The ERL Injector Project at Cornell University

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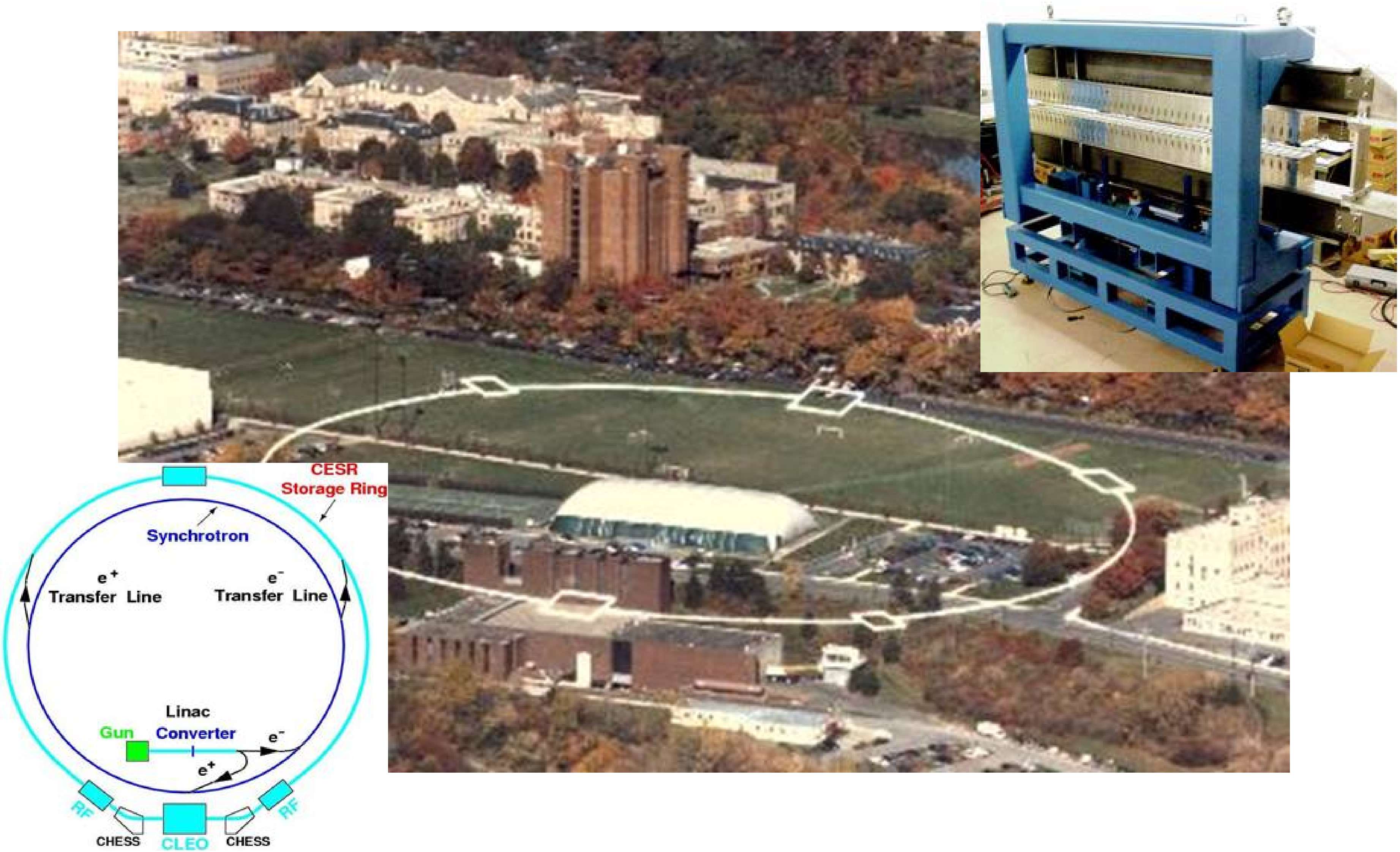
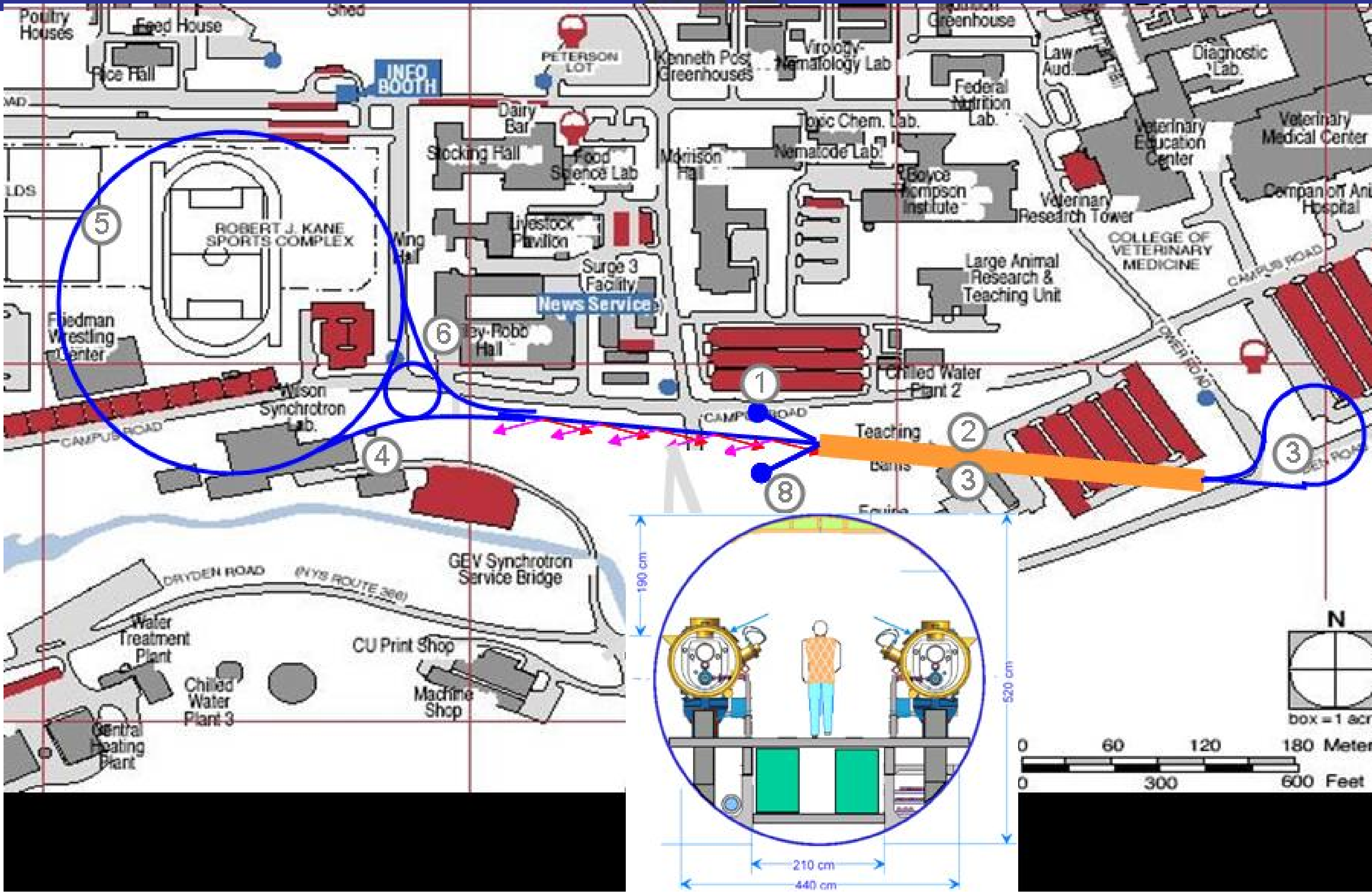
For the Cornell ERL Team

CESR at Cornell



ERL at Cornell



Outline

- Project Overview
- Gun and Laser Progress
- Beam Experiments and Results
- SRF and RF
- Diagnostic Beamlines
- Construction and Commissioning

Our Charter . . .

Build an injector for an ERL to demonstrate we can produce a beam with the required properties

Understand the limitations in the injector (both physics and technology) to allow for improved design in the future

Develop a cost estimate for a full ERL

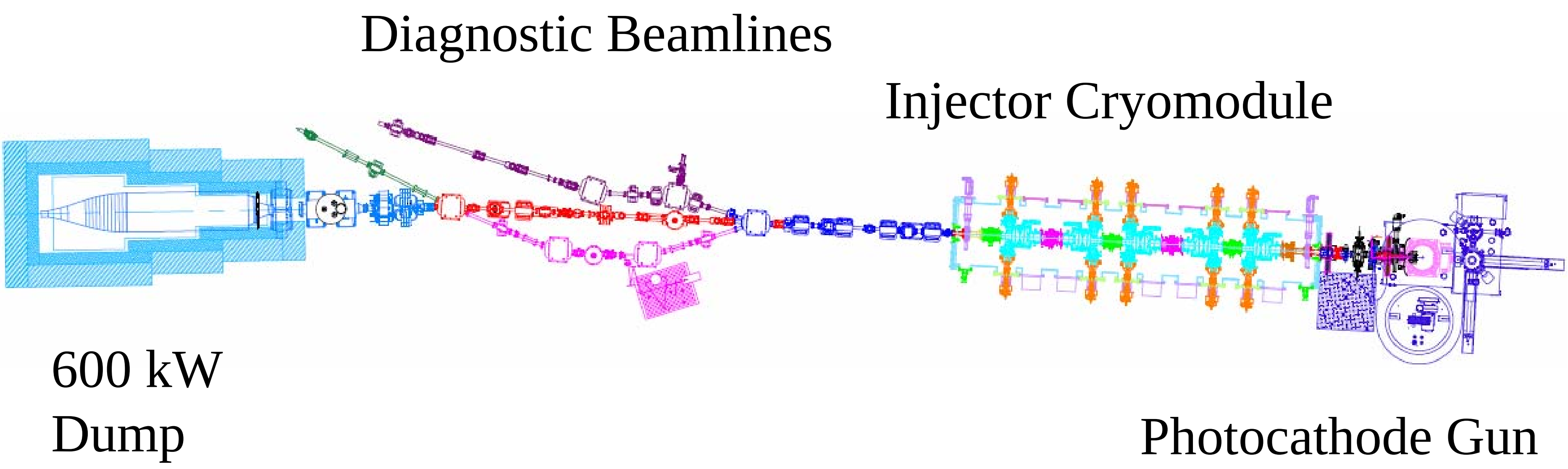
Injector Requirements

- 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%**

Many Challenges!

- 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 emittance.
- 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)

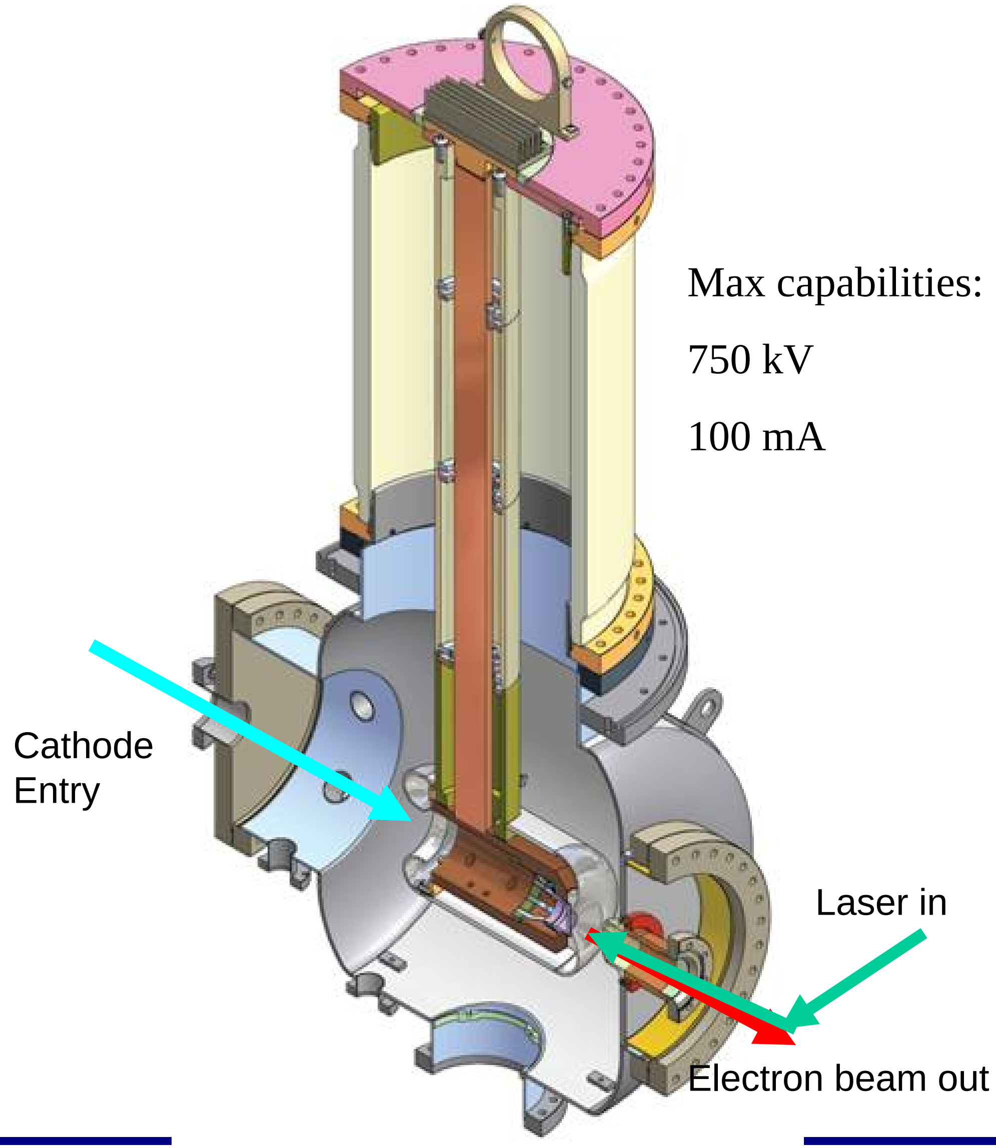
ERL Injector Layout – L0 Area



- Limited diagnostics after the gun (before the cryo-module)
- Full interceptive diagnostics capabilities at 5-15 MeV
- Limited full power diagnostics

Photoemission Gun and Laser System

750 kV Gun



Max capabilities:

750 kV

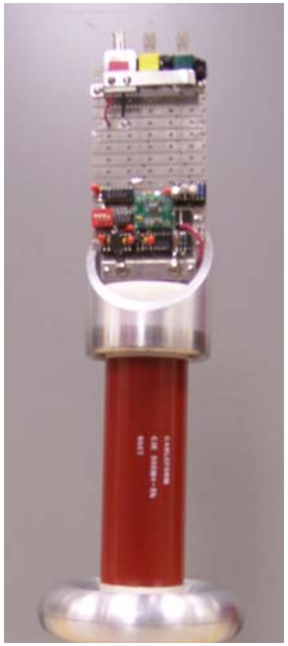
100 mA

750 kV Power Supply

750 kV, 100 mA
DC supply

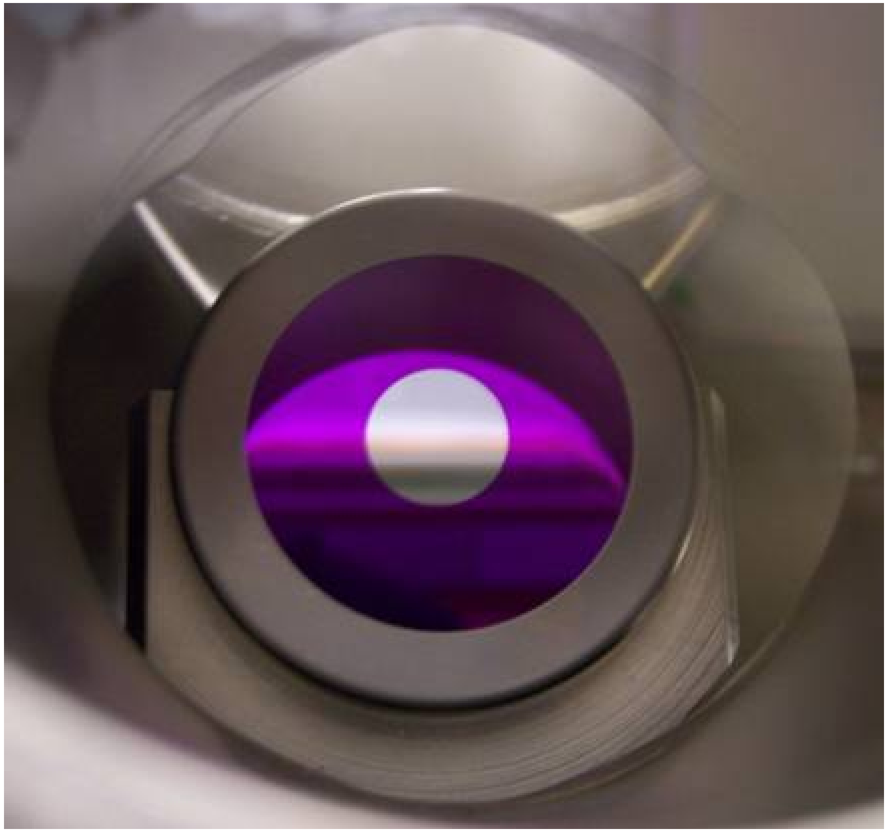
Kaiser Systems, Inc
in Beverly, MA

Inside the SF_6 Tank



Floating ammeter mounted on the processing resistor

GaAs Photocathode



GaAs is still our cathode of choice . . .

- good quantum efficiency

- low thermal emittance

- fast time response (@520 nm)

But . . .

- need extreme UHV

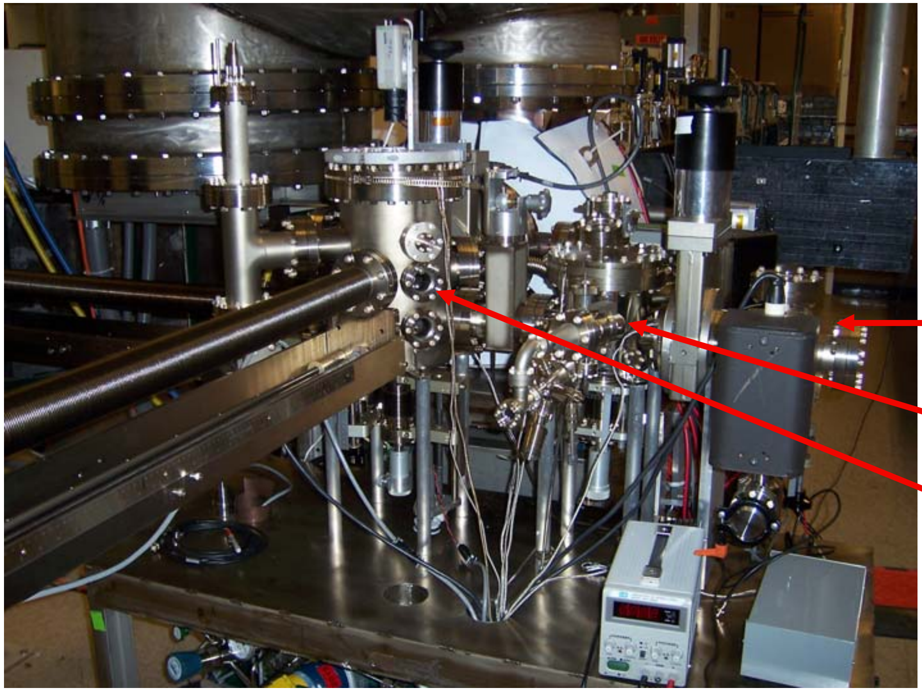
- limited lifetime

- minimum thermal emittance near bandgap (lower QE)

- thermal emittance degrades at higher QE

. . . We'll willing to try other cathodes

Load Lock System



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

Can swap a fresh cathode into the gun in ~30 minutes

HV Performance

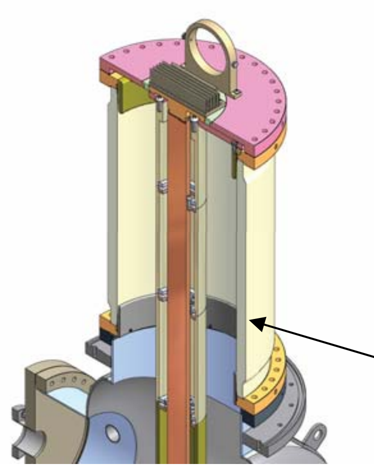
- For optimum emittance, need to operate between 500-600 kV
- So far, we have only reached 420 kV
- What are the problems and how to solve them?

Must have a way to control field emitted electrons near the insulator

Prepare electrodes for minimal field emission

Ceramic Properties

Must have a way to bleed off any field emitted electrons



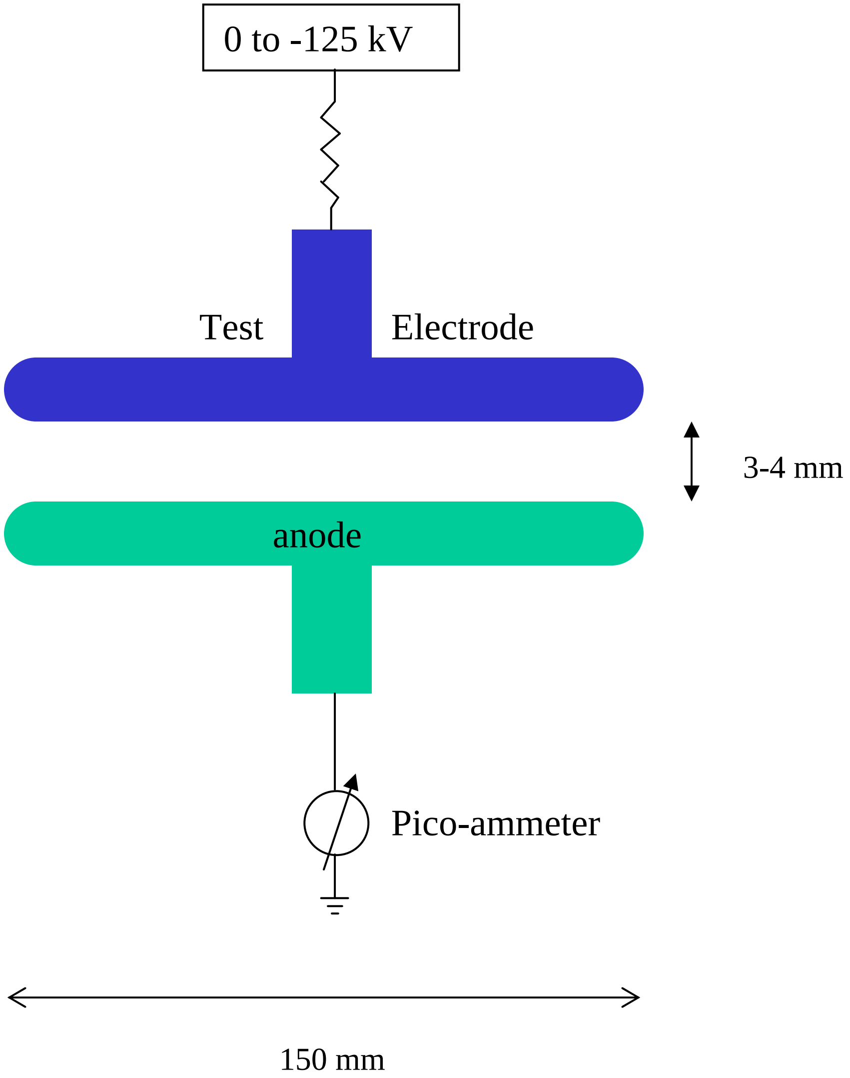
The resistive coating on the first ceramic was not done well (R ~ 7000 G-Ohm). Experienced a vacuum leak due to punch-through at 330kV

CPI made a second ceramic with a better coating ~100 G-Ohm. Good up to ~420 kV

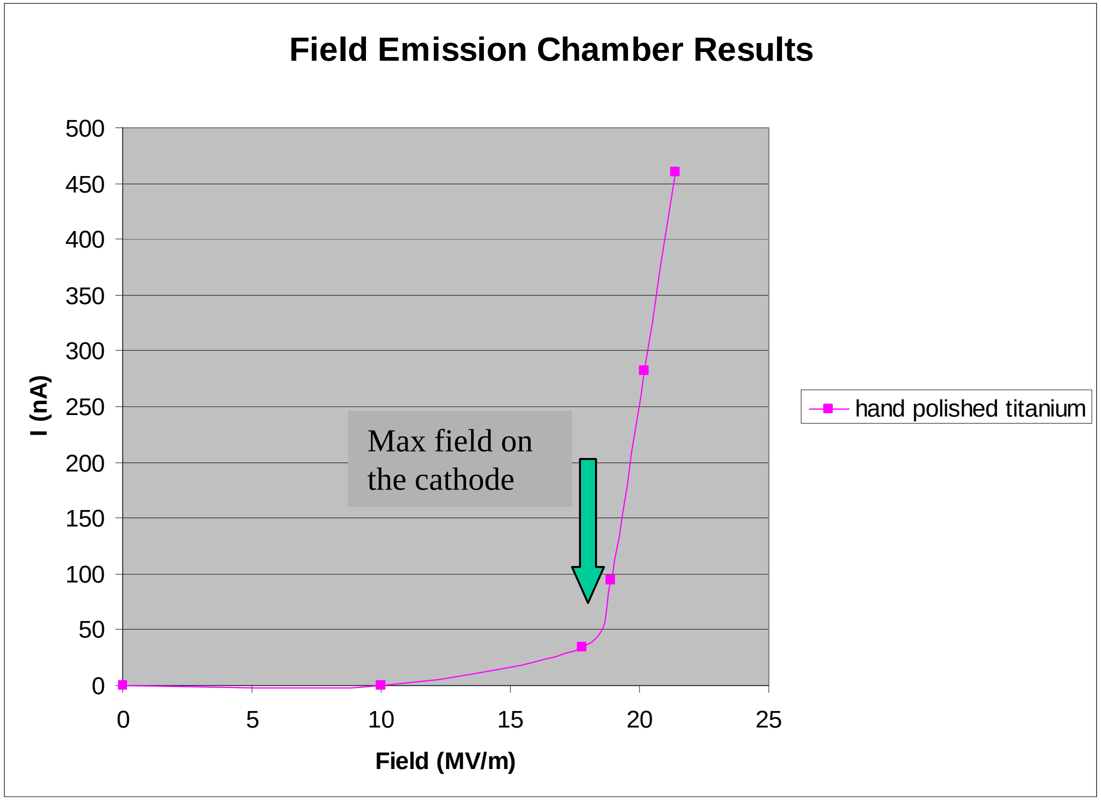
Third Try

Daresbury Lab purchased a ceramic with a bulk resistivity doped alumina, which has worked well (480 kV). We just ordered one for our geometry.

HV Testing – Large Area Electrodes



Initial Results



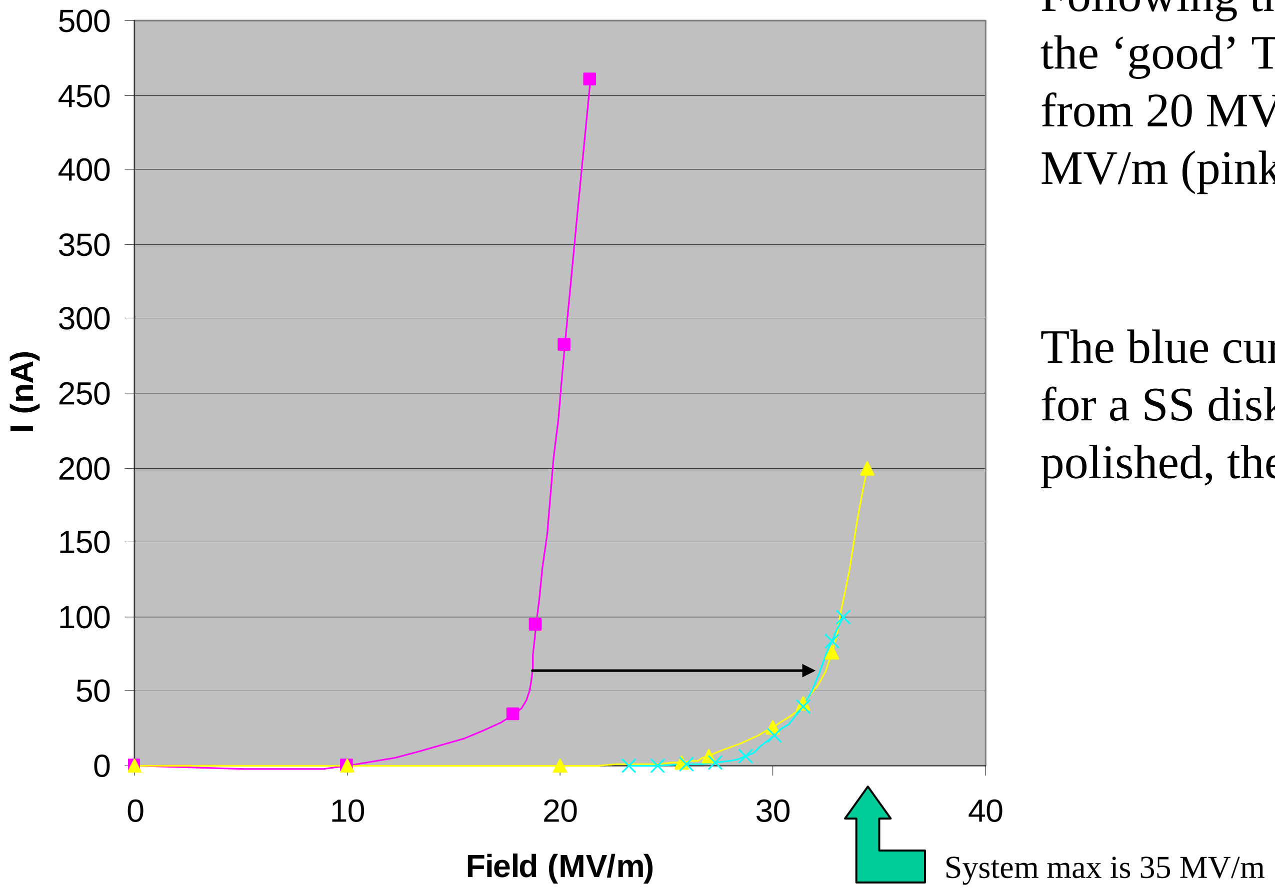
This titanium disk was hand polished and reached a field higher than the gun will see.

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

"SRF-clean" results

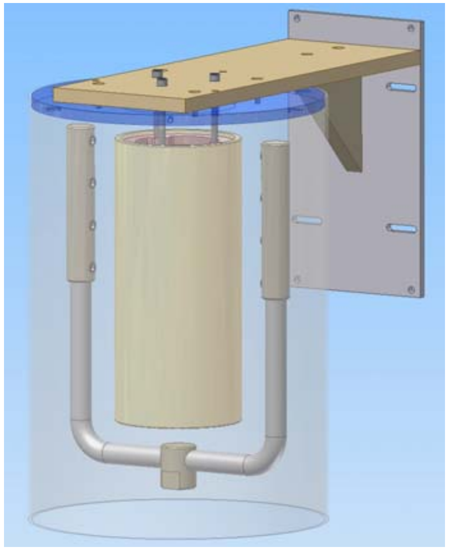


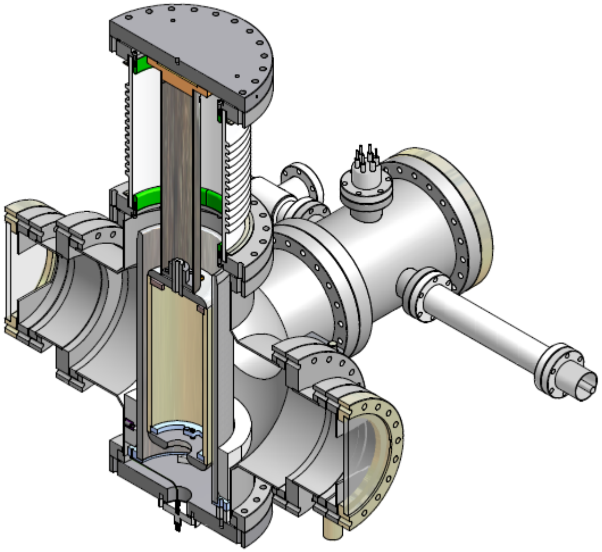
Following the new procedures, the 'good' Ti electrode improved from 20 MV/m to nearly 35 MV/m (pink to yellow curve)

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

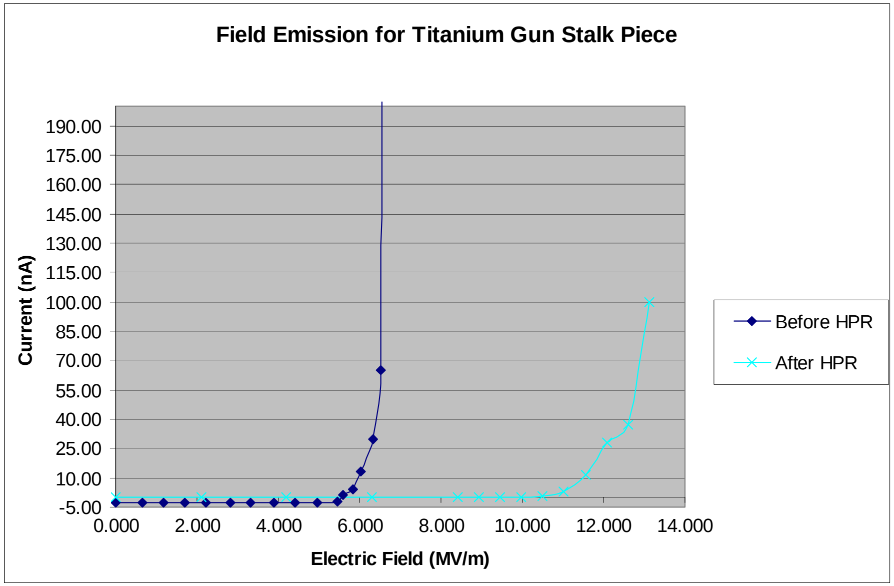
HV Testing – Real Gun Parts

HPR equipment for large gun electrodes





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



New Gun Assembly Procedure

1. Clean all electrodes per the ‘SRF-clean’ procedure
2. Pre-test 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.

Present Gun Status

Currently:

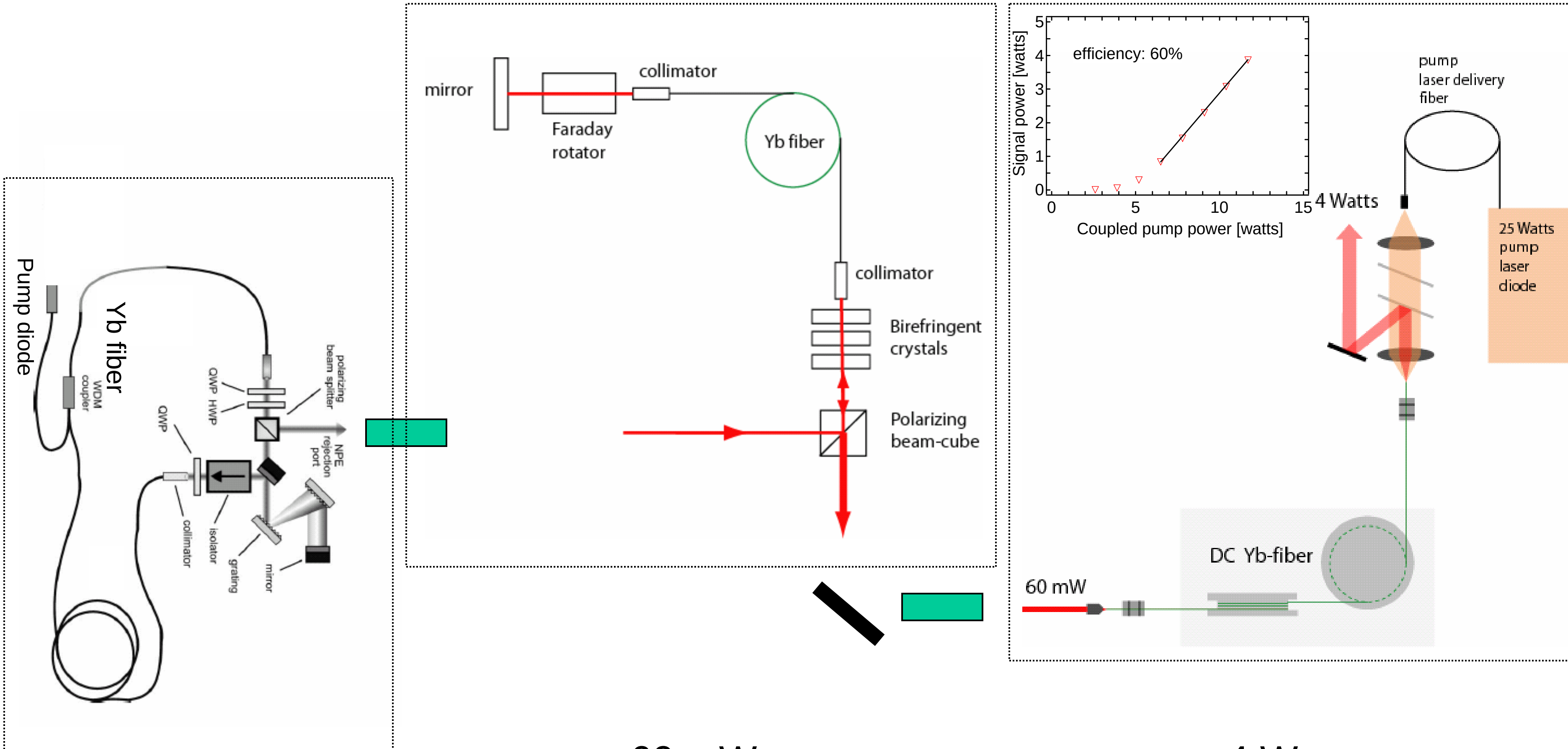
- Reached 420 kV, beam experiments carried out at 250/350 kV
- 20 mA DC current obtained (no life-time measurements yet)
- 70 pC/bunch at low duty factor
- GaAs cathode performance typically 6-10% QE

Next Steps:

- New ceramic on order
- Continue tests with electropolishing/HPR of electrodes
- HV modeling for field emission mitigation/future insulator

Fiber Laser Description – 50 MHz

Oscillator | Pre-Amplifier | Amplifier

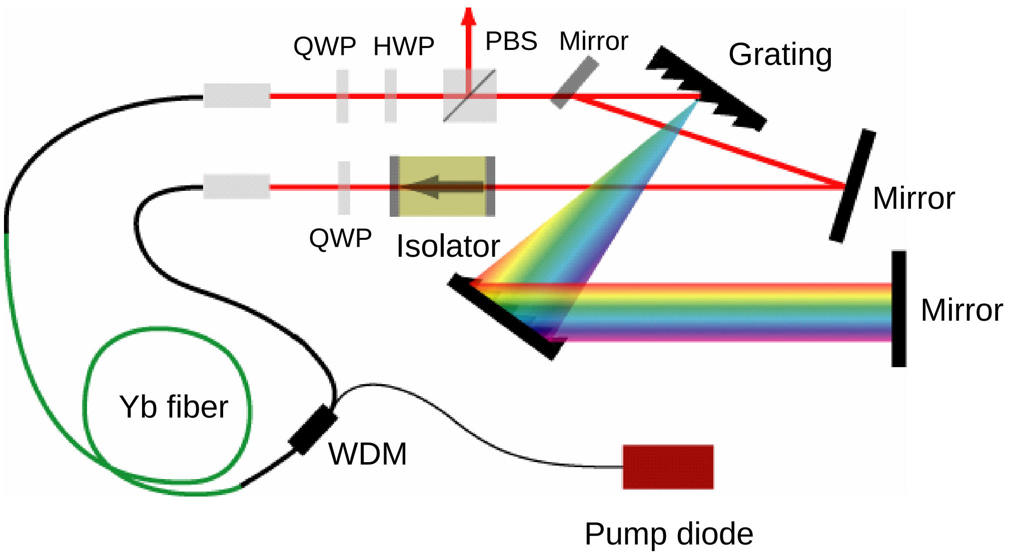


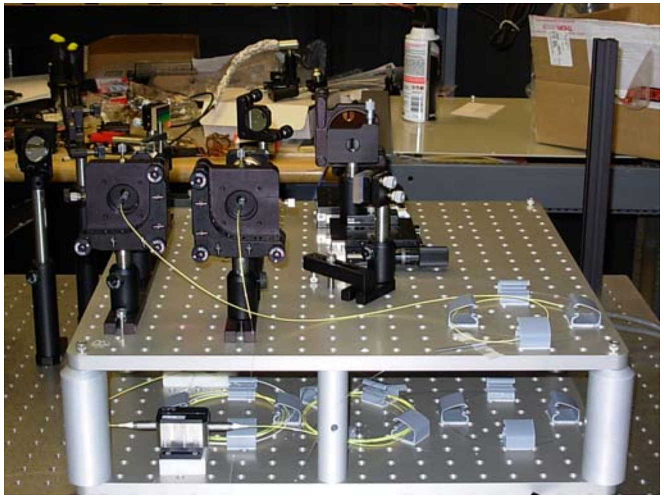
15 mW
300 pJ

60 mW
1.2 nJ

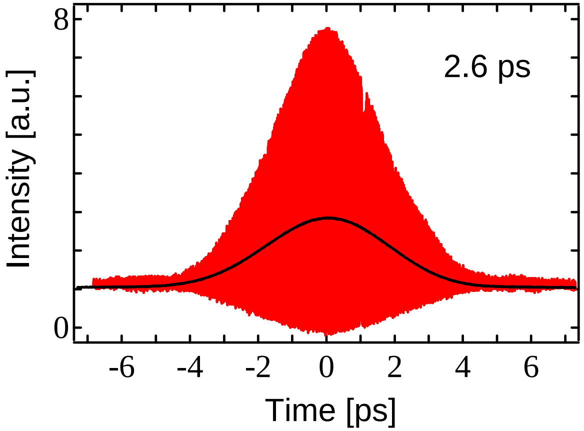
4 W
80 nJ

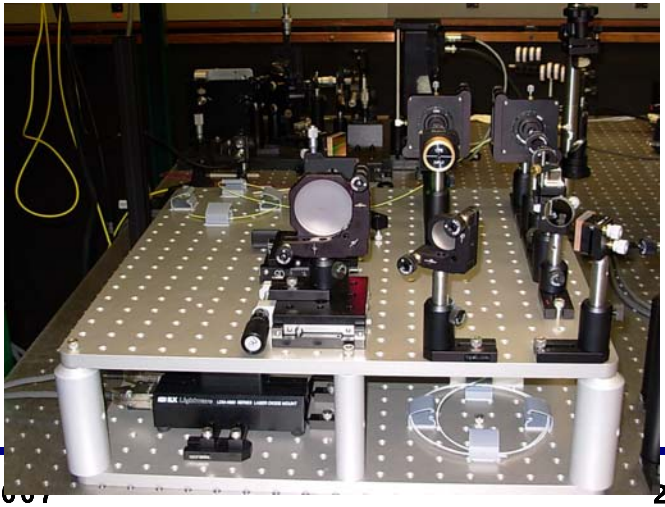
The 50 MHz Laser Oscillator



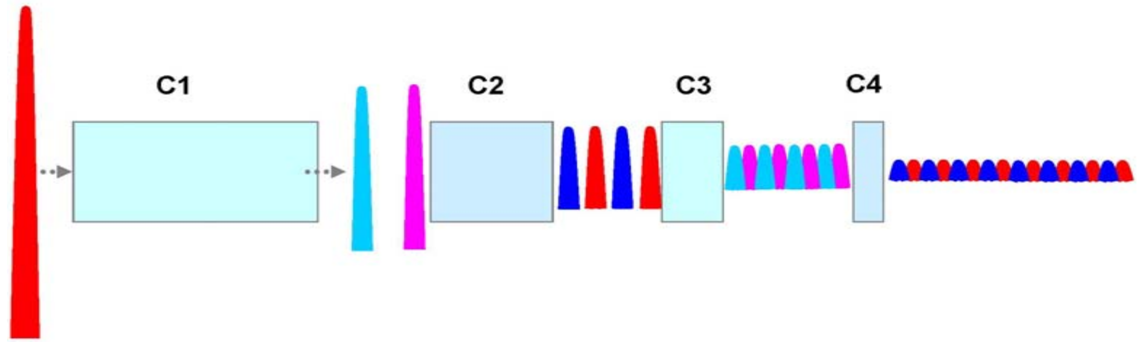


λ = 1040 nm
pulse duration ~ 2.5 ps
power ~ 15 mW
f_r ~ 50 MHz





Laser Shaping



We use an ‘optical pulse-stretcher’ to get 20-40 ps flat-top pulses from a 2 ps laser (DPA – divided pulse amplifier)

A ‘beer-can’ distribution is the goal

Gauss to flat top transformation using a commerical aspheric lens (Newport Corp)

Laser Summary

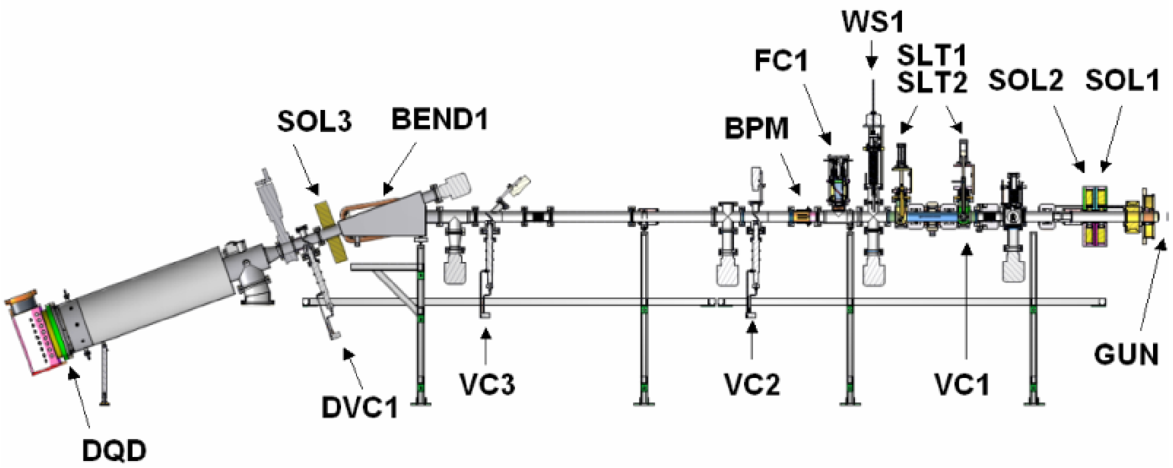
The laser itself works as advertised, need work on

- Synchronization
- Beam shaping
- Pulse control
- Transport to the gun
- Stability control (position, power)
- Laser beam ‘halo’
- 1.3 GHz oscillator
- Sensitivity to acoustical noise

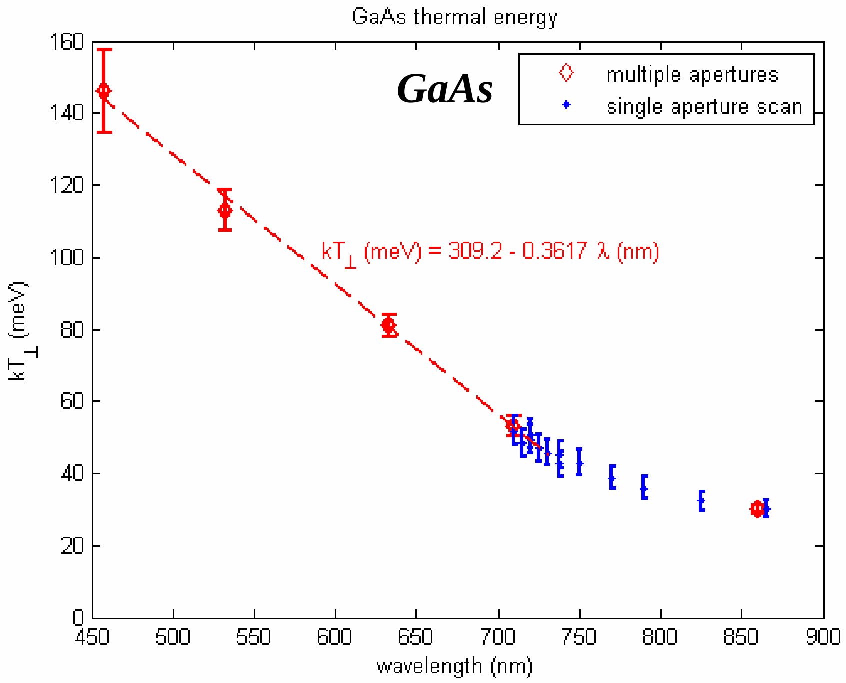
Beam Experiments and Data

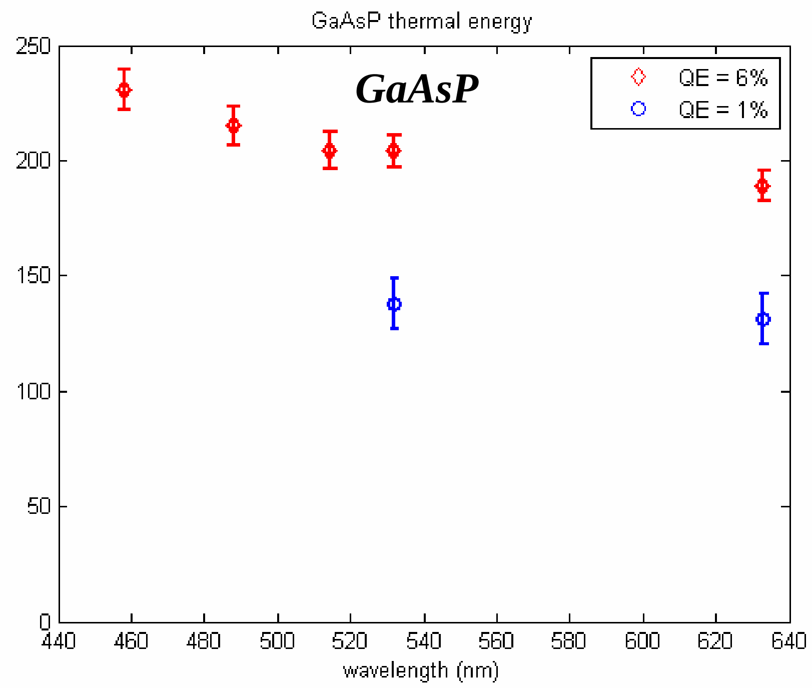
Initial Beam Tests

- Goal: full understanding of the beam phase space from the gun
- Gun & diagnostics line
- Full phase space characterization capability after the gun
- Temporal measurements with the deflecting cavity
- Lifetime studies



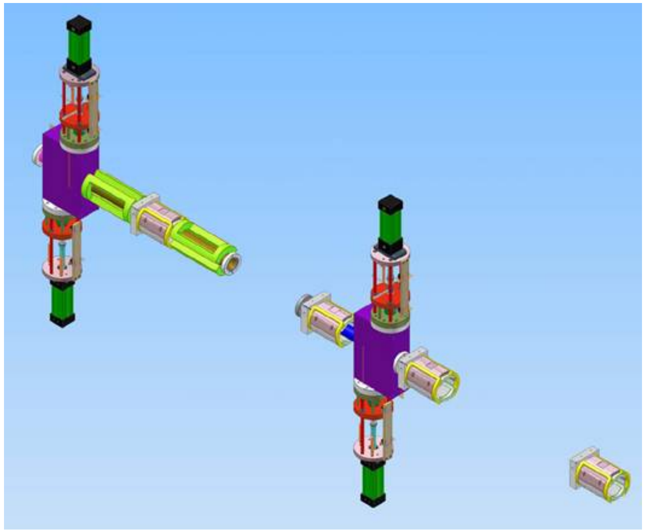
Thermal emittance

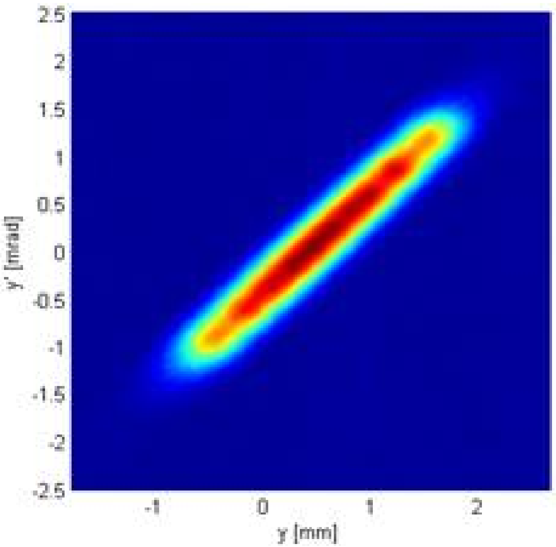




- $kT_{\perp}$ = ***121±8 meV*** at ***520 nm***
- or ***0.49 mm-mrad*** per ***1 mm*** rms
- GaAs still best overall perform.

Emittance measurement system

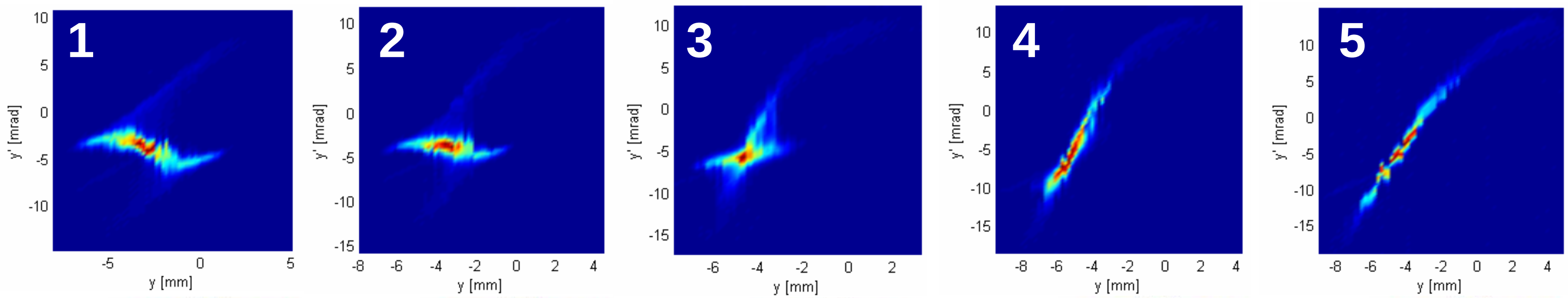




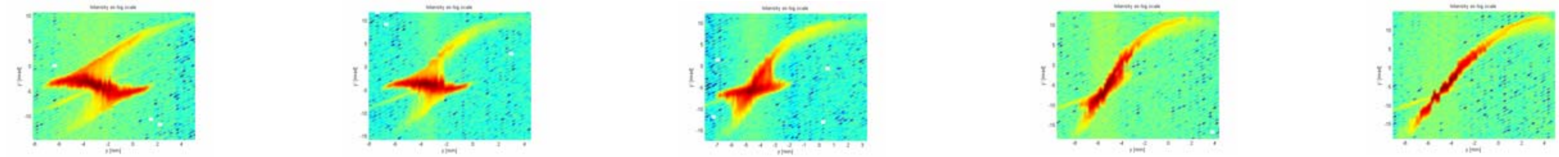
measured phase space

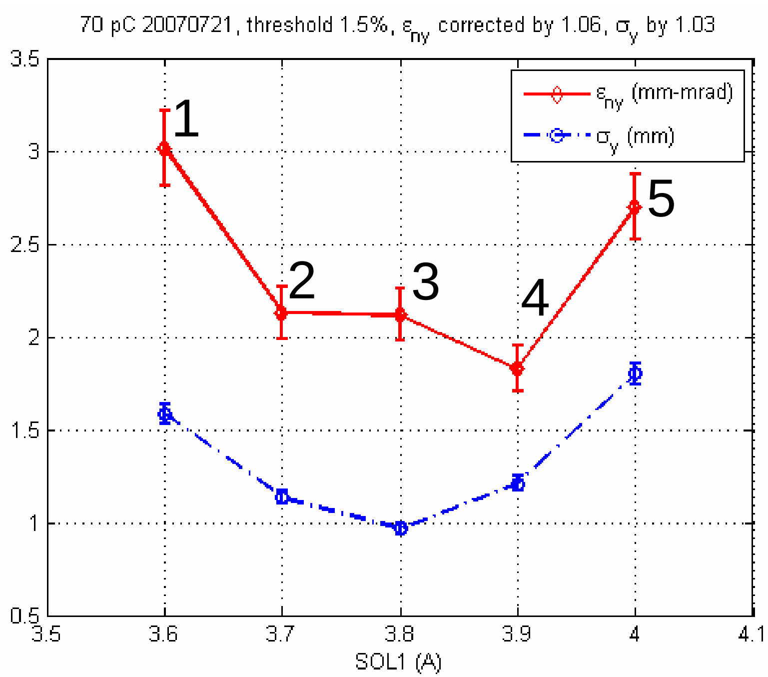
- Uses a pair of 20 μm precision slits to sample the beam
- Instead of scanning the slits, pairs of identical coils deflect and scan the beam across the slits
- armor slit intercepts most of the beam
- kW beam power handling

70 pC/bunch



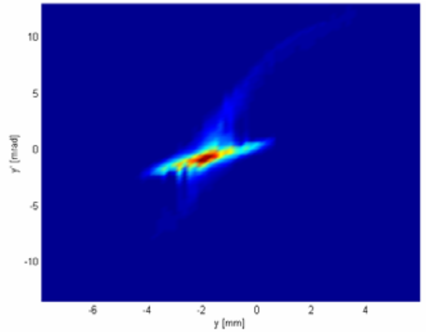
log scale



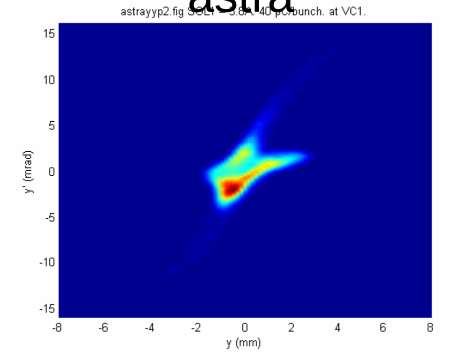


Good agreement with Astra prediction:
77 pC/bunch: about 2 mm-mrad

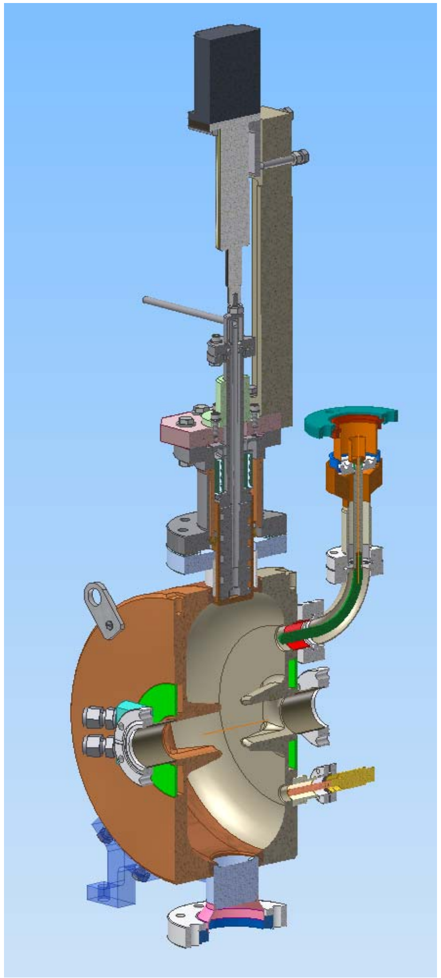
data



astra



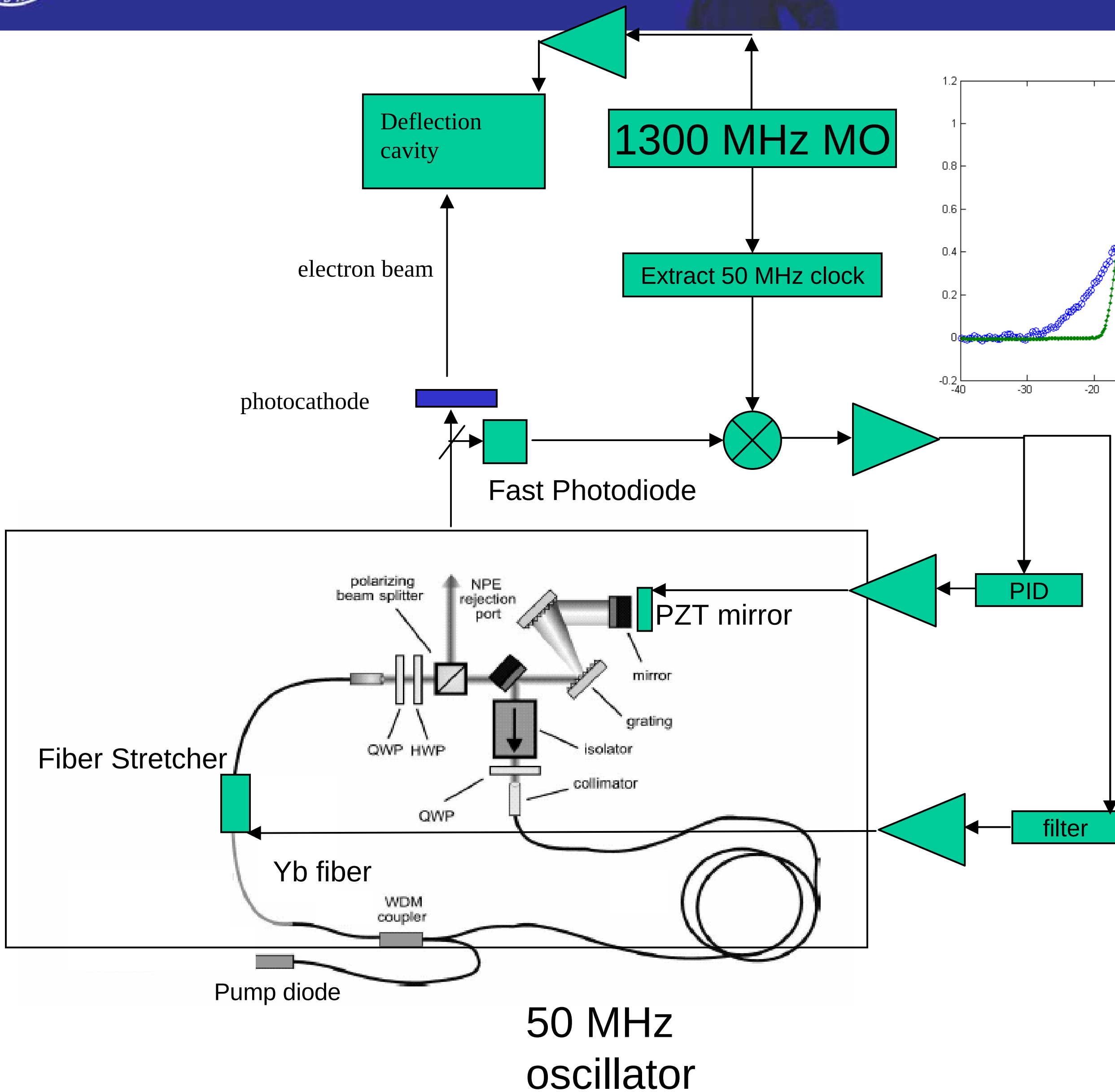
Cathode Response Time

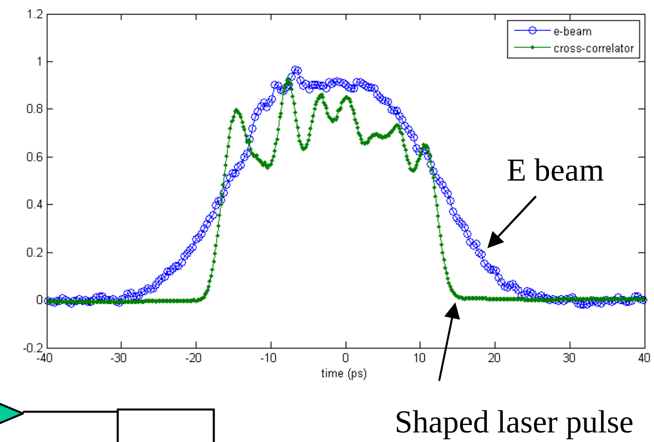


A deflecting cavity is used to transform bunch length into transverse spot on a viewscreen.

This gives a direct measurement of bunch length

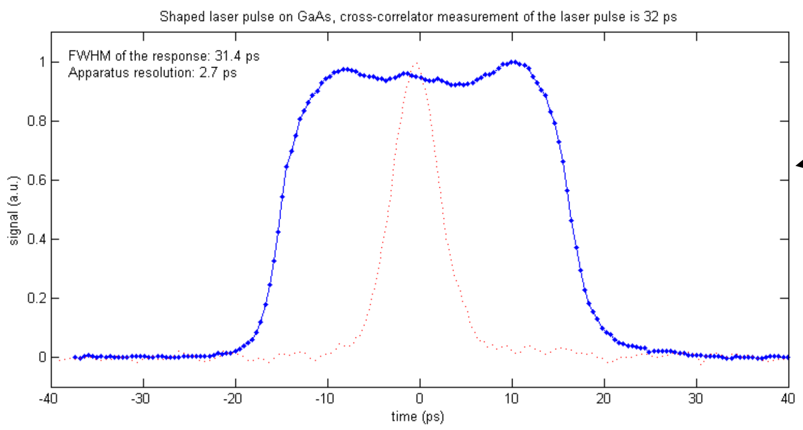
Cathode Response Time

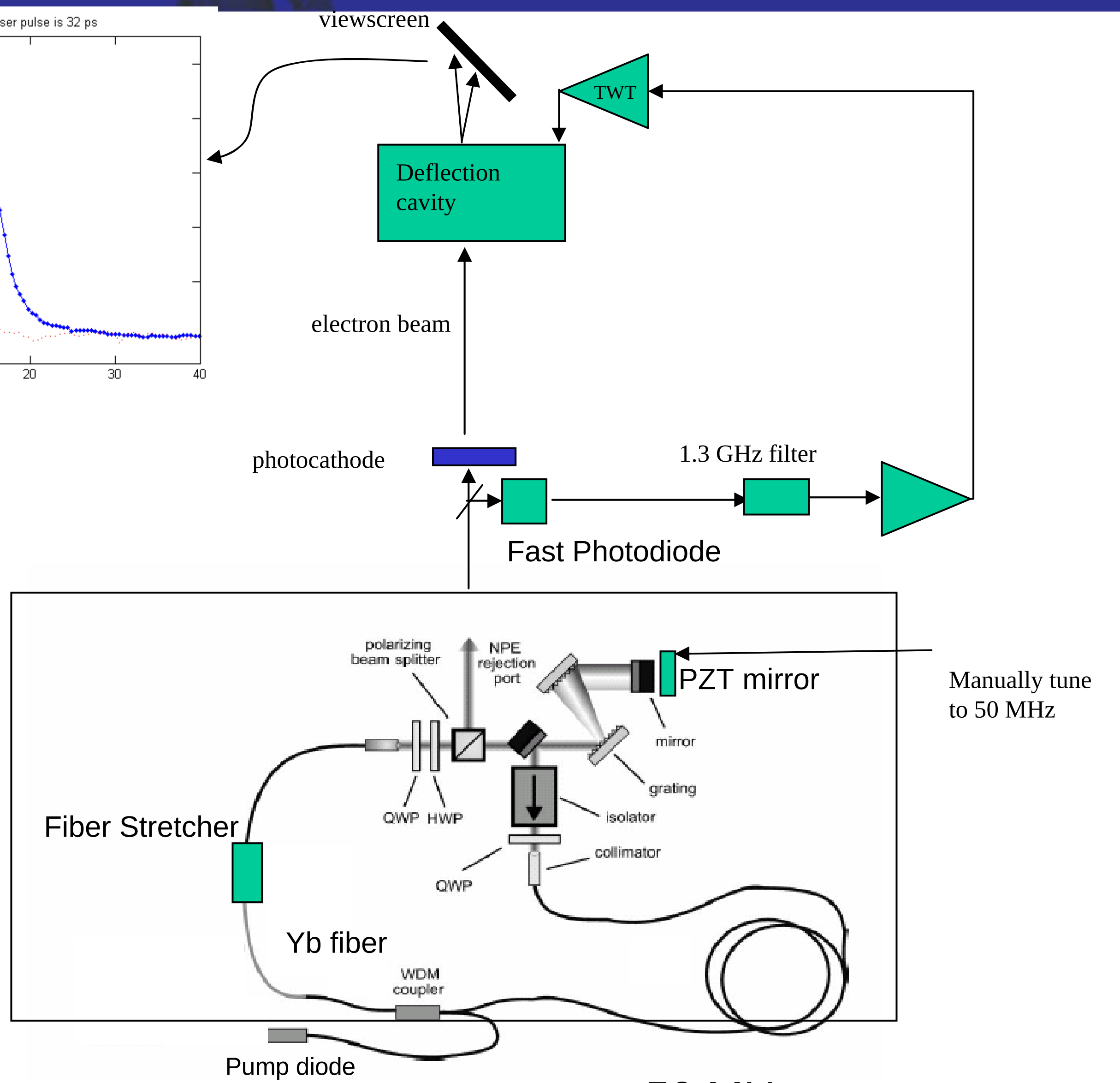




Laser to RF synchronization has not worked well due to acoustical noise – phase jitter is too high

Cathode Response Time



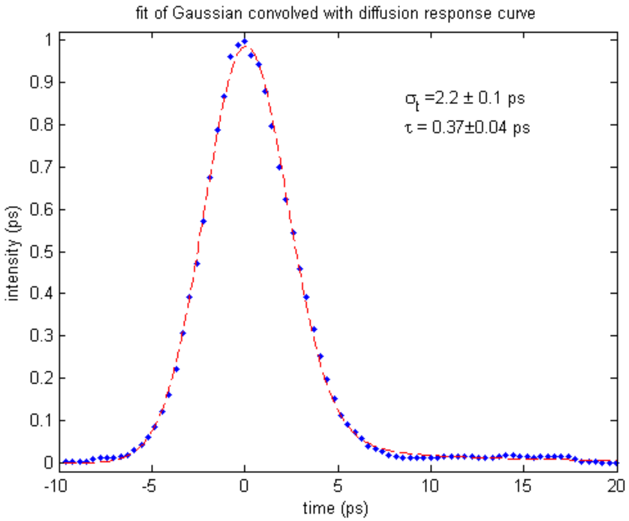


Now, use the laser signal to drive the cavity for better synchronization. The RF controls still have ~2 ps of jitter, we need < 1 ps for.

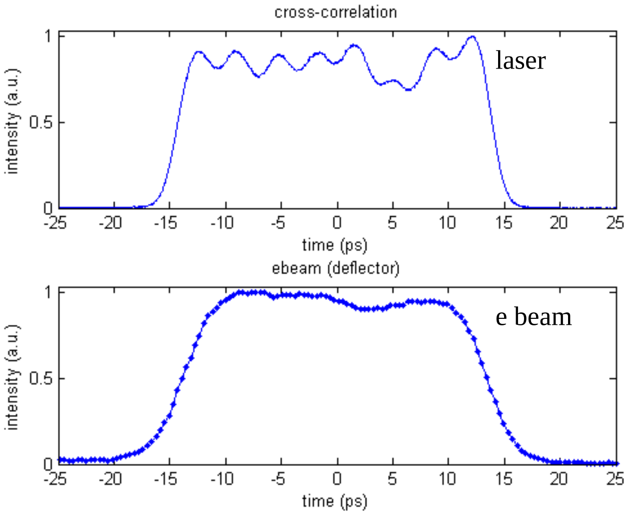
50 MHz oscillator

Cornell University
Laboratory for Elementary-Particle Physics

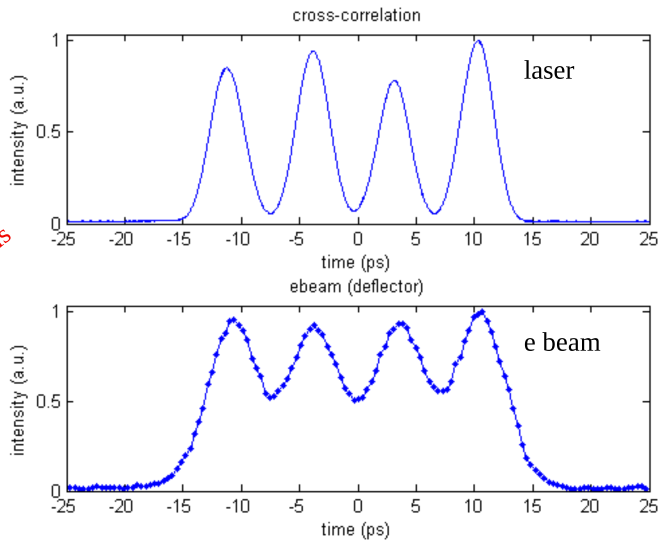
Cathode Response Data



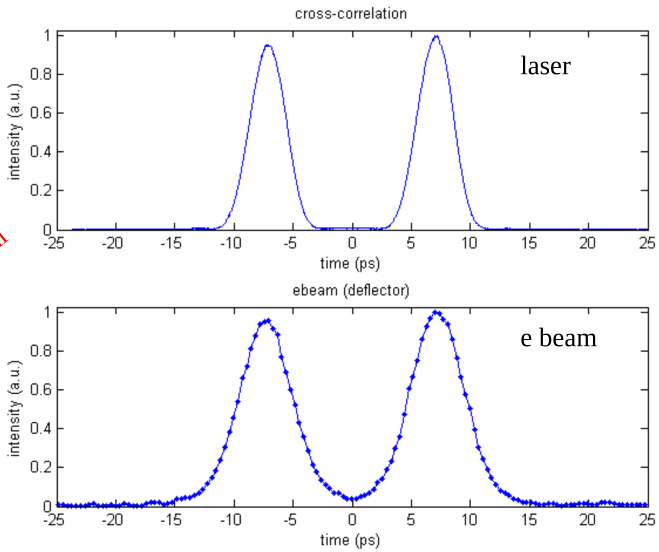
3 crystals



2 crystals



1 crystal

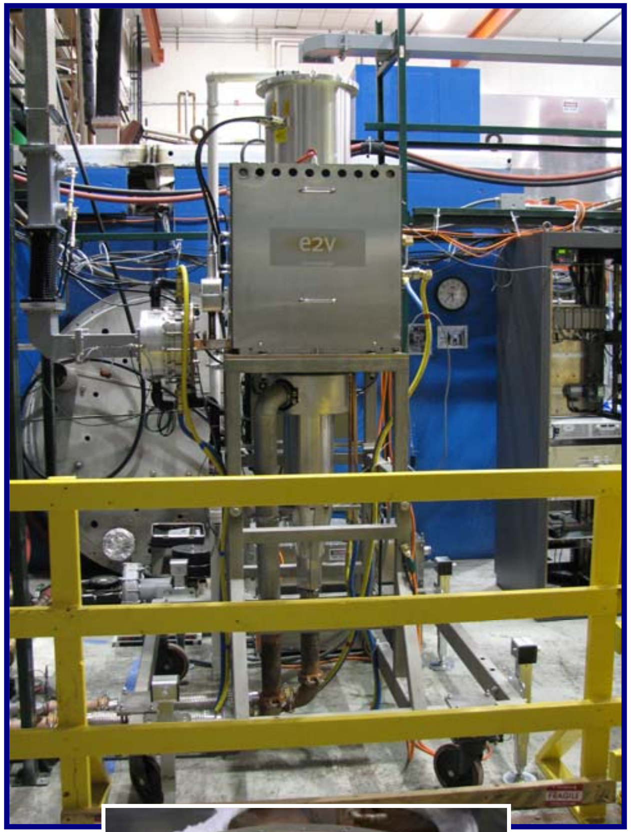


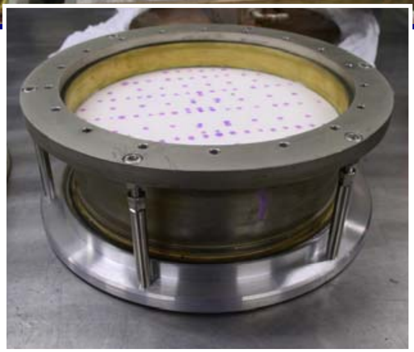
Upcoming Experiments

- Complete cathode response data
- Emittance measurements using 77 pC/bunch and ‘beer can’ laser shape, other shapes
- Push towards 100 mA

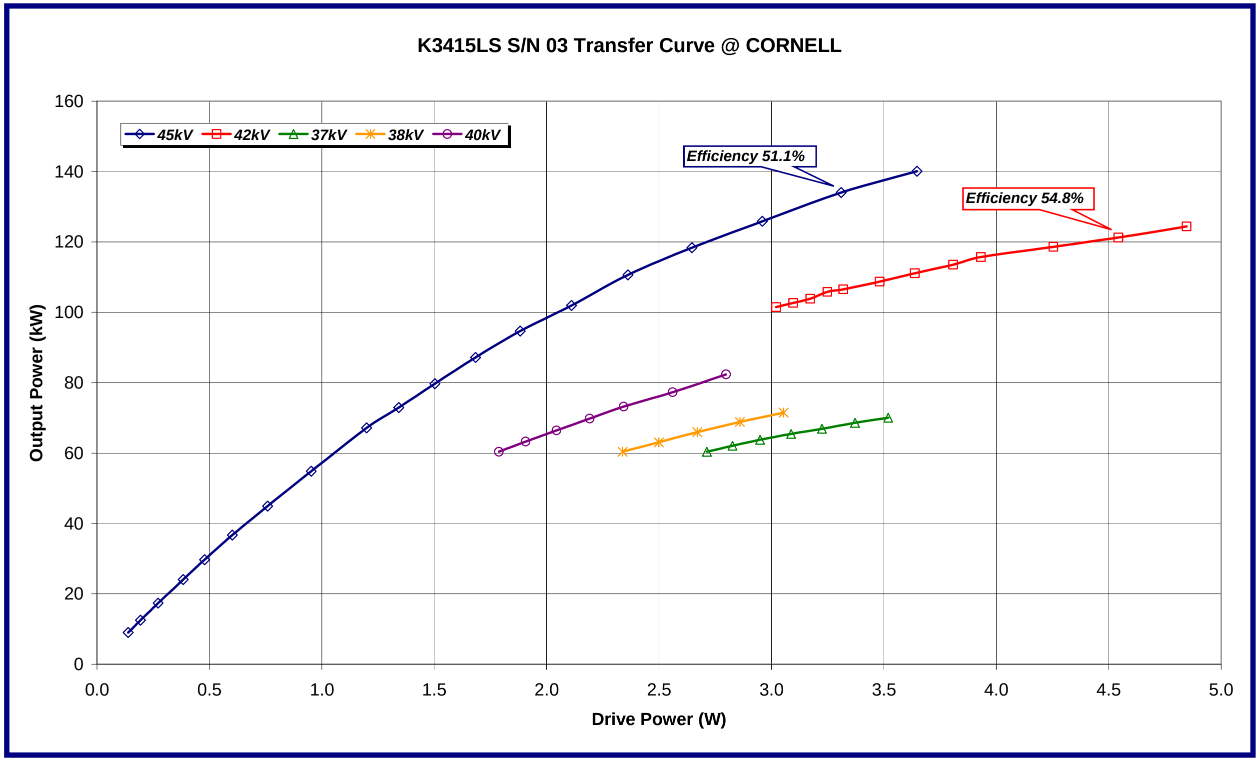
SRF and RF Systems

ERL injector klystron





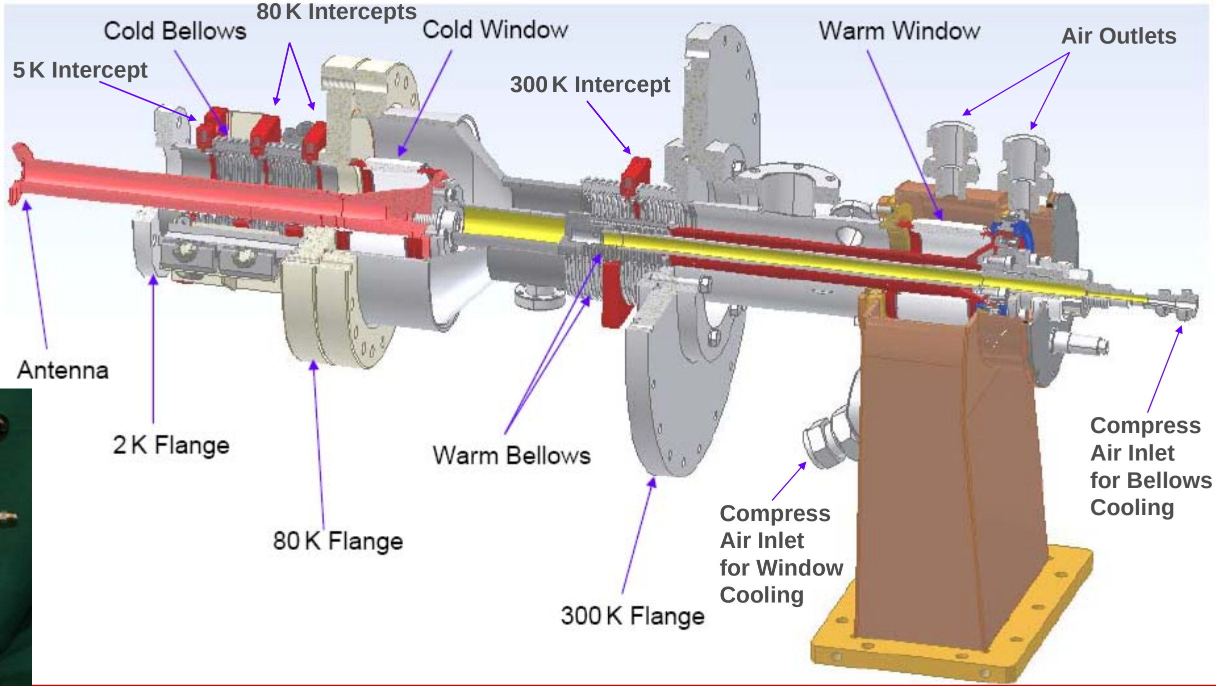
- e2v designed a high CW power klystron.
- Parameters of this 7-cavity tube: max. beam voltage 45 kV, current 5.87 A, full power collector, at max. output power of 135 kW the efficiency is >50%, gain >45 dB, bandwidth is >±2 MHz @ 1 dB and >±3 MHz @ 3 dB.
- The first tube (SN03) was delivered and successfully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

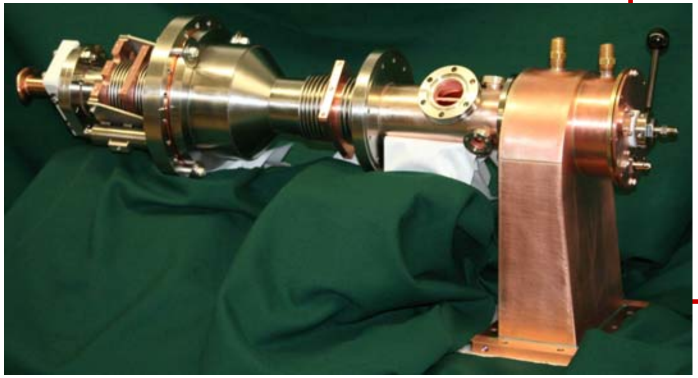


Coupler design highlights

Design features:

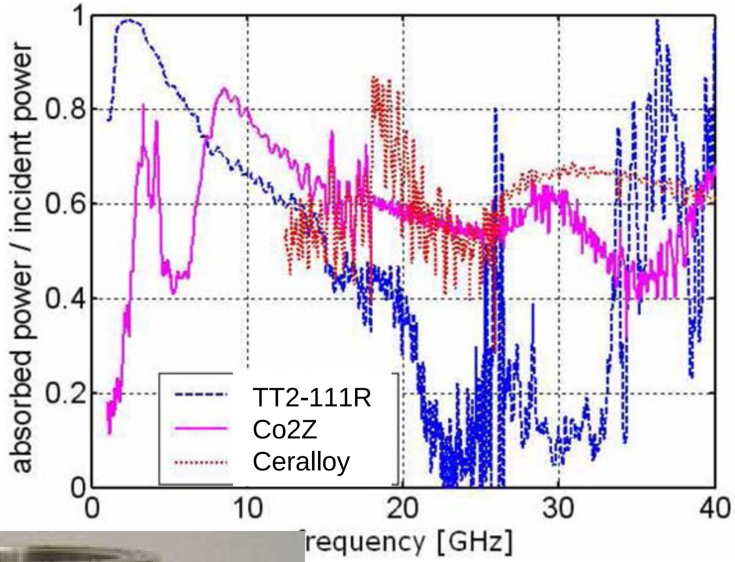
- The cold part was completely redesigned using a 62 mm, 60 Ohm coaxial line for stronger coupling, better power handling and avoiding multipacting
- Antenna tip was enlarged and shaped for stronger coupling
- "Cold" window was enlarged to the size of "warm" window
- Outer conductor bellows design was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

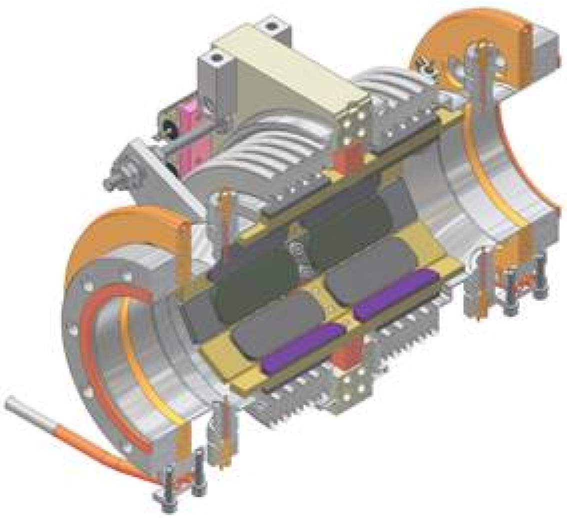




HOM Loads

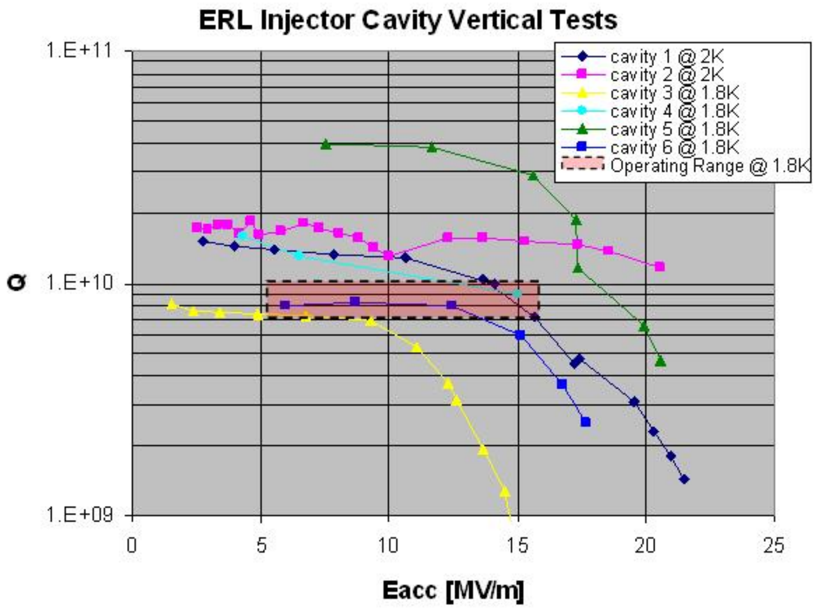
Total # loads	3 @ 78mm + 3 @ 106mm
Power per load	26 W (200 W max)
HOM frequency range	1.4 – **100 GHz**
Operating temperature	80 K
Coolant	He Gas
RF absorbing tiles	TT2, Co2Z, Ceralloy





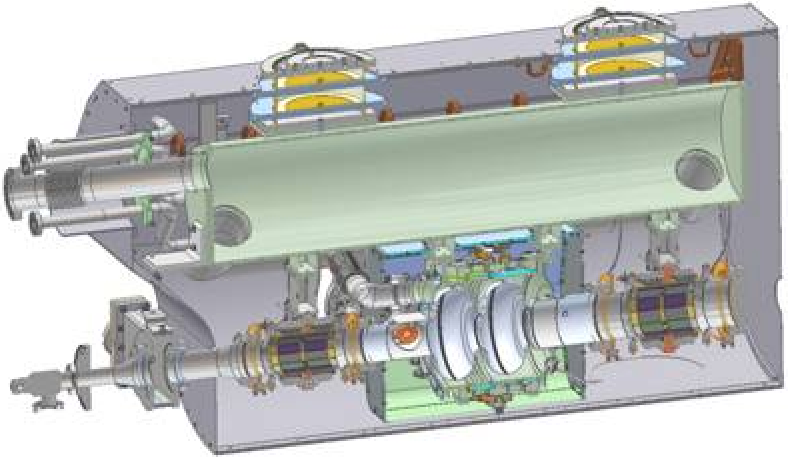
2 Cell Cavity

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}	$4.6 \cdot 10^4$ – $4.1 \cdot 10^5$
Active length	0.218 m
Total length	0.536 m

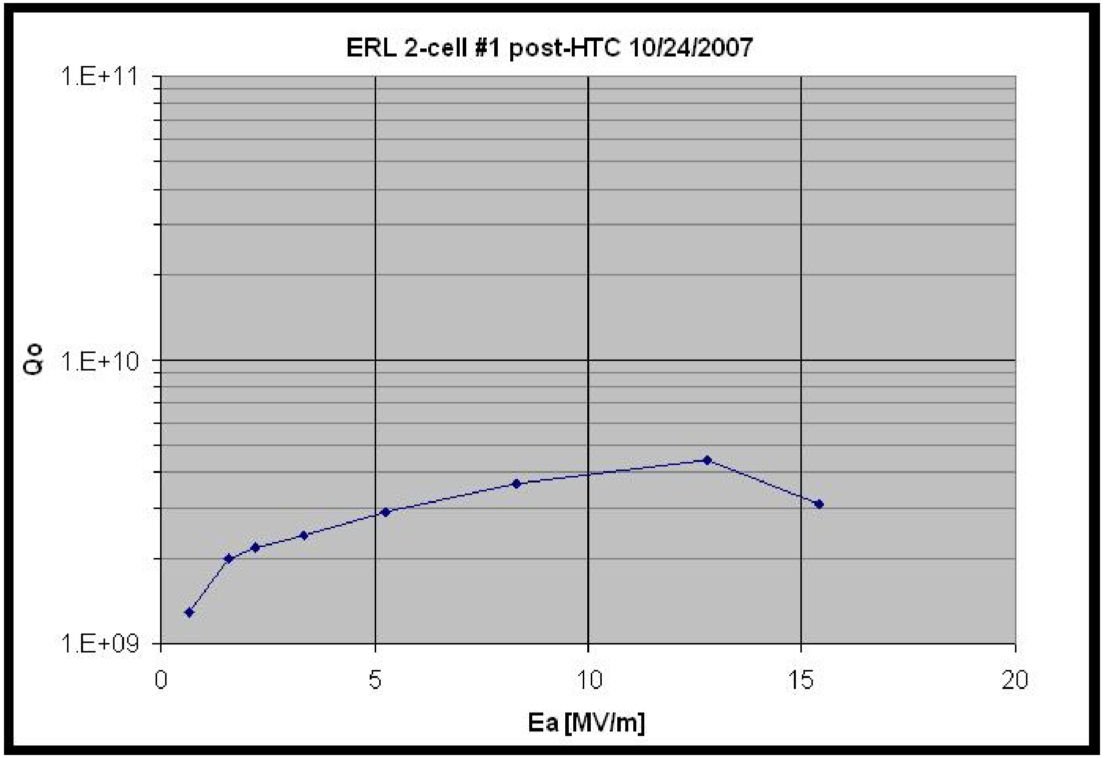


- 5 cavities tested, all meet specs, E > 15 MV/m (most E > 20 MV/m) , $Q > 10^{10}$ @ 2K
- Only BCP, no 800C treatment
- Two tested for H disease, no H disease

Horizontal Cavity Test

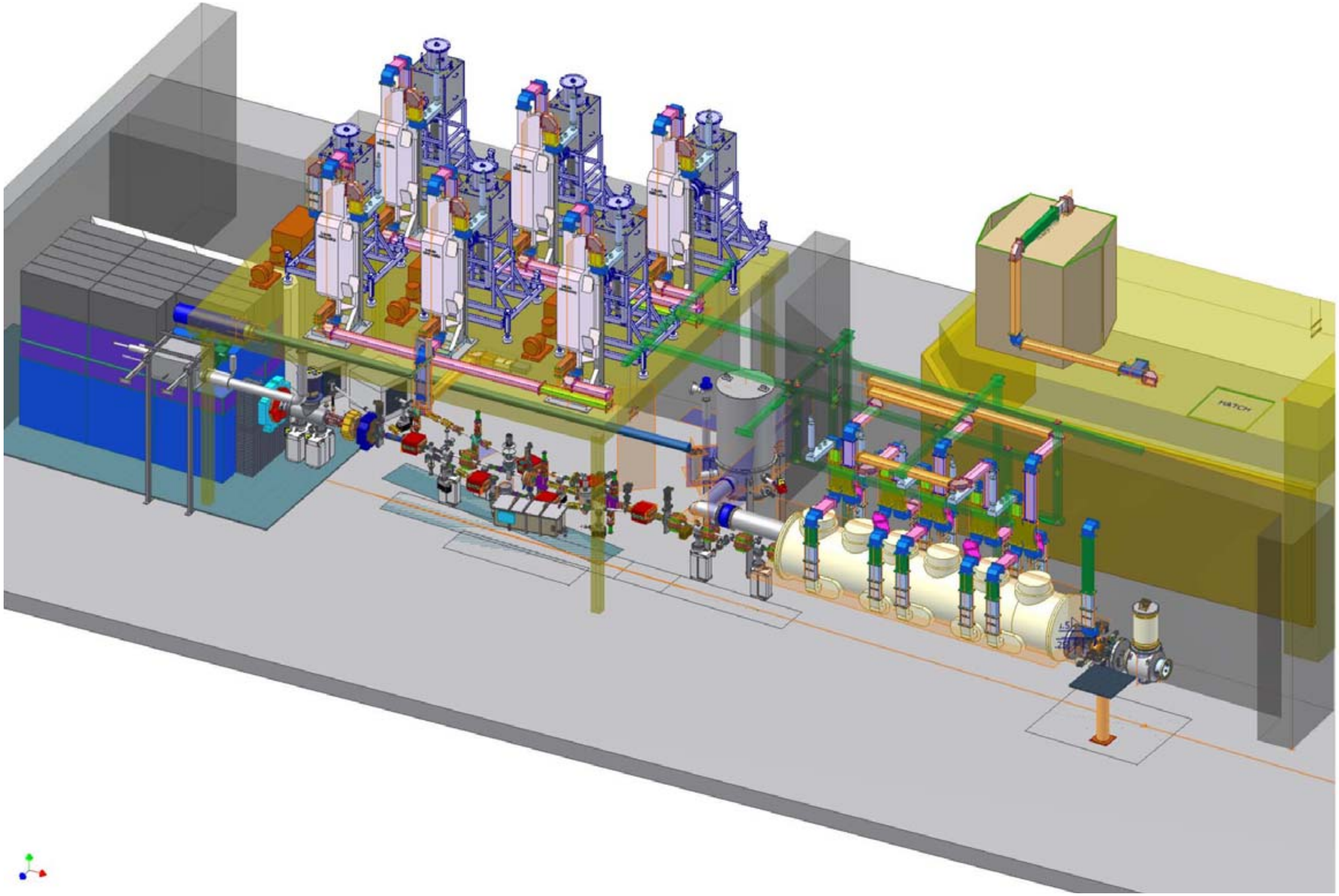


Horizontal Test Results



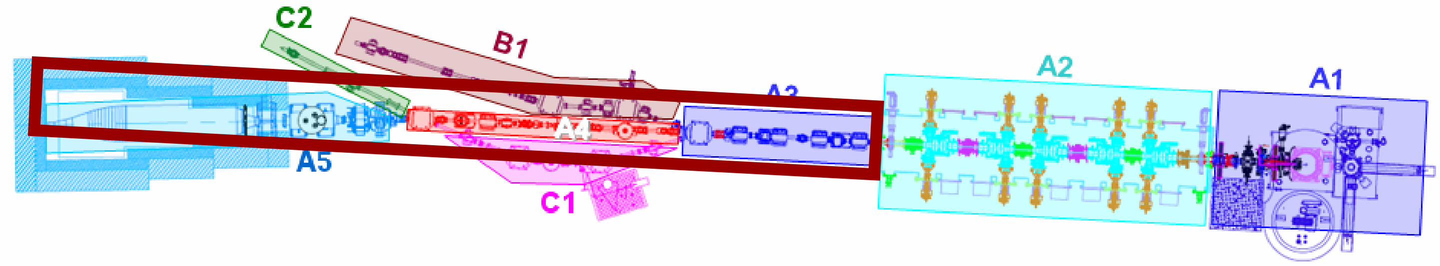
Low Q probably due to dust from broken tiles. Now cold testing all HOM loads

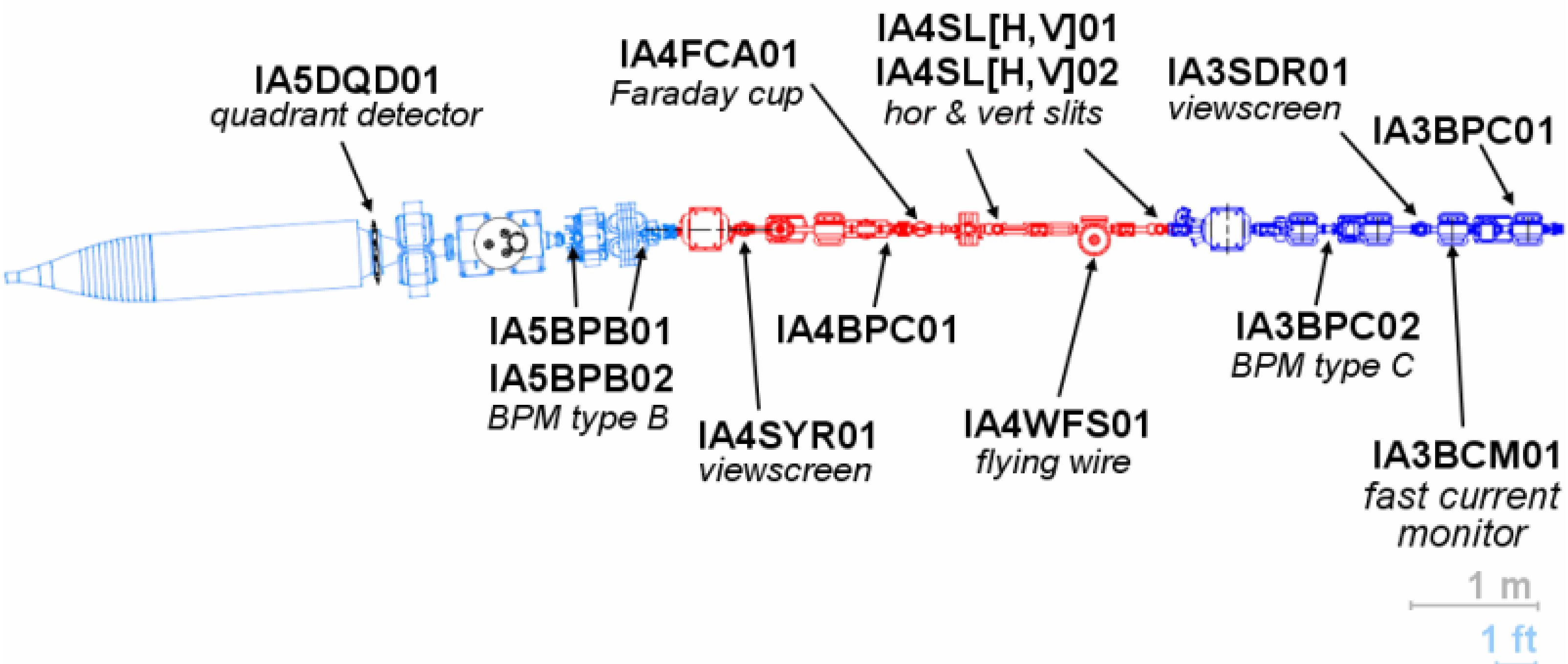
RF Power Distribution



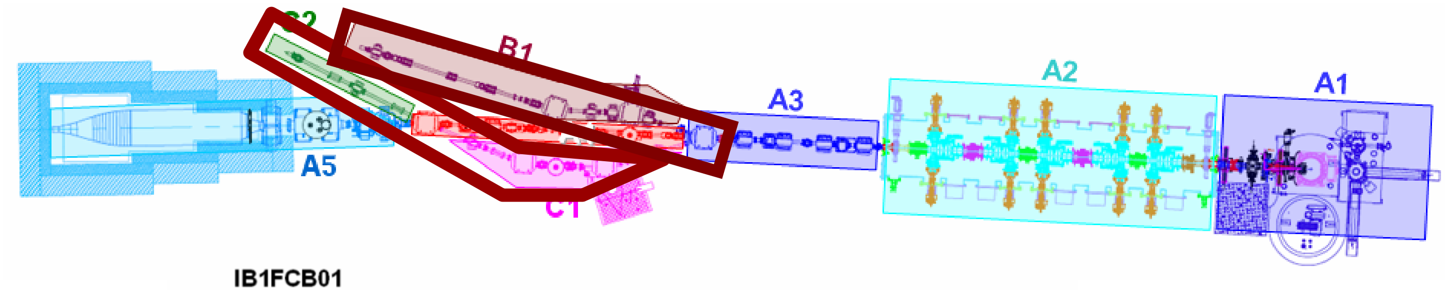
Diagnostic Beamlines

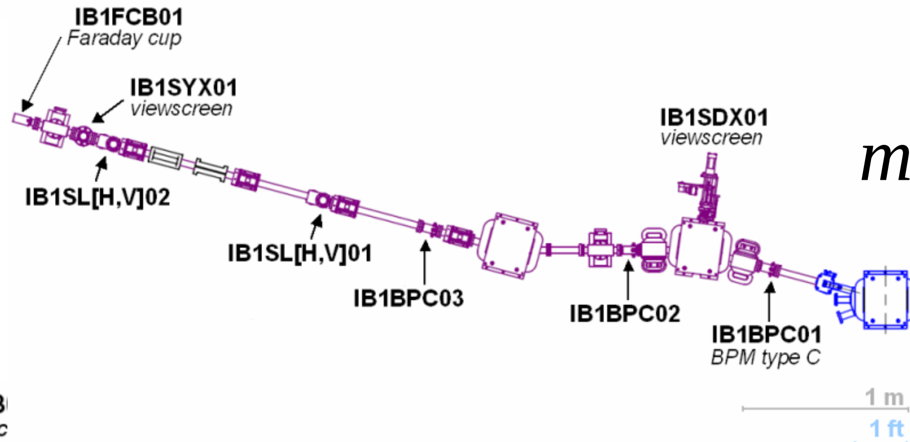
L0 layout: 15 MeV straight-thru



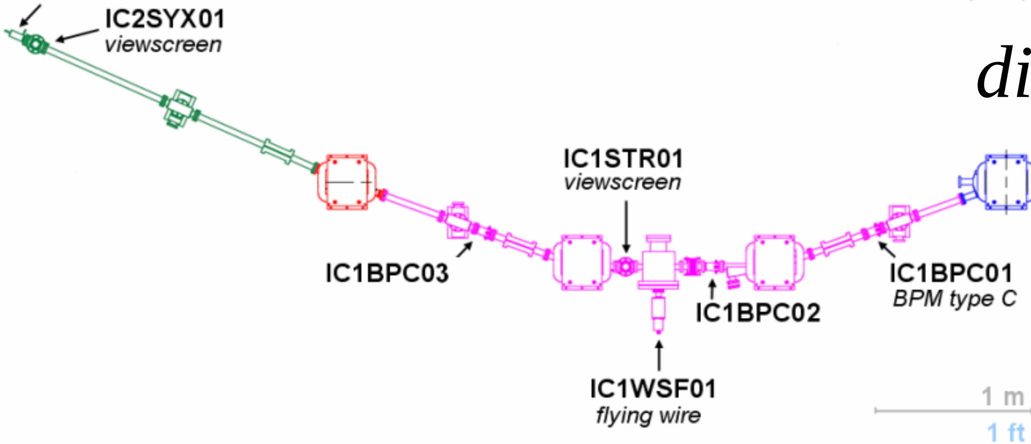


L0 layout: merger & chicane





merger



diagnostics chicane

Diagnostics overview

- Beam position resolution: 10 μm (spec)
- Energy spread resolution: 10^{-4}
- Transverse beam profile resolution: 30 μm (viewscreens)
  10 μm (slits)
  30 μm (flying wire)
- Angular spread resolution: 10 μrad
- Pulse length (deflecting cavity&slits): 100 fs
- RF phase angle: 0.5°

Ability to take phase space snapshots of the beam, both transverse planes, and longitudinal phase space

Construction in Progress

Summary

- Construction and utilities finish Feb/March
- Move the gun in March
- Cryomodule complete March/April
- Commissioning begins in April

Acknowledgements

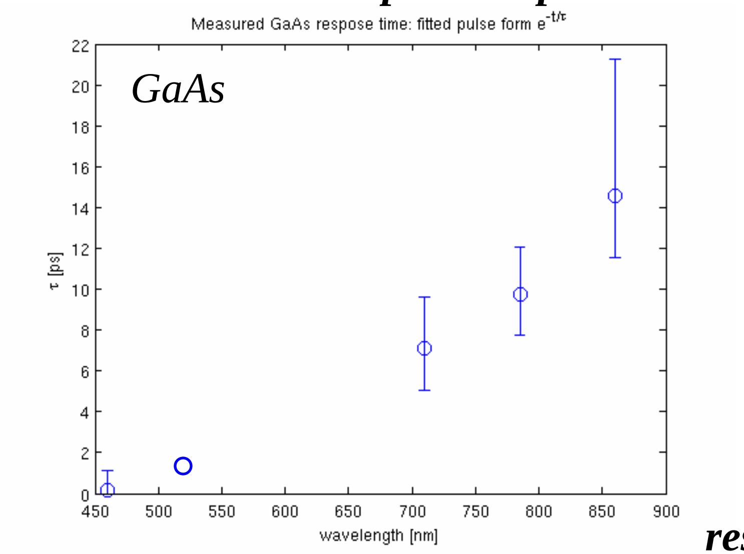
This work is supported by NSF.

PHY-0131508

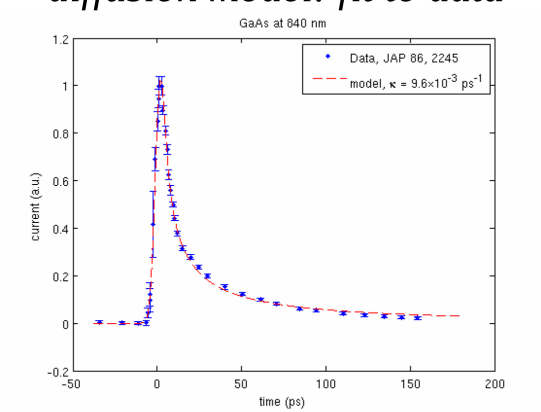
Cathode time response – Part 1

- Measured response time from GaAs and GaAsP at different wavelengths
- GaAs response @ 520 nm on the order of a picosecond
- Diffusion model correctly describes fast response and a slow tail

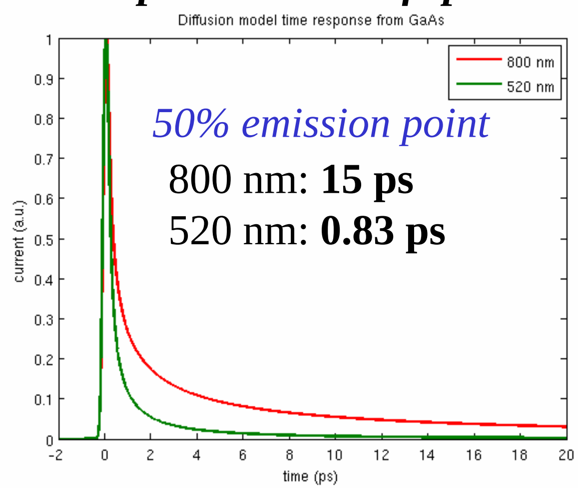
measured temporal response



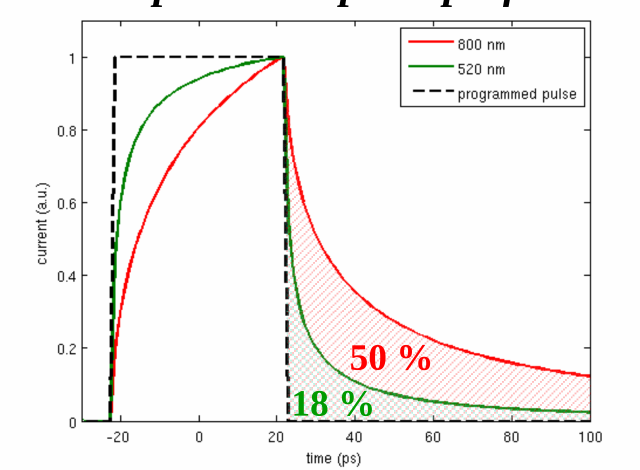
diffusion model: fit to data



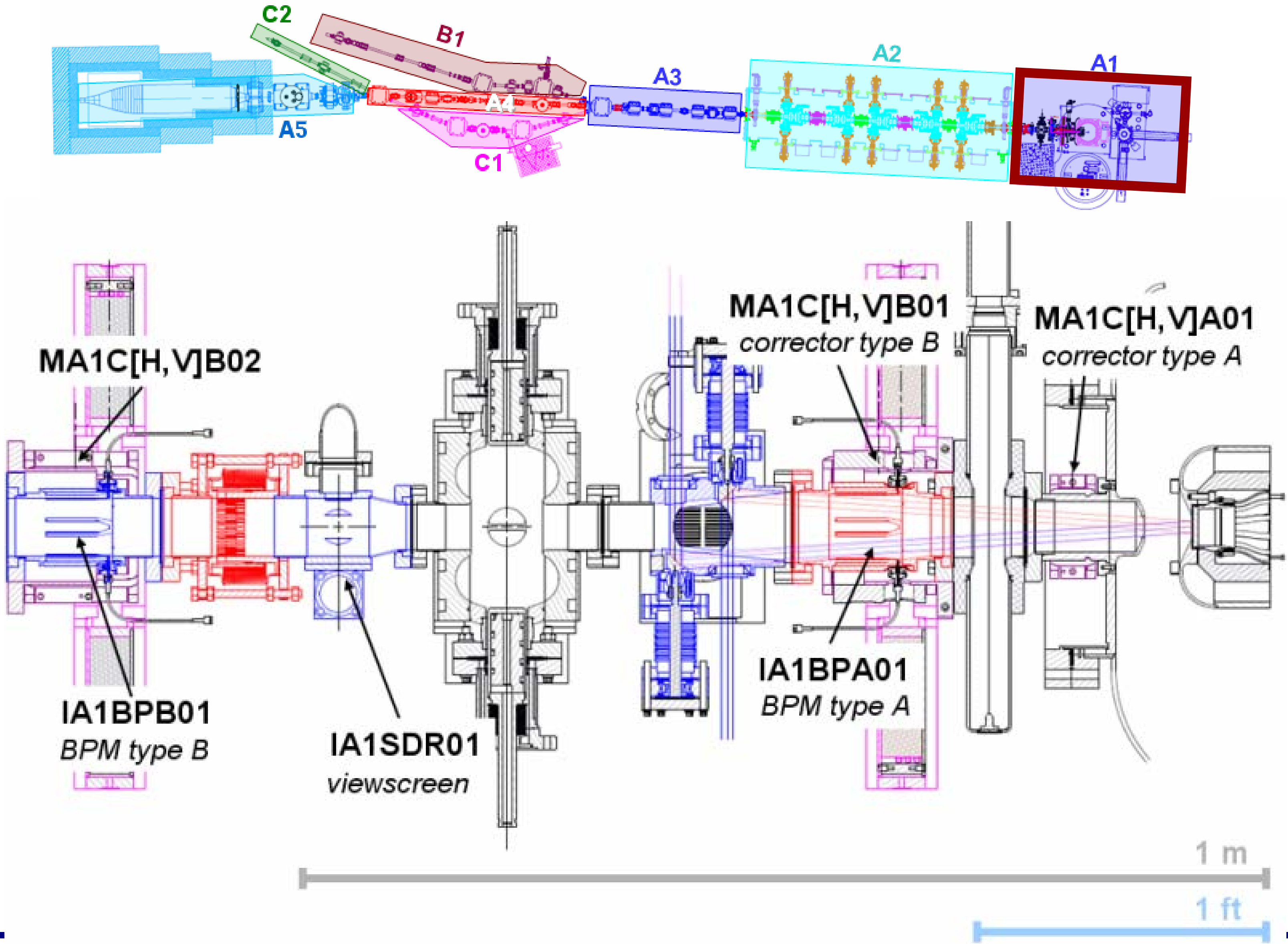
response to a 100 fs pulse



expected temporal profile



ERL Injector Layout – L0 Area

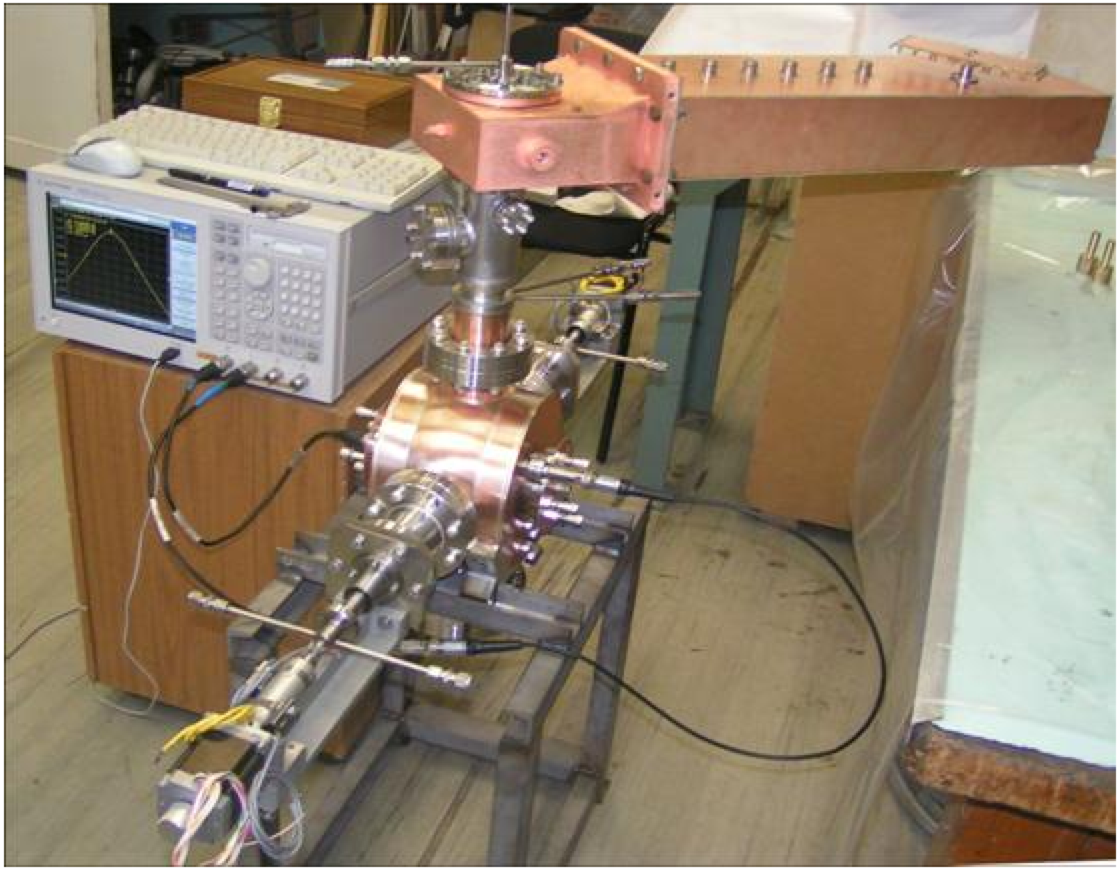


Vacuum Performance

- Want extreme UHV levels to reduce ion back-bombardment (which is the key for long lifetime)
- Many getter pumps (16 strips, 20000 L/s)
- Stainless steel parts fired at 400C in air to reduce hydrogen out-gassing (similar to LIGO)
- System vacuum bake to 150C

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

Buncher



Injector Cryomodule