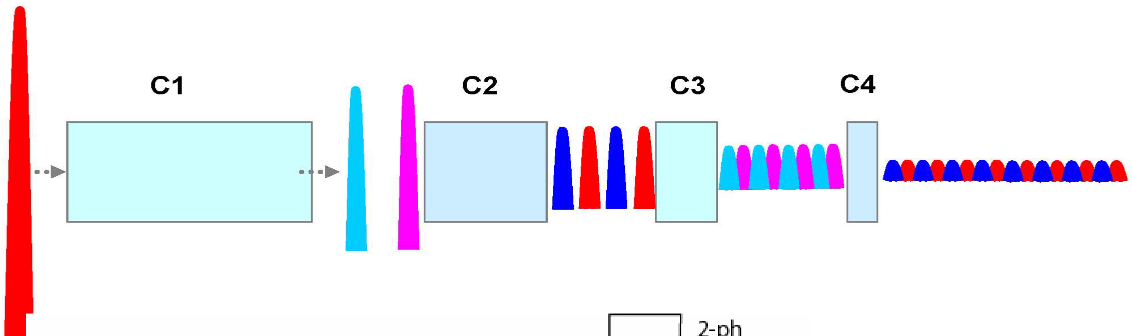


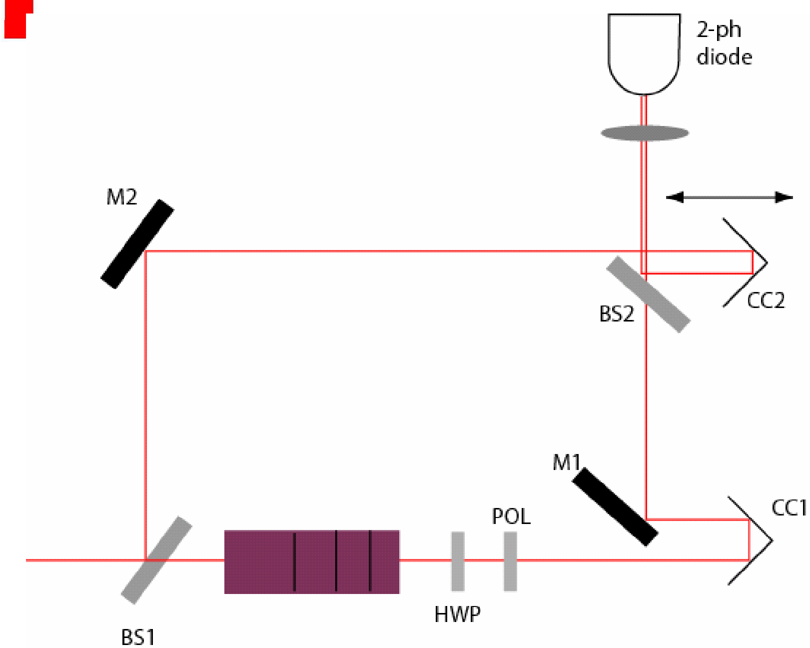


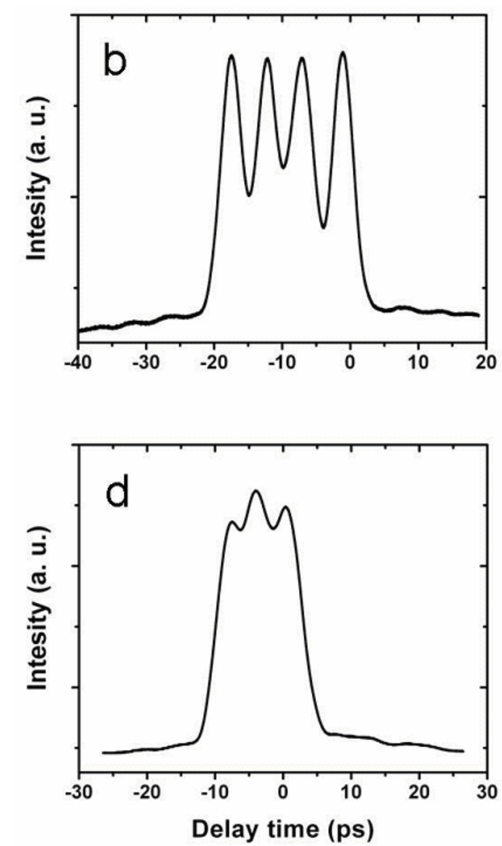
Phase-lock loop for timing stabilization



Temporal Shaping



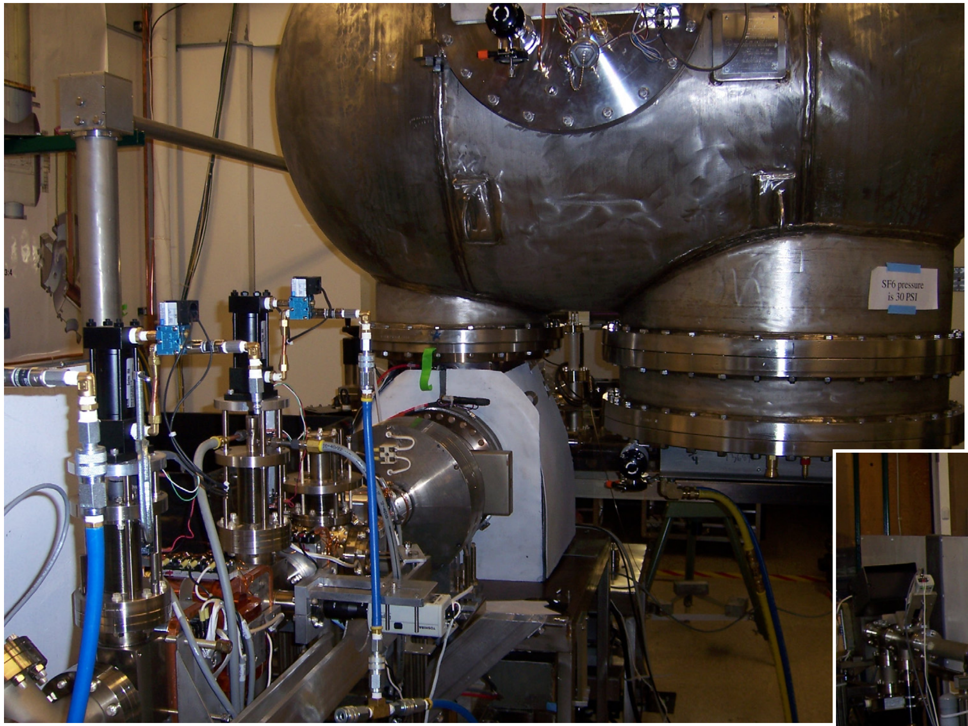


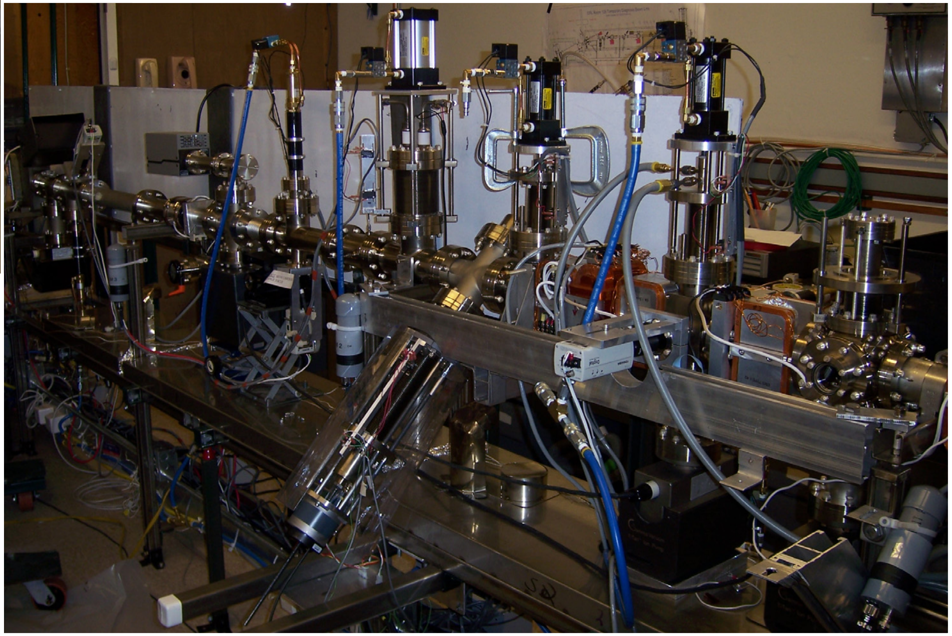


We use an 'optical pulse-stretcher' to get 20-40 ps flat-top pulses from a 2 ps laser

laser shaping: transverse

Gun Characterization Beamline





Initial Results

Three methods for transverse emittance measurement

- View screen + variable solenoid (low current)
- Wire scanner + variable solenoid (low current)
- Pair of slits with a scanning magnet (high current)

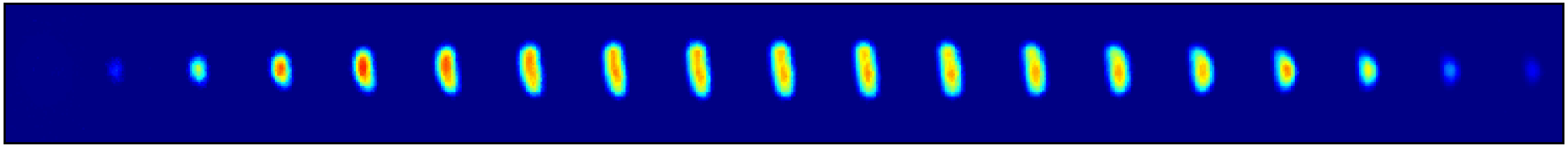
These agree to within ~10% at low current

High current measurements will begin soon

Bunch length/cathode temporal response

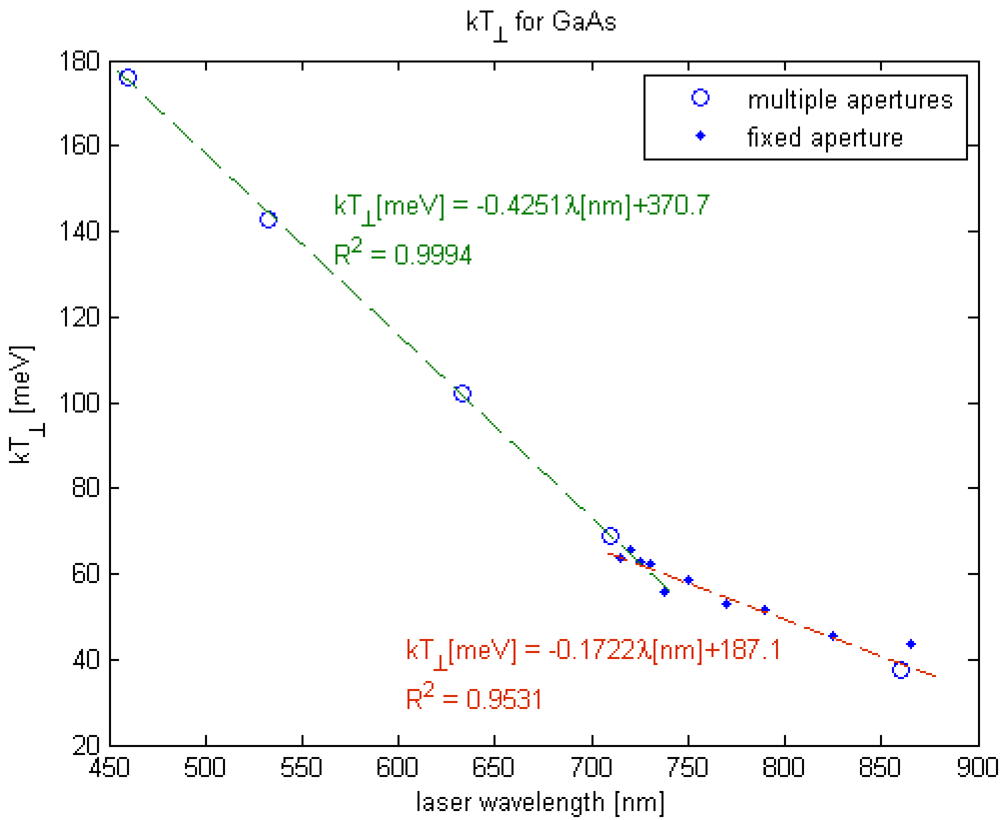
Deflection cavity + view screen/wire scanner/slits -> Cavity is almost complete

Max Current to date: 5 mA, ready to go for 100mA!

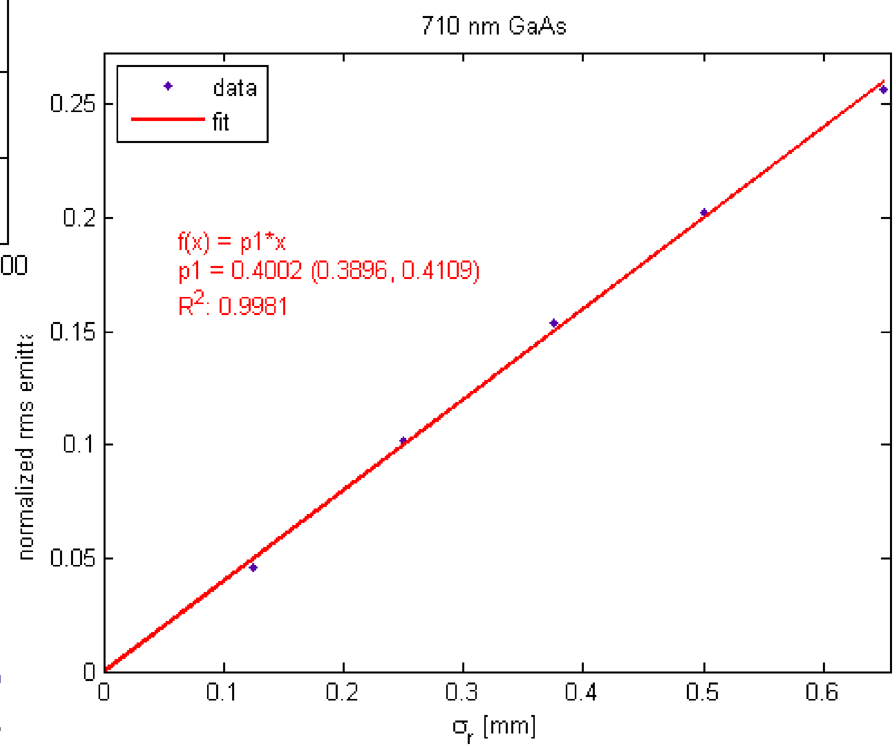


This shows images of a beamlet after passing through one slit (scanned using a corrector)

Thermal Emittance Data



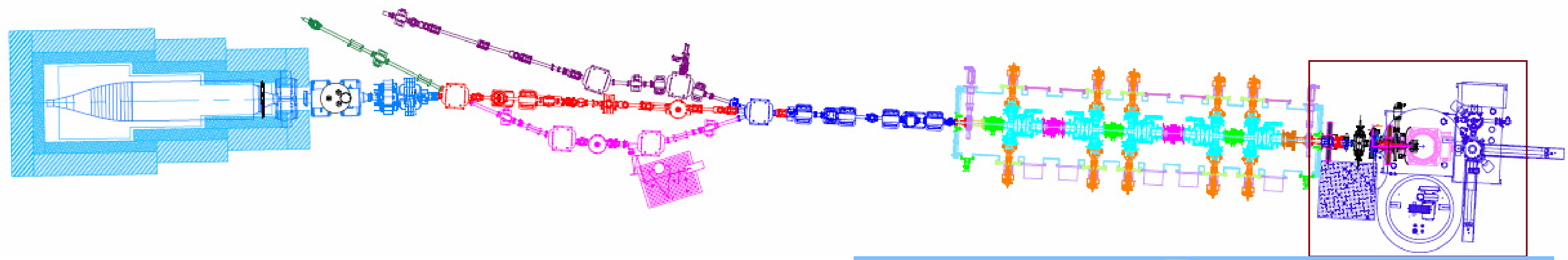
$$\varepsilon_{n,rms} = \sigma_{rms}\sqrt{\frac{kT}{mc^2}}$$

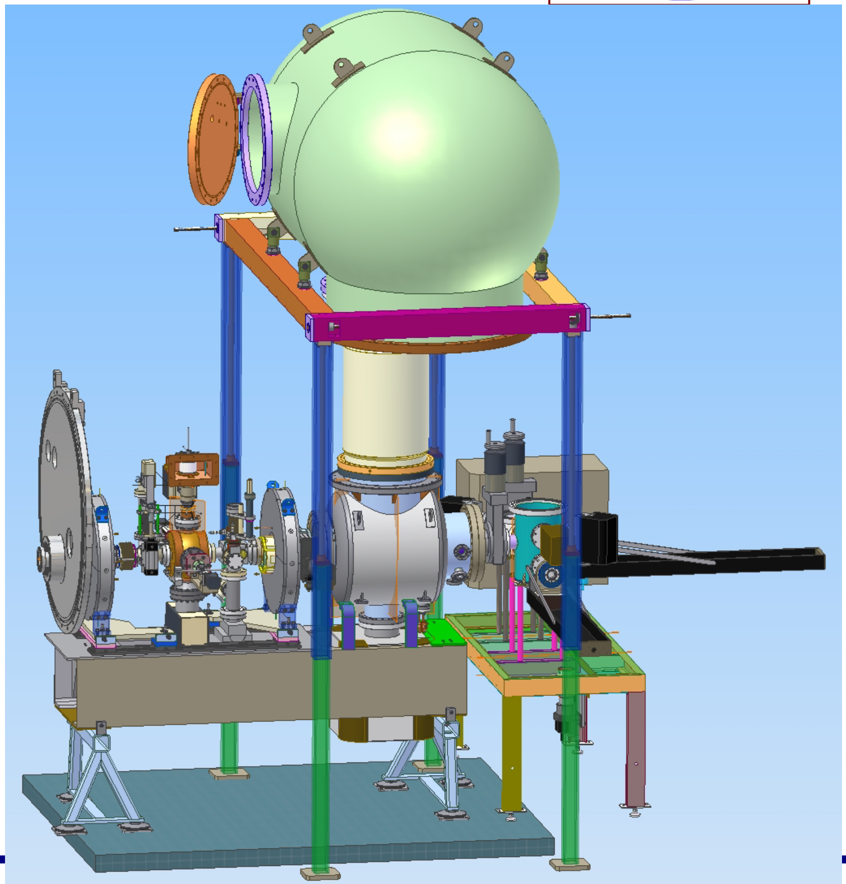


Data taken at 250 kV, 1 μA

Beamlines

Low Energy Section

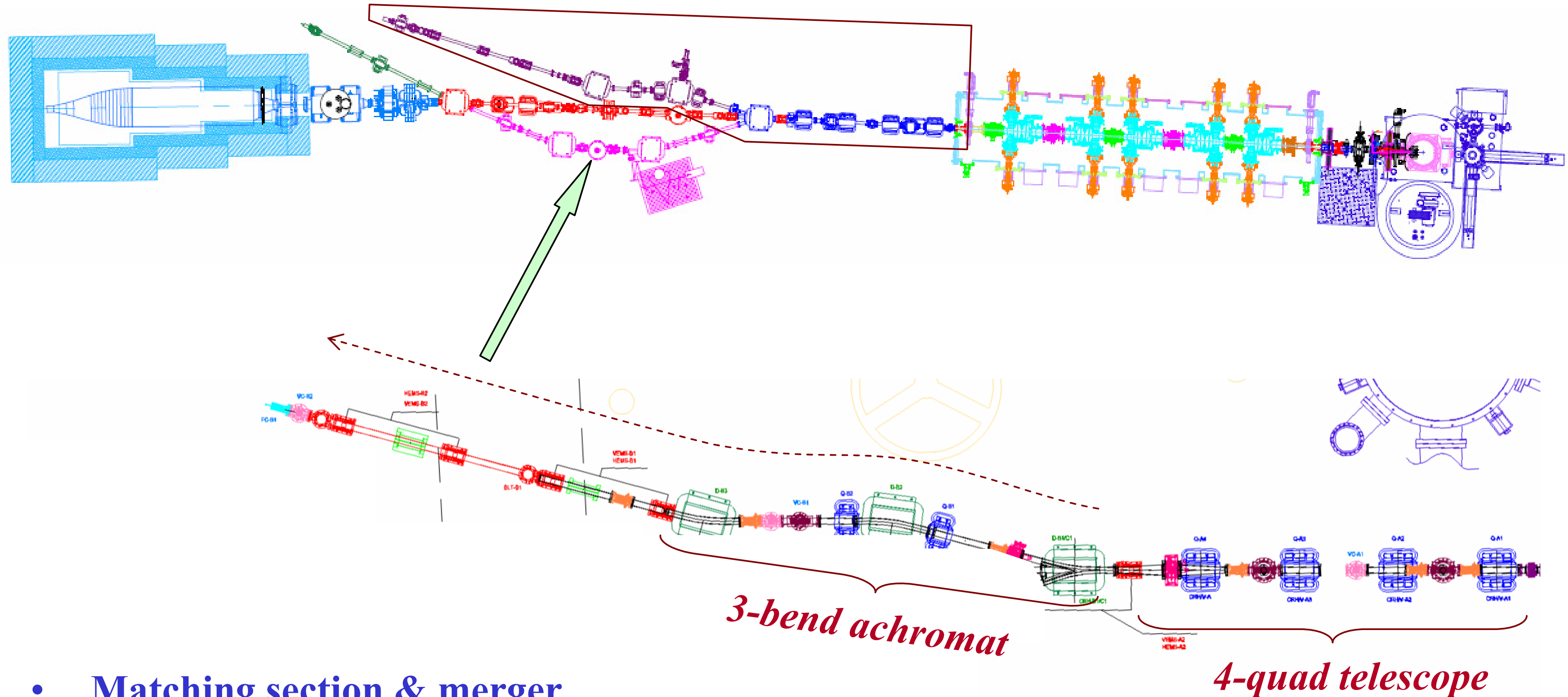




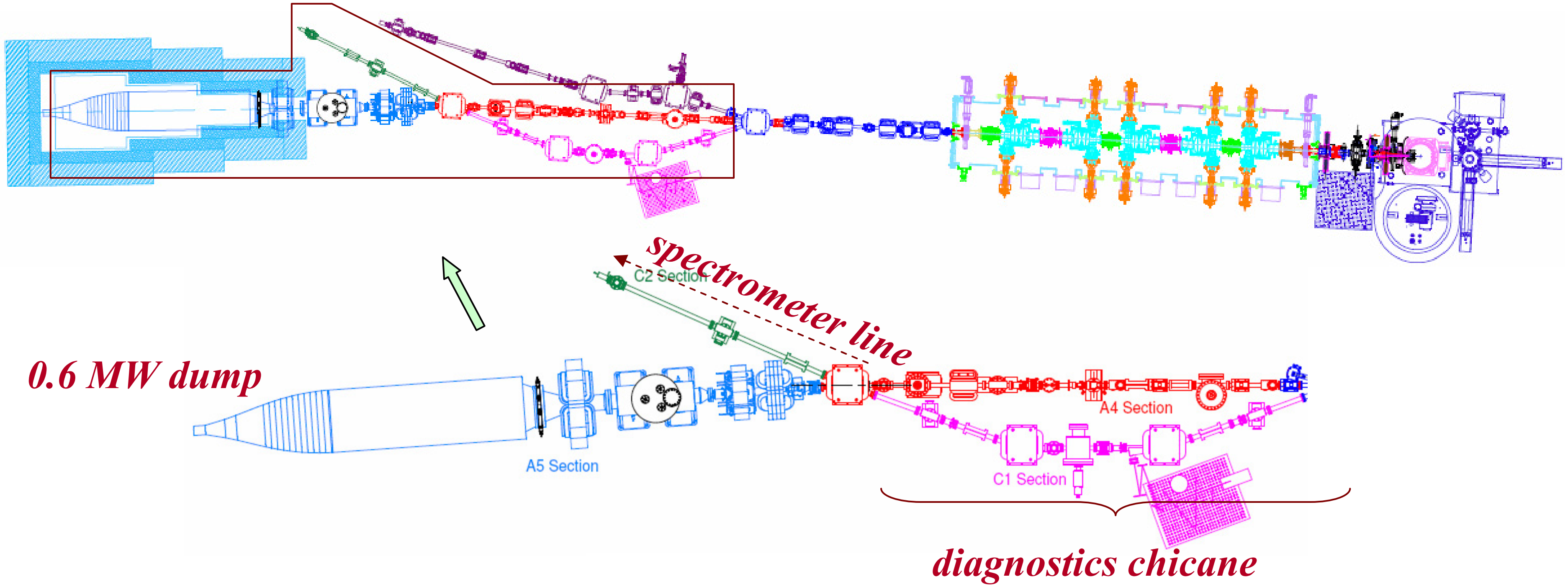
Injector front end

- Two solenoids for emittance compensation and matching into the injector's linac
- Copper buncher cavity that shortens the bunch by ×6

ERL injector components



- **Matching section & merger**
- 4-quad telescope for for matching into merger & main linac
- 15° 3-bend achromat followed by diagnostics section designed to take low beam power

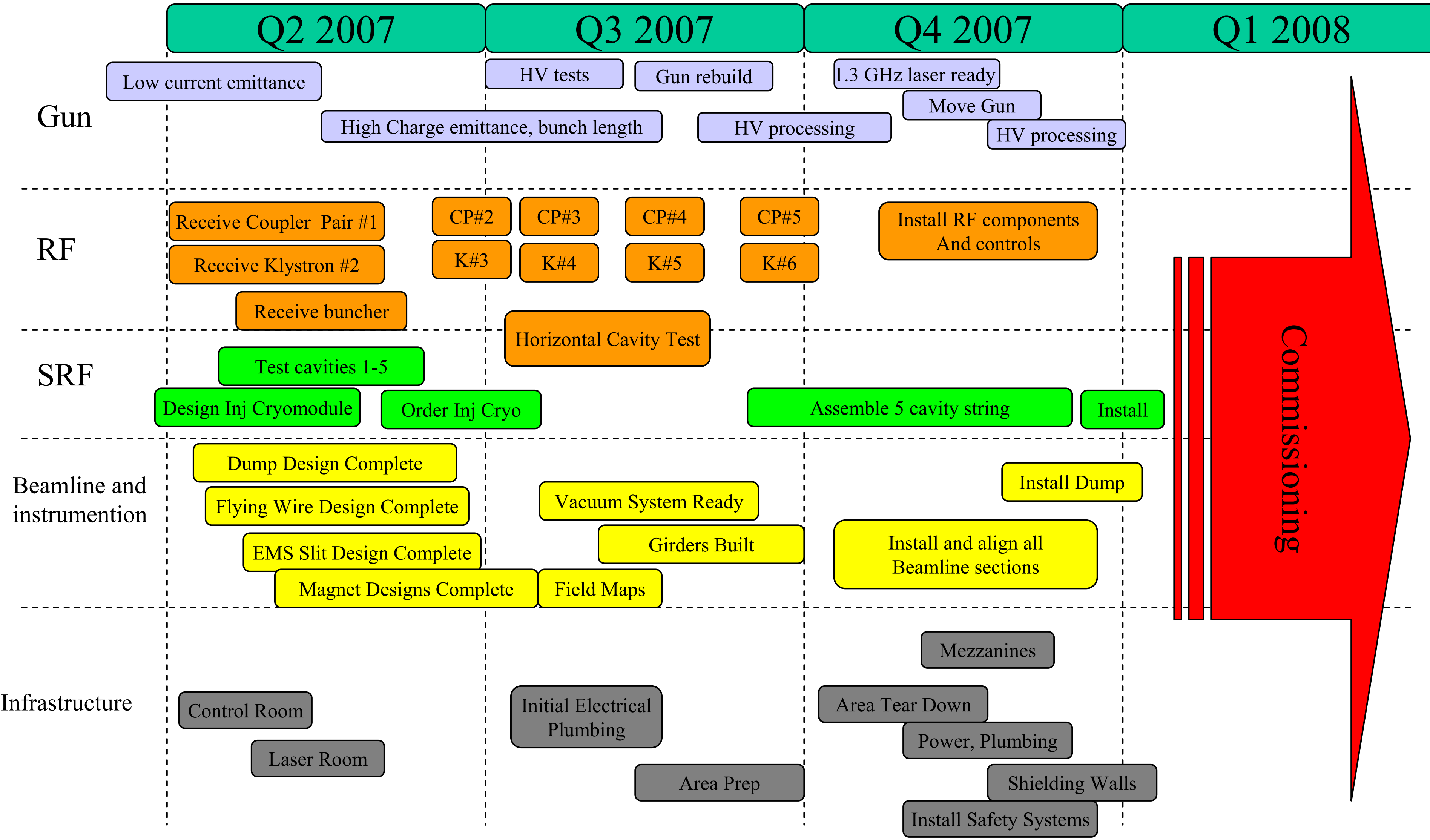


Diagnostics line & high power dump

- chicane and straight-ahead beamline which handles average beam current of up to 100 mA
- Interceptive and non-interceptive diagnostics for characterization of single bunch and intra-bunch effects

Commissioning and Planning

Schedule


Q2 2007
Q3 2007
Q4 2007
Q1 2008
Gun
Low current emittance
HV tests
Gun rebuild
1.3 GHz laser ready
Move Gun
High Charge emittance, bunch length
HV processing
HV processing
RF
Receive Coupler Pair #1
Receive Klystron #2
Receive buncher
CP#2
CP#3
CP#4
CP#5
K#3
K#4
K#5
K#6
Install RF components
And controls
Horizontal Cavity Test
SRF
Test cavities 1-5
Design Inj Cryomodule
Order Inj Cryo
Assemble 5 cavity string
Install
Beamline and
instrumentation
Dump Design Complete
Flying Wire Design Complete
EMS Slit Design Complete
Magnet Designs Complete
Field Maps
Vacuum System Ready
Girders Built
Install Dump
Install and align all
Beamline sections
Infrastructure
Control Room
Laser Room
Initial Electrical
Plumbing
Area Prep
Mezzanines
Area Tear Down
Power, Plumbing
Shielding Walls
Install Safety Systems
Commissioning

Acknowledgements

This work is supported by NSF.

PHY-0131508