LCLS-TN-01-8
September 2001

LCLS 120 Hz Gun Review

E. Colby (chair), E. Jongewaard, J. Schmerge

Stanford Linear Accelerator Center, Stanford, CA 94309

I. Summary

Introduction

The review was held at SLAC on September 11 and 12, 2001. Presentations concerning the thermal analysis, mechanical design, integration with the laser and accelerator, general beam dynamics considerations, a load lock mechanism, and symmetric power feed options comprised the review. Slides from these presentations are available elsewhere.

The review committee was charged with evaluating the 120 Hz gun design including proposed load lock and power feed options and recommending improvements. Broader evaluation of the injector as a whole (including focussing and diagnostic systems that do no impact the envelope of the gun itself) is expected to be covered in a future review and will not be commented on here.

In general, the long operational experience with four generations of s-band RF guns at numerous labs worldwide has led to considerable experience in design, fabrication, and operation aspects, and provides an excellent base on which to design the higher duty factor LCLS injector. While open questions remain on obtaining the design performance from these injectors, the microwave design of the gun has reached a state of relative maturity.

120 Hz Gun Design

Driving issues affecting the 120 Hz gun design beyond the present Gun IV design are: (1) increased average heat load, (2) increased vacuum load, (3) potential for increased RF breakdown, and (4) increased average laser power requirement. Issue (4) potentially impacts the gun design through the choice of photocathode.

It is recommended that thermo-mechanical simulations be carried out for the most demanding case: at the peak desired gradient (140 MV/m) for the longest available RF pulse (3.5 μs) so that the RF system will be the limit on performance, not the thermo-mechanical design of the gun. If this leads to unusual expense, then the decision to reduce these requirements can be made.

Large thermal gradients seen in the initial round of thermal modeling across the cathode and gun body are worrisome on three counts. An axial temperature gradient will result in a differential expansion of one cell with respect to the other, making tuning the gun for balanced field amplitudes in each cell problematic. The bench tuning, done at constant temperature, and the “hot” tune will differ significantly. Model prediction of the correct bench tune to obtain flat fields for the “hot” tune will need to be completed. A radial temperature gradient in the iris will result in a strong, radially outward stress on the outer wall, and will develop stress foci at the sharp corners between the iris and body. For these thermal gradients it is not believed that stresses will approach unsafe limits, but this should be checked. Finally, and most seriously, the radial temperature gradient across the cathode that will occur for either of the proposed cooling schemes (through the actuator of the load lock mechanism, or through the contact point with the gun body) will result in a radially directed stress at this critical RF current-bearing joint. Breakdown-free electrical performance will depend on making a well-defined linear contact around the entire circumference of the joint. Thermal stresses may cause the locus of contact to shift as the gun warms, and if stresses are large enough to overcome friction, slippage will occur. Improved thermal contact between cathode plate and gun body are likely to largely eliminate this thermal gradient and should be simulated. Very slight beveling of the stainless steel contact surface to ensure that the RF contact point is always at the inside edge may help ameliorate this problem.

The square cooling channel arrangement in the iris may give rise to unwanted asymmetries in the gun geometry when RF power is applied. Whether this warrants a simulation to assess its impact will be best decided once the overall dimensional changes from the radial temperature gradient in the iris are calculated. The effects of the asymmetry will be small by comparison.

Vacuum considerations derive from the 12-fold increase in repetition rate and roughly 2-fold increase in power over existing BNL gun operation, resulting in a roughly 24-fold increase in outgassing rate, which is dependent largely on the pulsed temperature rise during the RF pulse rather than the gun's average wall temperature. Vacuum considerations are important for the cathode lifetime, emitted dark current, and RF breakdown. Questions of whether specially processed coppers have lower outgassing properties (and dark current emission) make it potentially important to look at the comparative vacuum outgassing rates of similarly prepared copper surfaces from copper in standard, Hot Isostatic Press processed (HIP) and monocrystalline forms. Protocols for handling, machining, brazing and lapping the internal copper surfaces are worth revisiting as well for potential improvements in vacuum performance. The recent NLC experience in testing high gradient RF structures of differing material composition and surface preparation is relevant and should be considered in this regard. The recent SLAC klystron department experience with RF breakdown testing (using the x-band "windowtron" test setup) should also be reviewed in this regard.

The higher repetition rate also means that this gun will age faster than any of its contemporaries. Cumulative damage that occurs at acceptably slow rates in presently operating guns will accrue rapidly in the LCLS gun. In general, this will place greater weight on making RF joints more reliable or non-existent. It is recommended that consideration be given to eliminating the symmetric frequency tuners in the full cell. Operation experience demonstrates that they are non-essential, and the presence of two sliding RF contacts increases the potential for RF failure.

For field monitoring purposes, an RF pickup probe is recommended. The fields of the cavities themselves may be directly monitored and the amplitude and phase information used for feedback stabilization. Further, if the probes are inductive and positioned 90^o apart around the circumference of the cavity, they will respond to both polarizations of the dipole mode and yield beam position information.

Emittance dilution due to higher-order field distortions due to coupling irises and other cavity asymmetries remains to be numerically calculated. The decision to include or remove the grazing-incidence laser ports will profit from simulations which compute the emittance dilution due to: (1) the quadrupole error to the RF field in the half cell induced by the laser ports, and (2) the wakefield kicks induced by placing mirrors close to the beam for near-normal incidence cathode illumination. The decision to switch to a symmetric power coupling scheme, discussed below, will also profit from simulations of emittance dilution due to specific multipole error content in the RF fields.

The present design has the downstream focussing solenoid held in mechanical alignment and thermal isolation by a system of alignment keys and thermal isolation shims. With the recent work by M. Ferrario *et al* showing that the solenoid's optimum position is further downstream (and therefore out of thermal contact), this can be revisited with a possible simplification resulting. Even if the optimum solenoid location requires that the solenoid and gun be physically very close, it may be possible to provide for a small longitudinal clearance such that the solenoid may be slid a small distance away from the gun during bake out, providing the necessary isolation.

The choice of gun cathode will impact the laser system dramatically, with the tradeoff being between a robust, simple copper cathode with an expensive laser system, and an exotic, fragile cathode with a less expensive laser system. Magnesium is a relatively straightforward upgrade and offers roughly an order of magnitude better QE, and enjoys considerable operating experience at BNL. It is recommended that the thermal emittance advantages or disadvantages of each type of cathode be experimentally determined. The choice to convert to the more efficient Cs_2Te cathode, however is not straightforward, and a determination that the laser system requires this cathode should be made soon to permit the more complex cathode preparation and handling apparatus to be developed. The switch to this cathode will make the use of a load lock mandatory. By contrast, the use of a load lock mechanism for copper or magnesium cathodes is optional. The load lock system is regarded as a potential upgrade for the LCLS gun.

Load Lock Mechanism for the Photocathode

A vacuum load-lock mechanism was presented to permit exchange of the photocathode without breaking the gun vacuum. Mechanical requirements for such a system are complex, as the system must be bakeable, maintain $\sim 10^{-10}$ Torr vacuum, and accomplish three mechanical functions: (1) transfer of the cathode plate from the gun to a separate, detachable chamber (2) apply substantial, precisely distributed force to the back of the cathode plate to form a sure RF contact, and (3) apply substantial axial force at the center of the cathode plate for tuning the gun. A vacuum manipulation system affording 19 degrees of freedom via 18 actuators is proposed to meet this difficult set of requirements.

The cost and long commissioning time for the load lock make it important that a careful cost/benefit analysis be done to verify its cost effectiveness. Questions that should be answered to inform this process include: (1) what is the anticipated improvement in cathode turnaround time, (2) what is the increased cathode seating failure rate with the load lock over alternative designs (failure defined as a cathode that must be removed from vacuum and replaced because a reliable RF contact could not be made), (3) what impact does the relocation of the water cooling channels have on thermal stresses in the gun, (4) can the 16-actuator radial clamp assembly be simplified by substituting, say, an 8-actuator drive and a set of pressure distribution plates. The ability to expeditiously exchange cathodes is clearly desirable, affords flexibility in choosing cathode materials, and is essential for certain cathodes.

Design implications for the gun itself are several. The water cooling channels proposed for mounting on the rear of the cathode plate must be relocated out of the vacuum chamber. Enlargement of the upstream gun flange to permit inclusion of a water channel around the half cell is one solution. Routing a cooling circuit up through the axial translator in the load lock mechanism is another. Thermo-mechanical modeling of the first scheme should be examined in some detail, and if it is unworkable, the second scheme should be pursued.

The bucking solenoid, once its need and specifications become clear, must be redesigned to accommodate the geometry of the load lock or be eliminated altogether. This is believed to be straightforward, as the needed canceling field is of order 10 Gauss at the cathode.

It is recommended that the load lock be mechanically isolatable from the gun via a bellows fitted with stress bypasses. During gun alignment, the bellows will decouple the great weight of the cathode antechamber from the gun, permitting more accurate alignment. Once alignment is complete and the gun secured to its mount, the stress bypasses can be secured to transmit the axial force required for tuning. It is further recommended that a docking support be added to provide rigidity and better alignment during cathode transfer between the transverse cathode actuator and the axial cathode actuator.

It must be noted that one mechanical function of the load lock system, that of forming the RF contact between cathode and gun, is not calculable and must be thoroughly tested before mounting on the production gun. Failure of this joint will result in failure of the gun, and potentially in permanent damage to the gun body.

Symmetric RF Power Feed

The multipole content of the RF fields is a source of emittance dilution. Quantitative analysis of tolerances on specific multipole content (e.g. dipole, quadrupole) has not been done except in simple analytic approximation for the dipole case. Numerical simulation showing quantitatively the impact of dipole and quadrupole field content on beam quality is therefore recommended before a decision on switching to a symmetric power coupler is made. There is considerable experience with designing and operating high power symmetric couplers on s- and x-band systems so the risk is expected to be minimal. The decision will rest primarily on the potential to improve the beam quality and the cost.

II. Charge to the Review Committee

Evaluate the presented design for the gun, including especially the thermo-mechanical details for operation at 120 Hz, and also the interface with the load-lock and the symmetric dual rf feed. Before the conclusion of the Review, produce a 1-2 page summary listing any open questions about the design along with recommendations for addressing these questions.

J. Clendenin
LCLS Injector Manager

III. Committee and Attendees

Committee:
E. Jongewaard, SLAC
J. Schmerge, SLAC
E. Colby, SLAC (chair)

Attending:
X.J. Wang (BNL)
M. Woodle (BNL)
J. Clendenin (SLAC)
A. Fisher (SLAC)
M. Cornacchia (SLAC)
C. Limborg (SLAC)
B. Murphy (SLAC)
A. Vlieks (SLAC)
R. Kirby (SLAC)
G. Collet (SLAC)

IV. Agenda
(*Transparencies for talks enclosed)

Tuesday, September 11

14:00 (15) Welcome and introduction - Clendenin

14:15 (30) Overview of the 120 Hz gun – Wang
*1. X.J. Wang et al., *LCLS 120 Photocathode RF Gun*

14:45 (60) Thermal analysis of 120 Hz operation and mechanical improvements – Woodle
*2. M. Woodle, *120 Hz E-Gun–Mech. Aspects*

15:45 (15) Break

16:00 (60) Beam dynamics and laser system – Wang
*3. X.J. Wang et al., *LCLS 120 Hz Photoinjector II*

18:00 Cocktails [No-host coctail hour, see below]

18:30 Dinner [See below.]

Wednesday, September 12

08:45 (15) Coffee

09:00 (45) Load-Lock Design for the LCLS RF Gun – Kirby
*4.R. Kirby and G. Collet, *LCLS LoadLock*

09:45 (45) Symmetrical RF Feed Design Considerations – Vlieks
* 5. A.E. Vlieks, *Symmetrical RF Feed Design Considerations*

10:30 (15) Break

10:45 (45) Discuss design and write report sections

11:30 (30) Assemble and review summary report

12:00 Adjourn

Note: The time allowed for each presentation includes discussion time.

The Review will be held in the Conference Room in Trailer 270. This trailer is just inside the radiation fence near the SSRL LOS (main office) Building.

The Cocktail Hour and Dinner will be at Fontana's Restaurant, 1850 El Camino Real, Menlo Park (east side of El Camino near border with Atherton).

1. LCLS 120 Photocathode RF Gun

X.J. Wang, M. Babzien, I. Ben-Zvi, X.Y. Chang,
D. Lynch, S.Pjerov, and M. Woodle

National Synchrotron Light Source

Brookhaven National Laboratory

Upton, NY 11973

September 11, 2001

Presented at LCLS 120 Hz RF Gun Review

Outline

The focus of this review is to how make BNL S-band RF gun for LCLS 120 Hz operation, but I would like to present a complete picture , here is what we would like to present today:

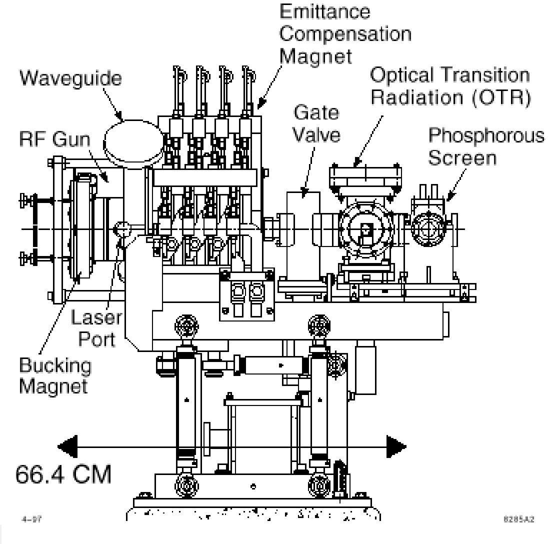
1. Overview of LCLS 120 Hz Photocathode RF gun Injection System – X.J. Wang
2. Preliminary mechanical design and thermal analysis – M. Woodle.
3. Beam dynamics of 120 Hz photocathode RF gun injector – X.J. Wang

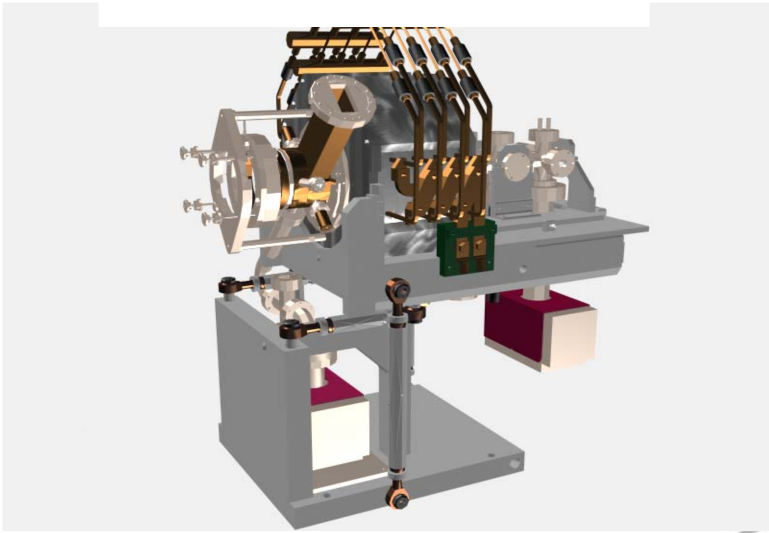
Photocathode RF Gun Injection System

ATF is the only user facility based photocathode RF gun injector:

- Photocathode RF gun injection system:

1. RF gun.
2. Solenoid Magnet.
3. Laser system and optics.
4. RF gun associate beam diagnostics.
5. Cathode technology
6. Operating techniques.





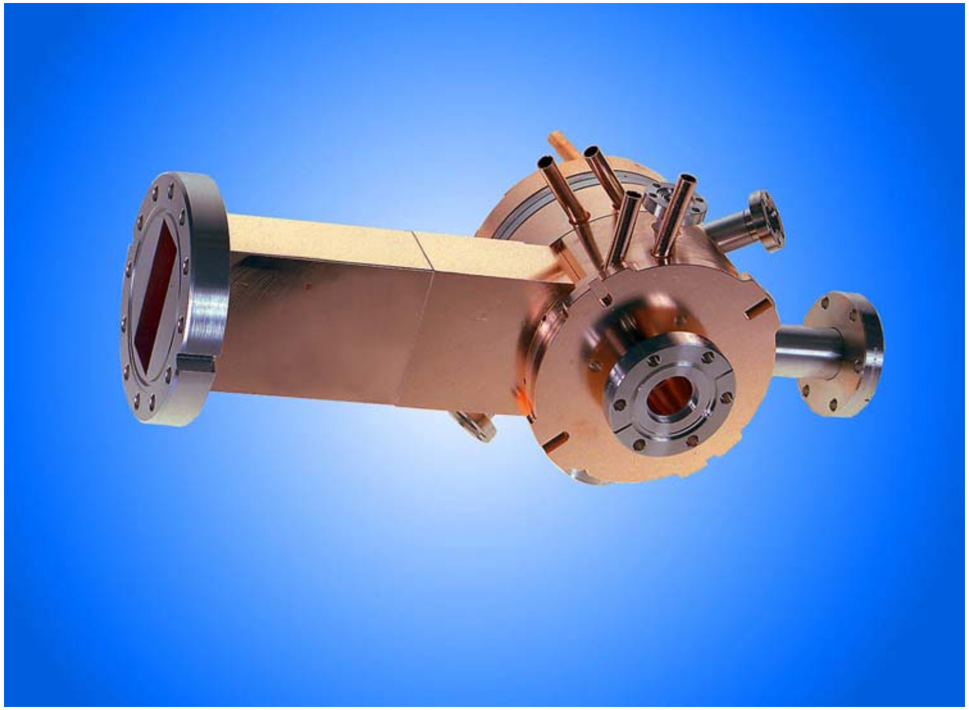
LCLS 120 Hz Photoinjector

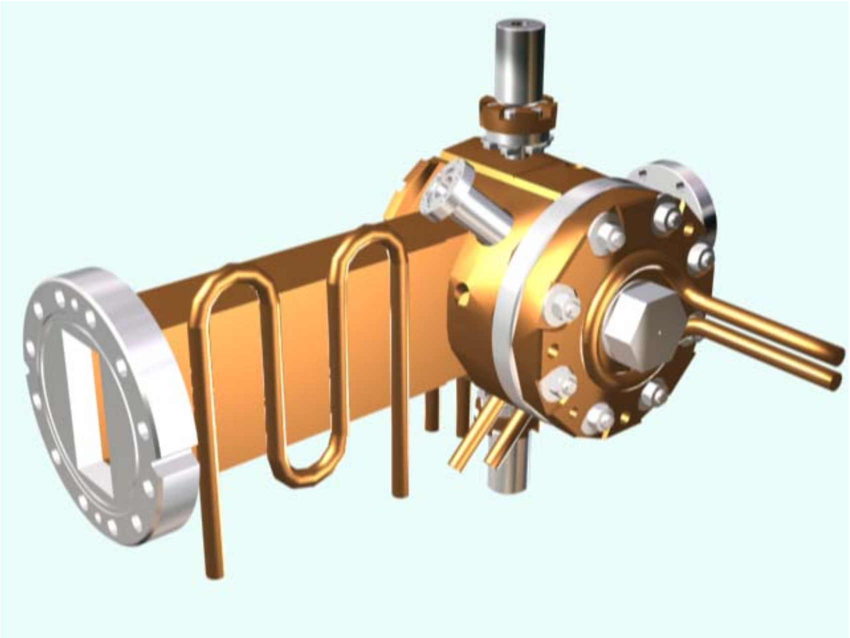
Higher operating rate ⇒ Higher heat load,
Increase pressure and beam loading

RF gun rep. Rate (Hz)	120
Field on the cathode (Mv/m)	100 - 140
Cathode material	Cu or Mg
Vacuum inside the gun	$< 3x10^{-10}$ with RF on
Operating Temperature (°C)	30

LCLS 120 Hz RF Gun

Demonstrated 50 Hz operation





Vacuum Characteristics

(at Room Temperature)

Pressure (Torr)	Molecular Density (molec./cm^3)	Molecular Incidence (molec./cm^2·sec)	Mean Free Path (cm)	Monolayer Formation Time (sec)
760	2.49×10^{19}	2.87×10^{23}	3.9×10^{-6}	1.7×10^{-9}
1	3.25×10^{16}	3.78×10^{20}	5.1×10^{-3}	2.2×10^{-6}
10^{-3}	3.25×10^{13}	3.78×10^{17}	5.1	2.2×10^{-3}
10^{-6}	3.25×10^{10}	3.78×10^{14}	5.1×10^{3}	2.2×10^{0}
10^{-9}	3.25×10^{7}	3.78×10^{11}	5.1×10^{6}	2.2×10^{3} (37 min)
10^{-12}	3.25×10^{4}	3.78×10^{8}	5.1×10^{9}	2.2×10^{6} (25.5 days)

LCLS 120 Hz Laser system

Rep. Rate (Hz)	120	
Laser energy on cathode (UV,uJ)	30 (Mg)	200 (Cu)
Laser pulse length (ps, FWHM)	5 to 20	
Laser spot (radius, mm)	0.5 – 1.5	
Laser energy stability (%)	1.5 (rms)	6 (p-p)
Timing jitter (ps)	0.1	0.5 (p-p)
Point stability (%)	0.25	1

Key issues: Environments, heat load and stability and reliability

Possible Laser system

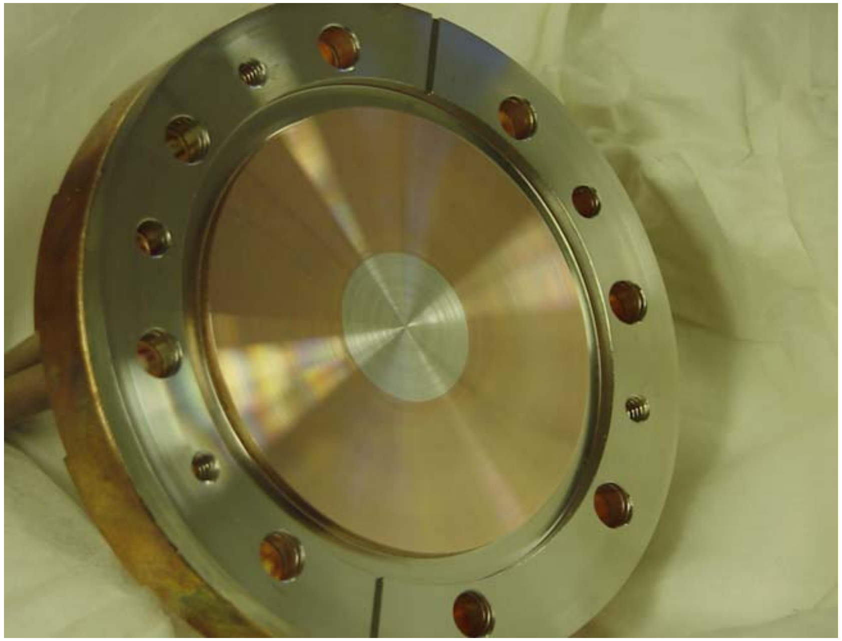
- Nd:Yag – Stable, better handling the heat, but bandwidth limited
- Yag glass: Wide bandwidth, heat load problem.
- Ti:sapphire: good bandwidth, but more complexity.
- Nd:YLF: reasonable bandwidth, good stability.

Diode-pumped solid state amplifier is the technology for 120 Hz operation.

Photocathode - Mgnesium

The performance of the Laser system is closely related to the cathode.

Mg has demonstrated 0.2% routine operation.



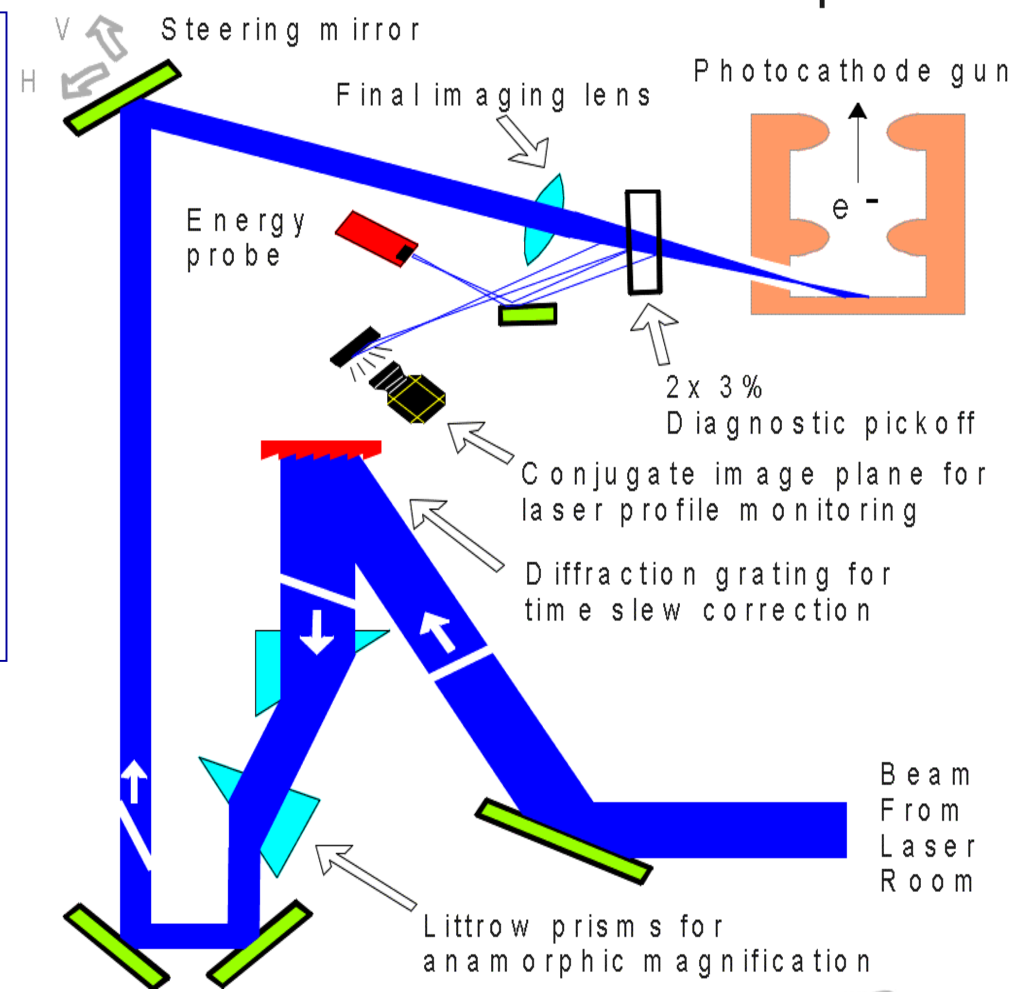
Laser Injection Scheme

Normal vs. Oblique incidents:

Normal Incident: simple laser optics. In-vacuum mirror and hard for beam diagnostics.

Oblique Incident: No in-vacuum optics, better for diagnostics. Complex laser optics.

ATF Gun Hutch Laser Optics



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Laser and Electron Beam Diagnostics

Laser beam diagnostics: On-line laser energy, transverse beam profile and position, and timing jitter.

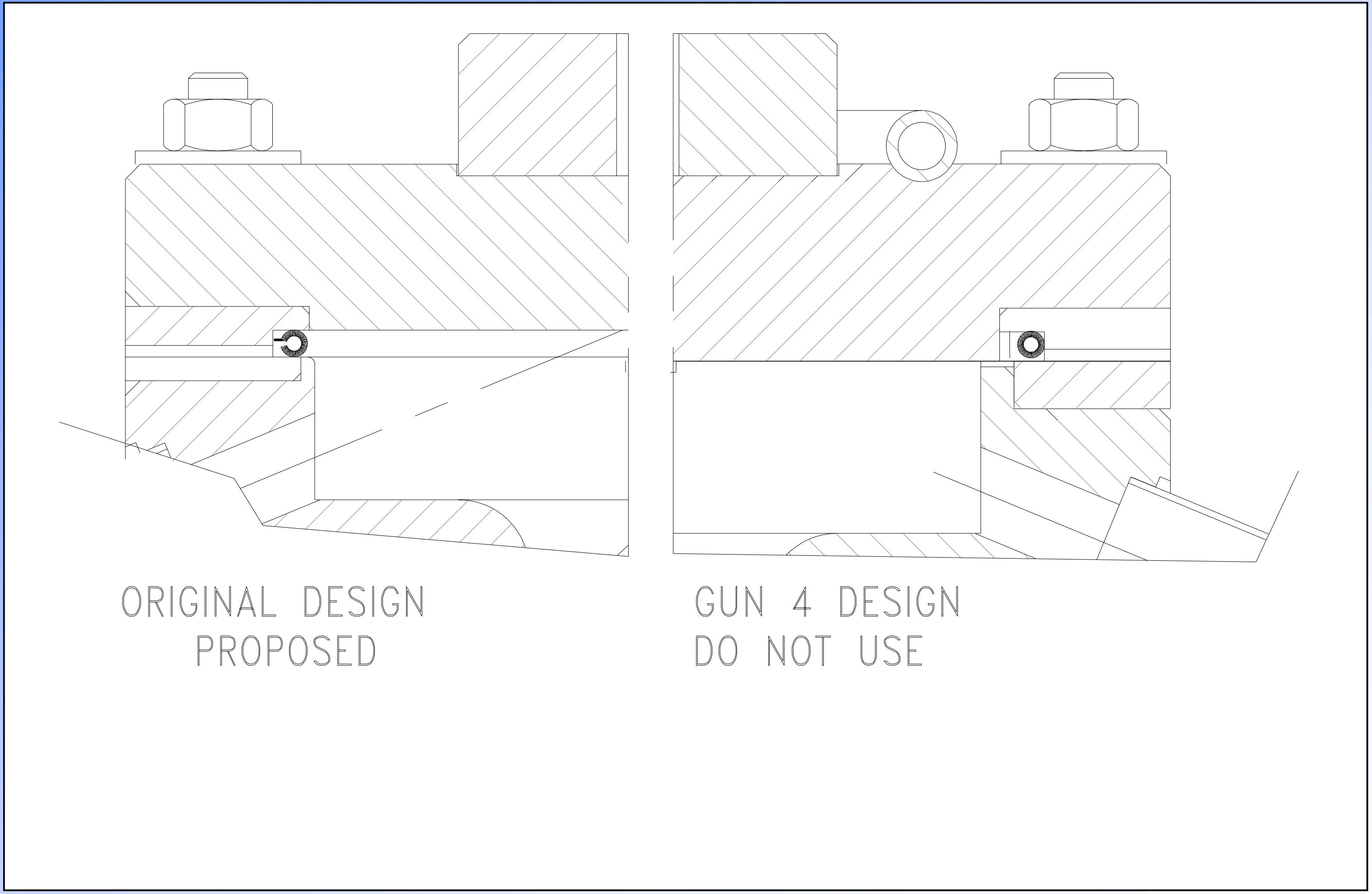
Electron beam diagnostics: Be able to determine the RF gun field, the absolute relative phase of laser to the RF field, and charge produced.

2. 120 Hz E-Gun – Mech. Aspects

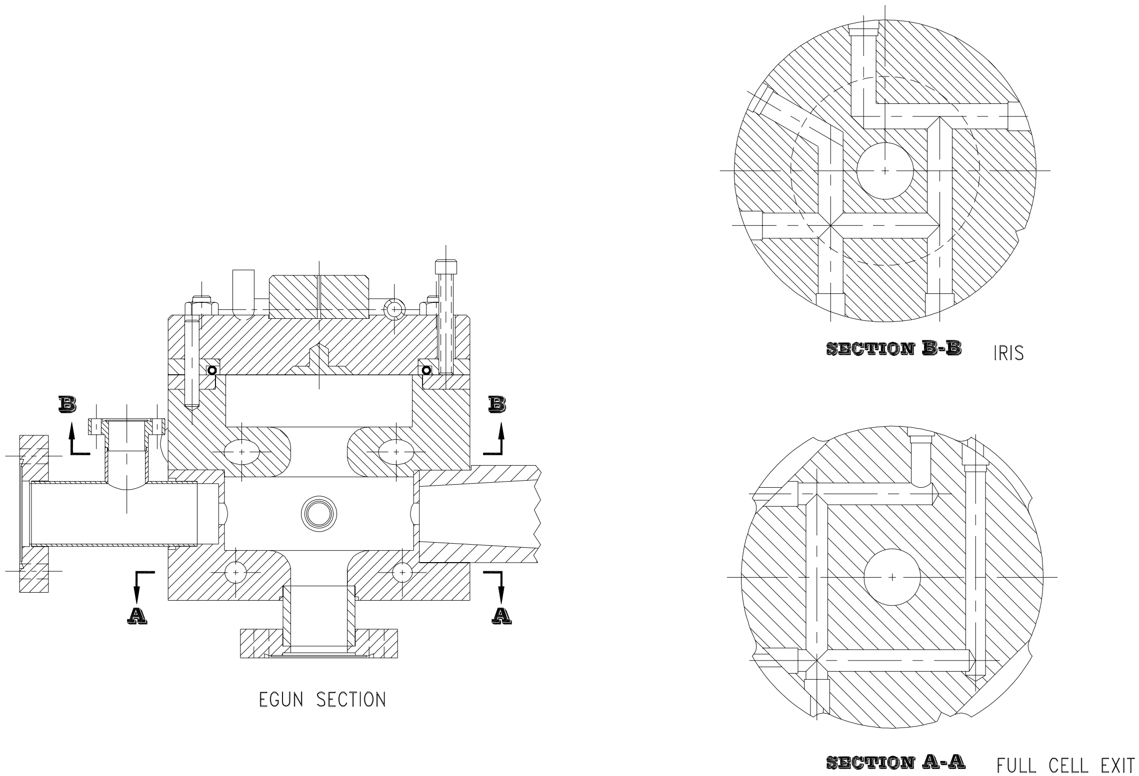
M. Woodle (NSLS)

- Cathode Seal Configuration
- Egun Cooling Modifications
  - Iris cooling
  - Cathode cooling
  - FEA analysis
- Remote Plunger Tuning
- Thermally Insulated Mounting
- Dual RF Feed

Cathode Seal Configuration



Egun Cooling Modifications



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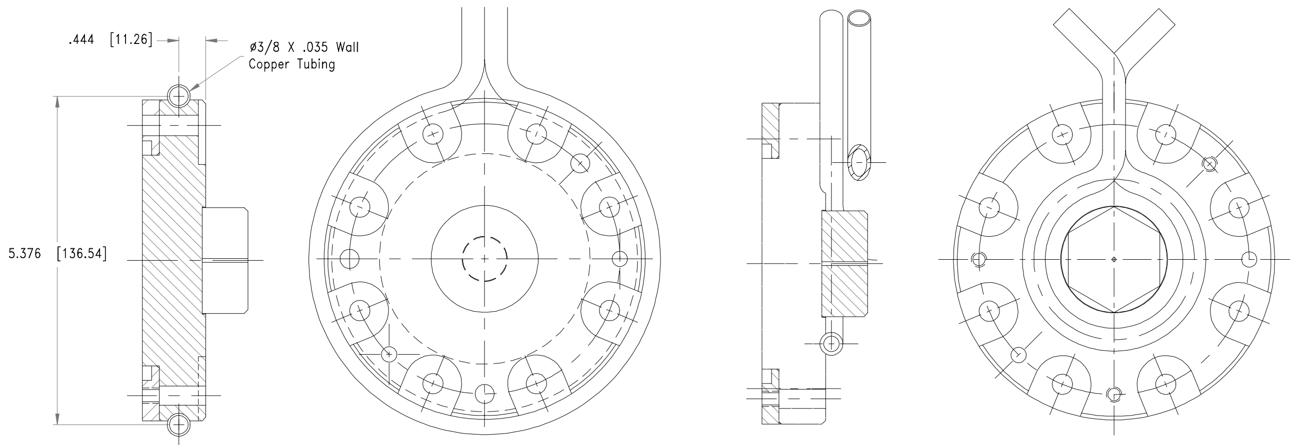
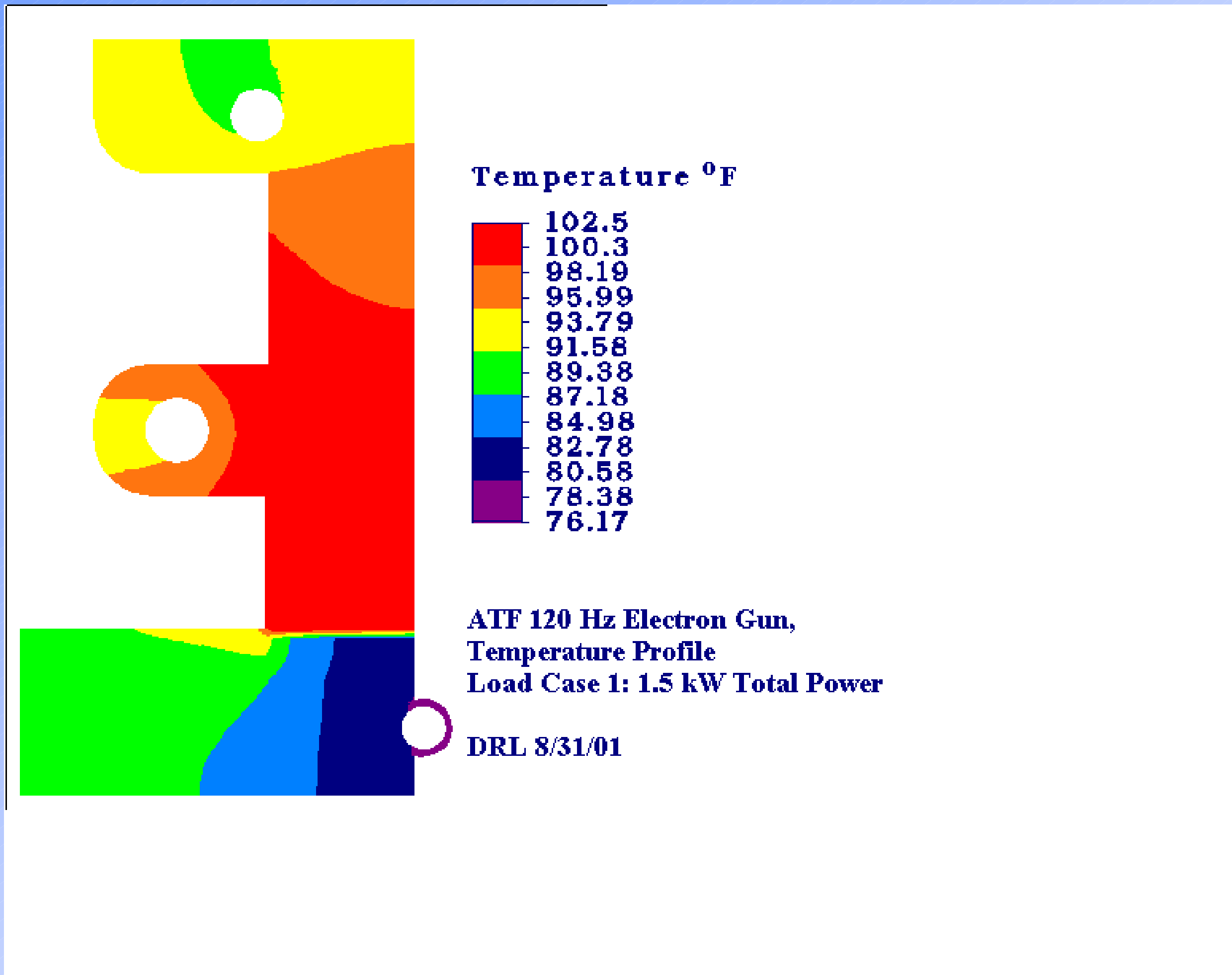
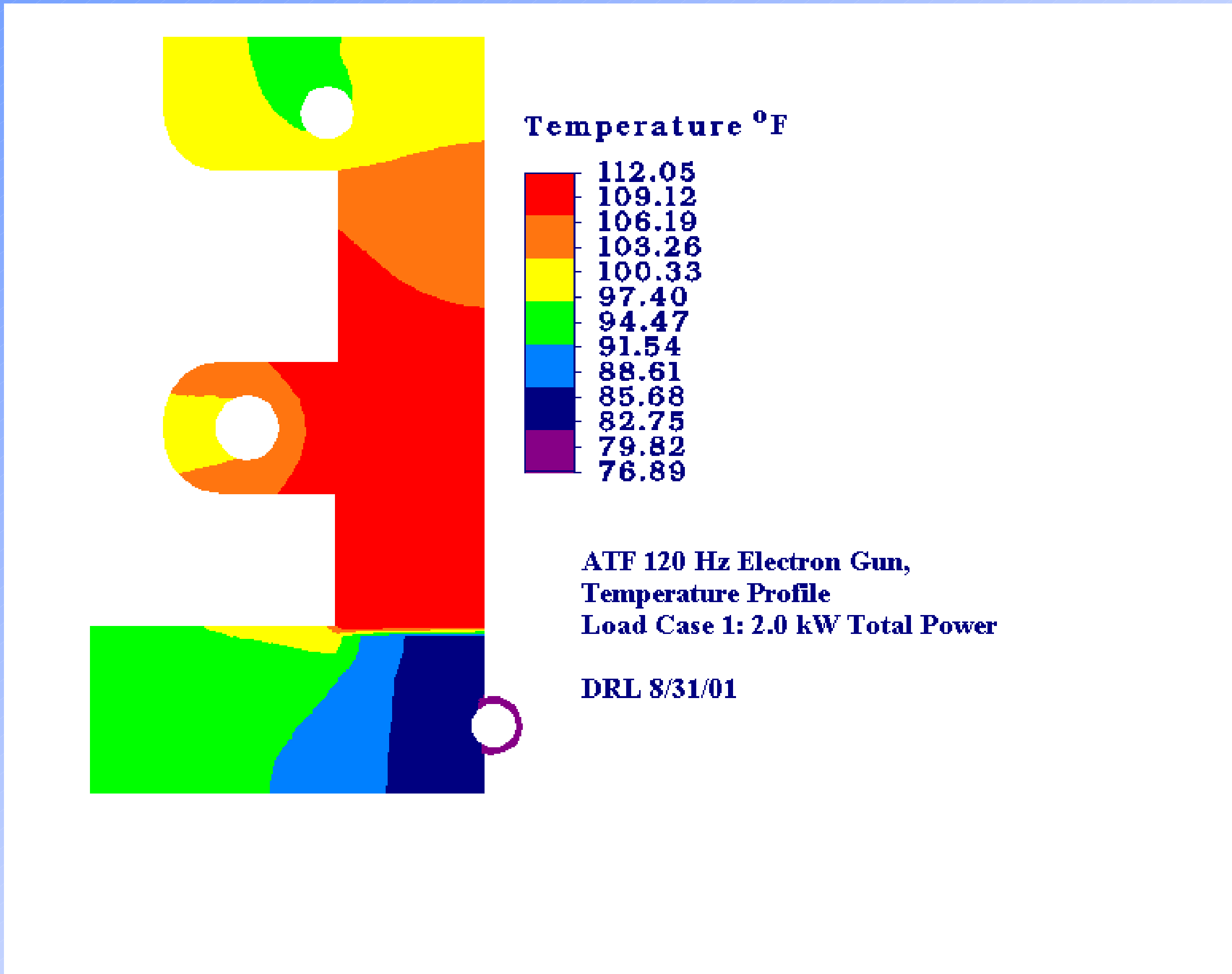
Cathode Cooling Options



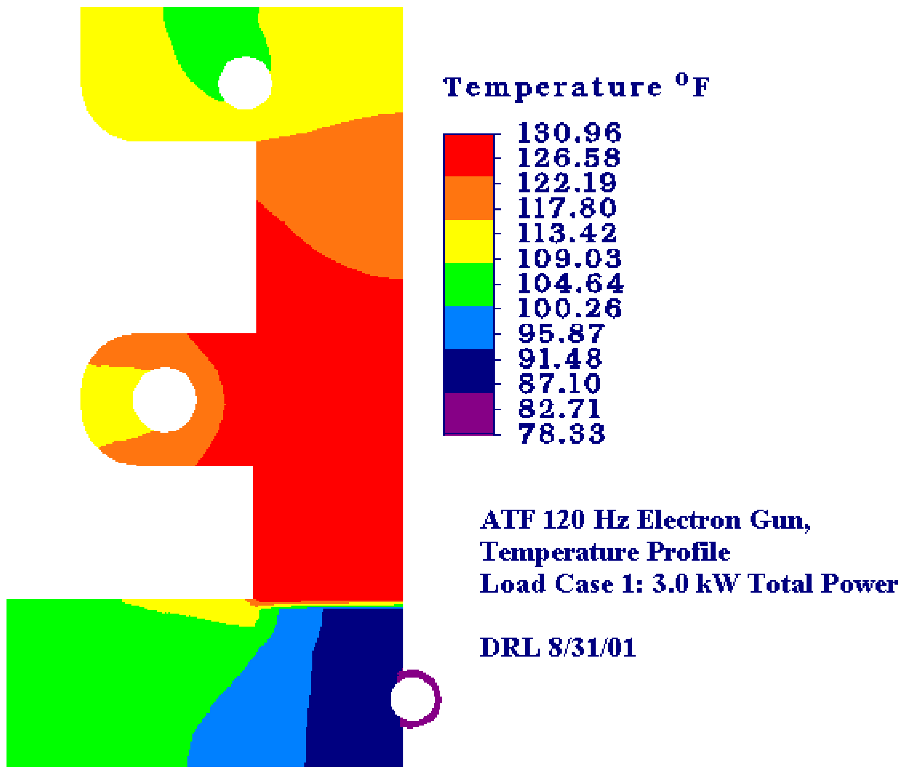
Temperature Distribution 1.5 KW



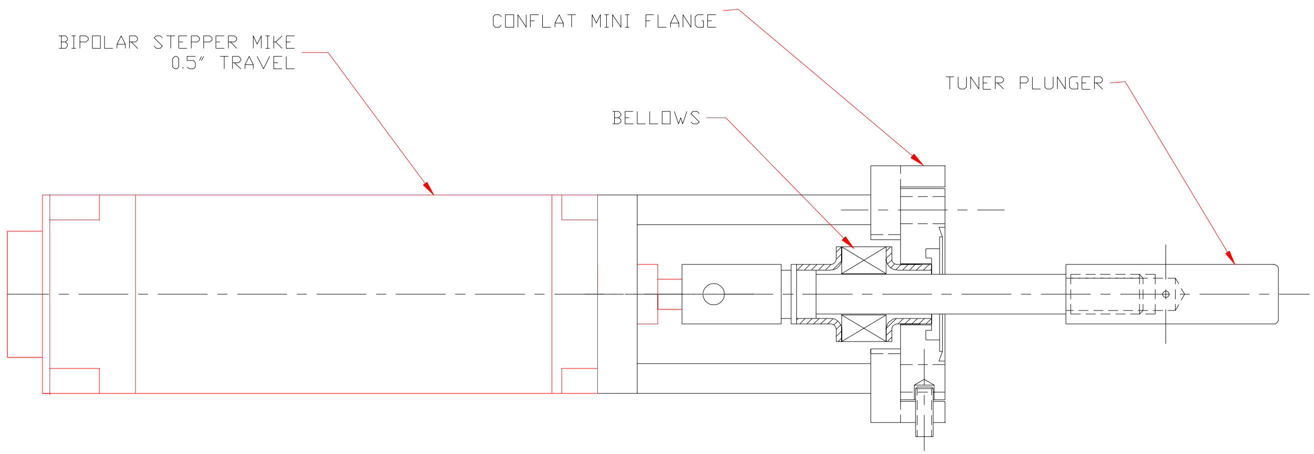
Temperature Distribution 2.0 KW



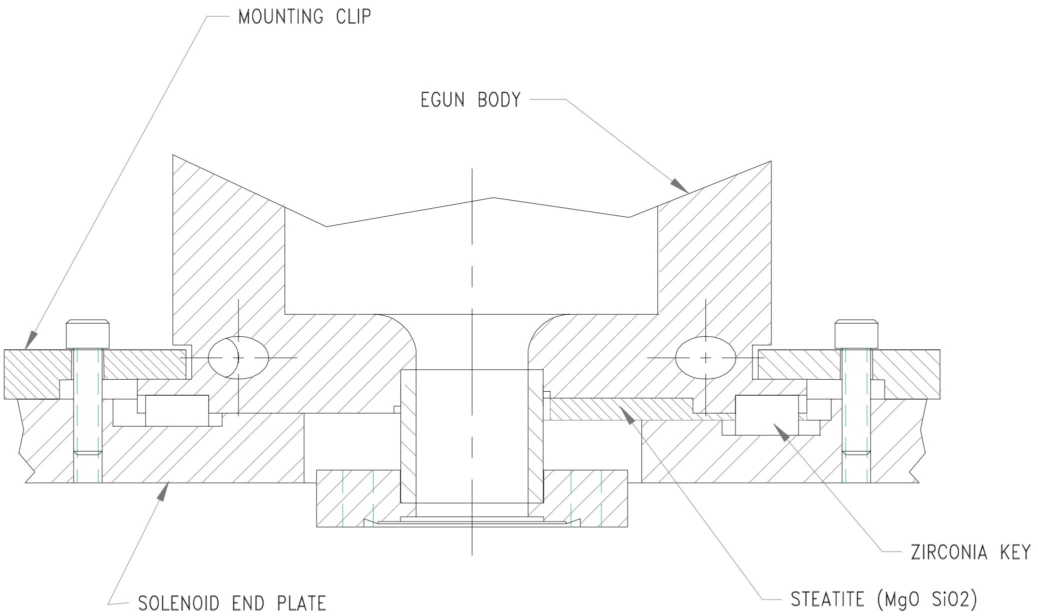
Temperature Distribution 3.0 KW



Remote Tuner



Thermally Insulated Mounting



3. LCLS 120 Hz Photoinjector II

X.J. Wang et al. (NSLS)

- Critical Issues in Determining the performance of the Photocathode RF gun.
  1. Stability reliability.
  2. Photo-injector system.
  3. Laser and Electron Beam Diagnostics.
  4. Longitudinal Emittance Compensation.
- Laser system – SHI PULRISE-100.
- Transverse and longitudinal laser pulse shaping.
- Thermal emittance of Mg cathode.
- Longitudinal Emittance Compensation.

Stability and Reliability

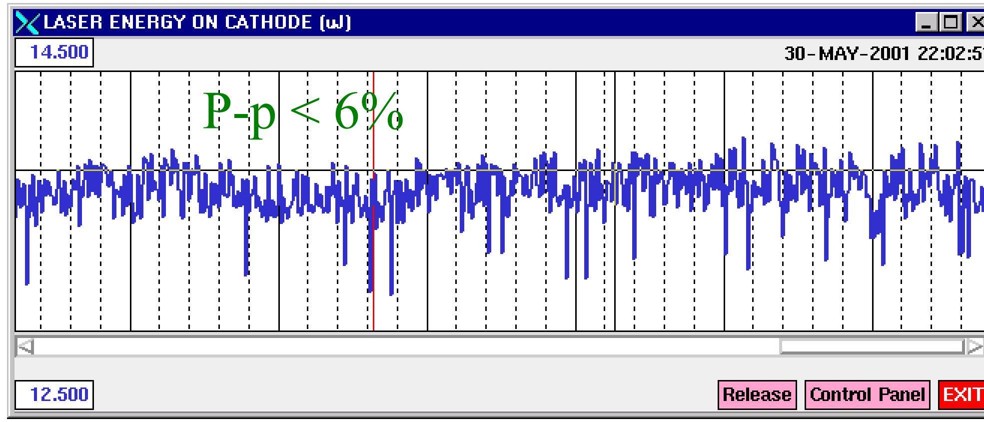
Laser system: Energy stability, timing jitter, point and transverse distribution.

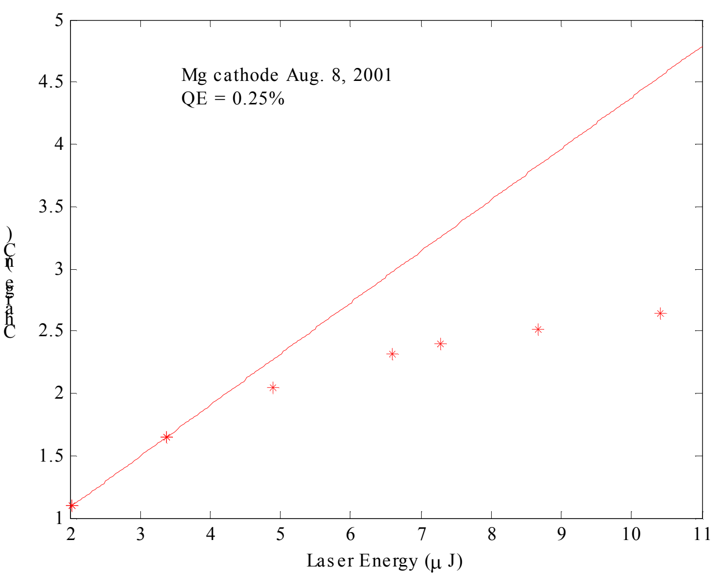
Photocathode RF gun: Reliably operating, no breakdown.

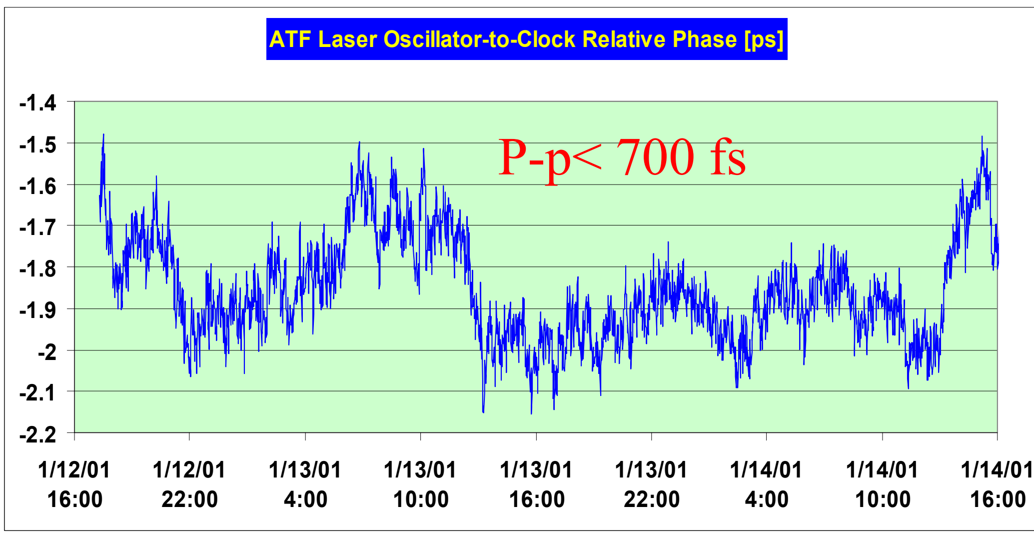
Cathode: Long life, and uniformity.

Performance of Photocathode RF gun Injector at the ATF

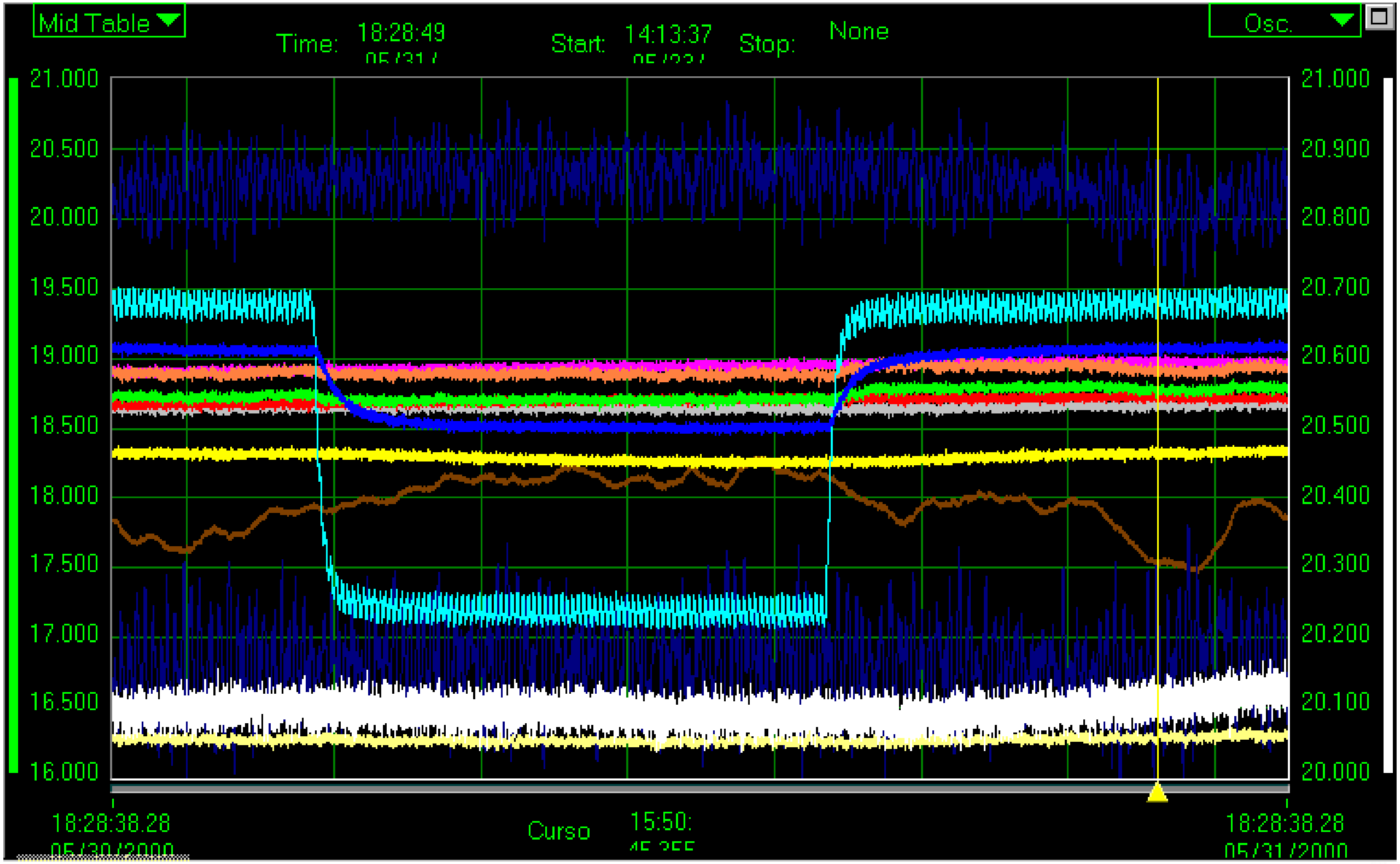
ATF is the only multi-user facility based on the photocathode RF gun injector, it provides more 1000 hours per year for user beam time. We have demonstrated **0.8 mm-mrad** emittance for **0.5 nC** charge.







Temperature Control



PULRISE-100
All-solid state picosecond laser

SHI

[Main specification]

- Laser medium Nd:YLF
- Pulse width 12 ps @1047 nm, 8 ps @262 nm
- Pulse energy 2 mJ @1047 nm, 0.2 mJ @262 nm
- Jitter <0.5 ps RMS
- Dimension 600 mm(W)×900mm(D)×300mm(H)
- Repetition rate 25 Hz

[Feature]

- Ultra low jitter: capable of precise synchronization with external RF.
- Active stabilization control system for the environmental fluctuation, such as temperature, vibration and atmospheric pressure.

[Application]

- Light source for photocathode RF-Gun system.
- Light probe for high-speed photochemical reaction.
- Laser material processing.

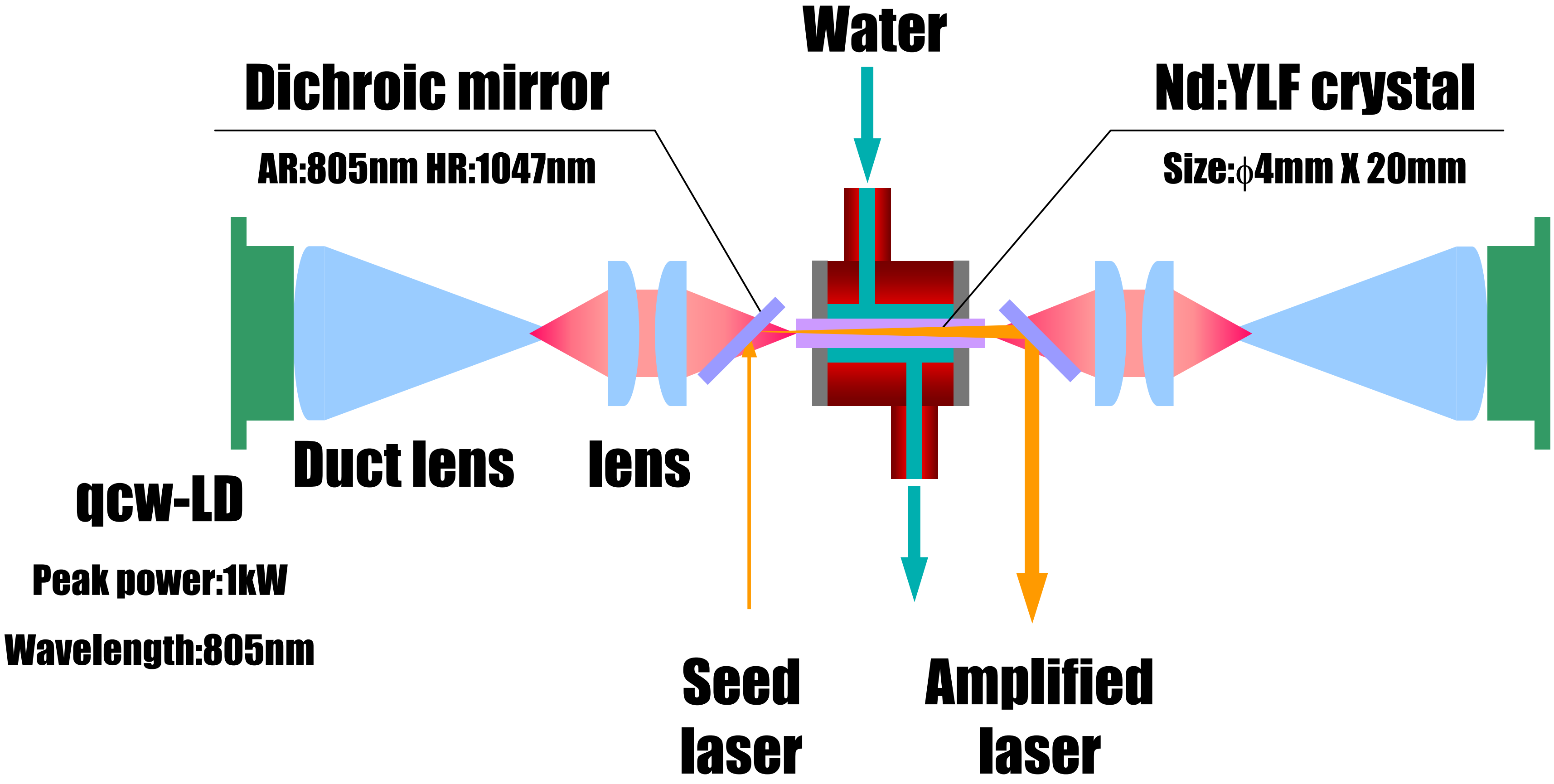
[Option]

1. Photocathode irradiation optical system
2. Pulse width measurement system
   (Rep mode, single shot mode available)
3. Pulse energy monitor
4. Beam profiler (transverse mode)
5. Temperature, vibration and atmospheric monitor
6. Electric beam shutter
7. Time jitter measurement system
   (Rep mode, single shot mode available)
8. Remote controller
9. Pulse compression system
10. High power amplifier module

★ 100 Hz model is also available

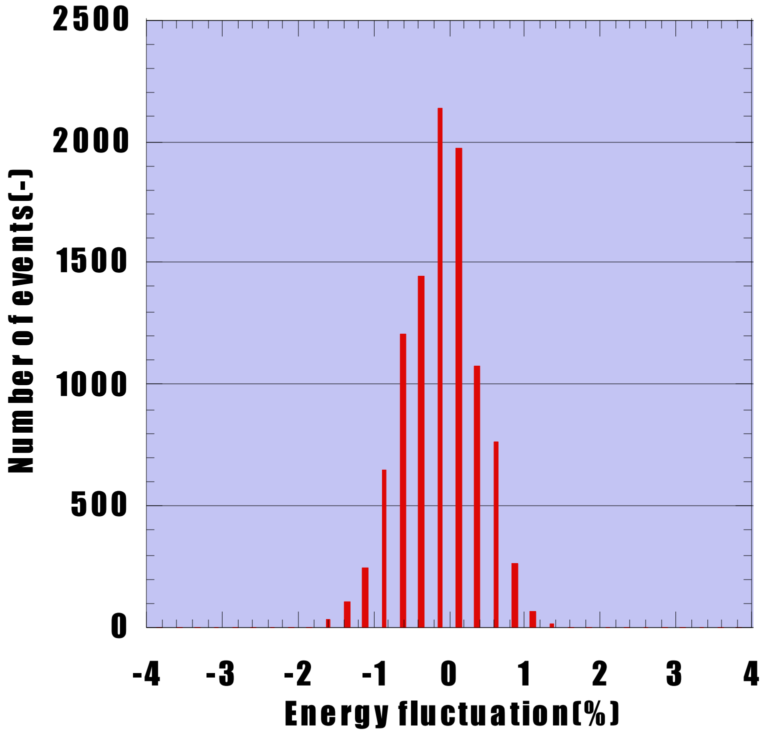

Time-Bandwidth
PULRISE II
Time-Bandwidth
SHI

Nd:YLF Amplifier (SHI)



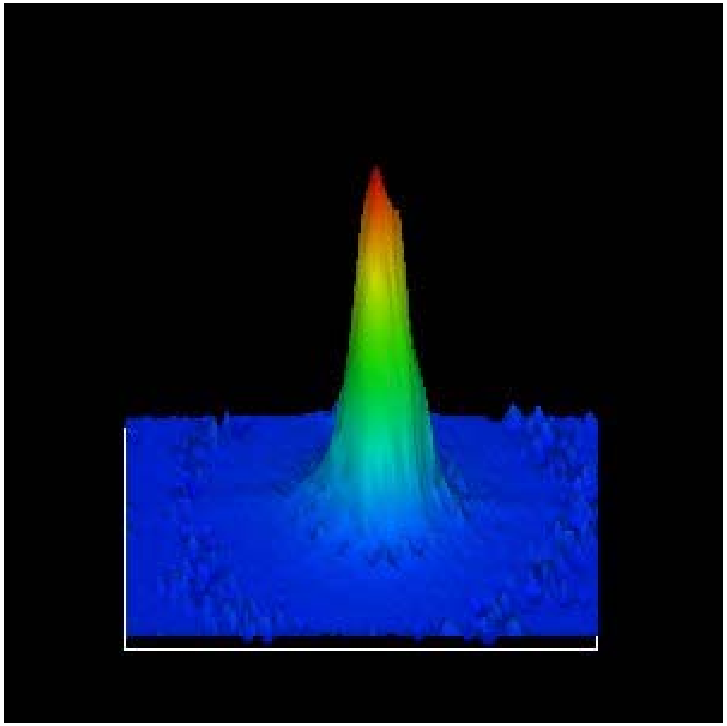
Stability of Pulrise

Energy stability (IR)



Total shot number	10000
Standard deviation	0.55%

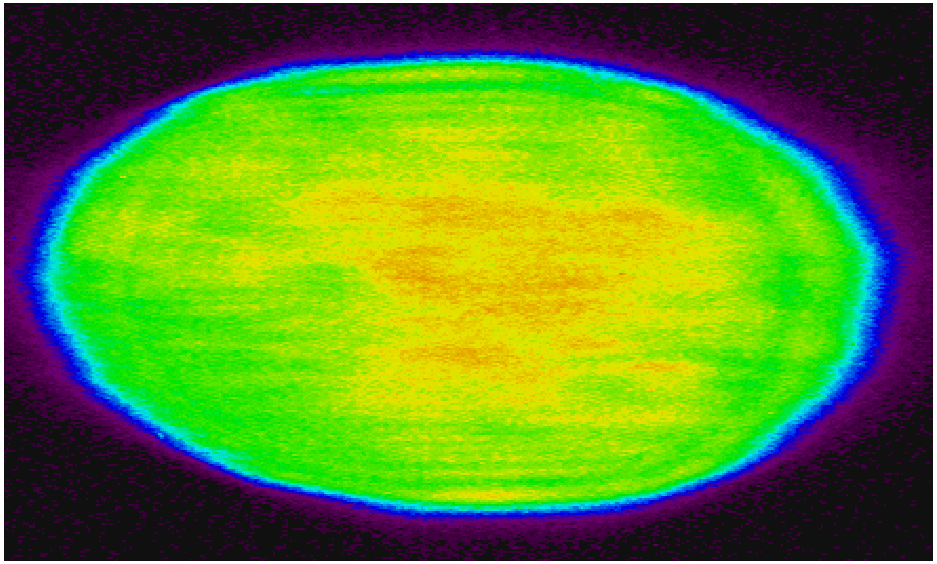
Beam profile (IR)



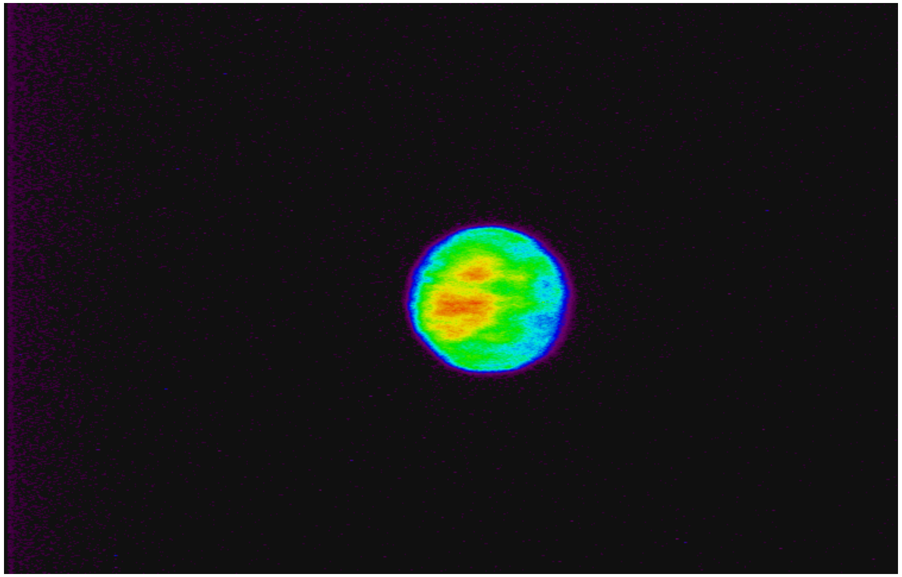
Pointing stability σ=5μrad

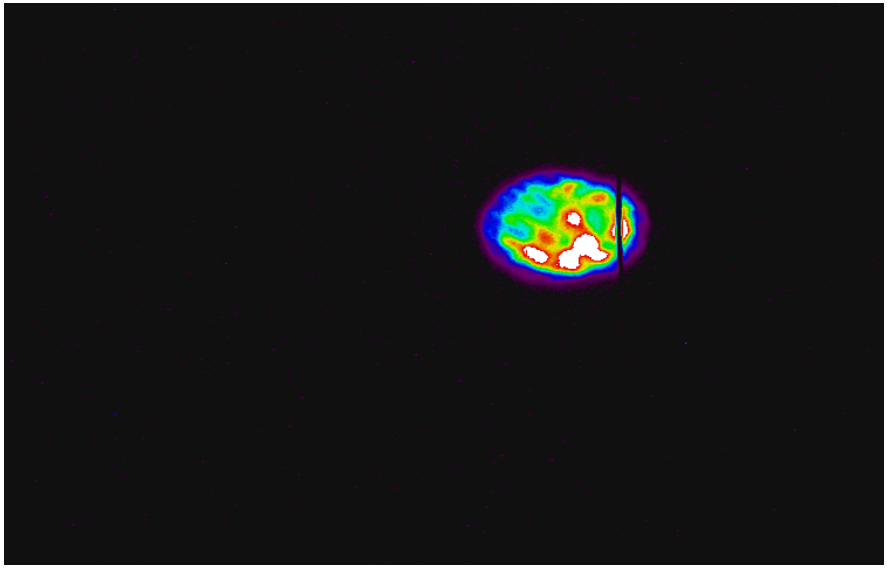
Laser transverse Profile Shaping

- Truncation – inefficiency, and simple.
- Gaussian mirror.
- Transverse diffraction shaping.
- Deformable mirror.

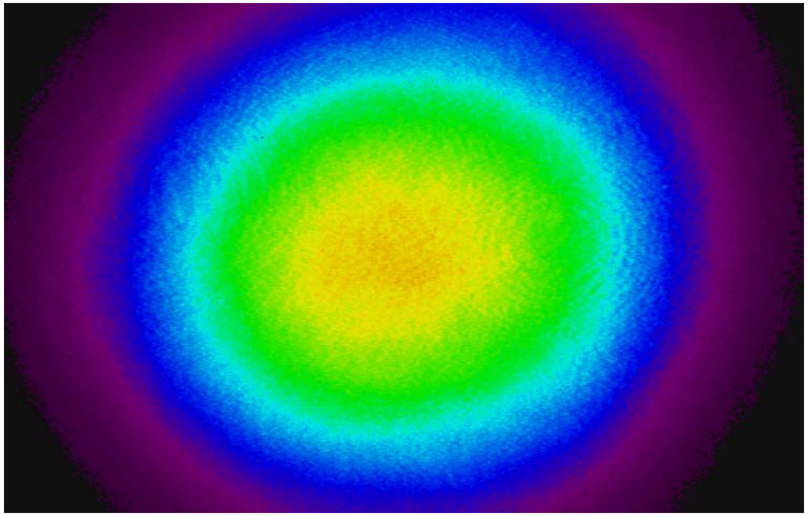


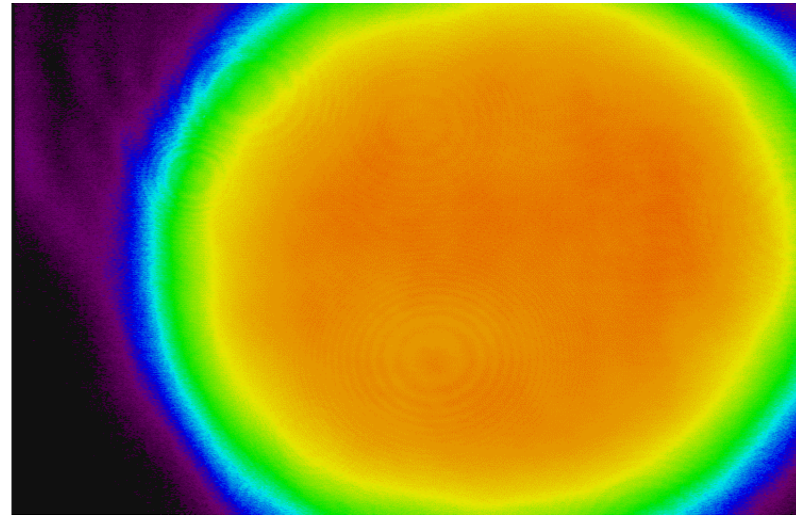
Transverse beam profile



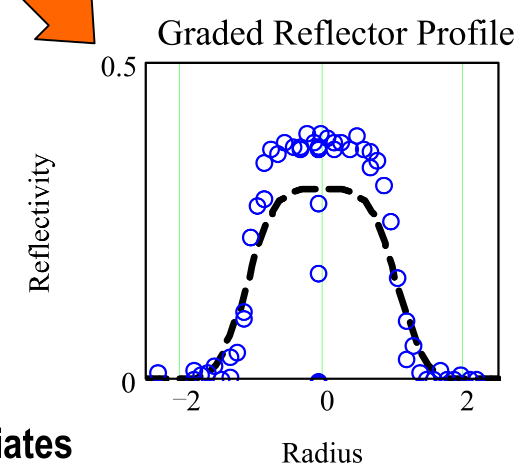


Profile Flattening with a Graded Reflectivity Mirror





- Gaussian input



- Normalized intensity profile after passing graded reflector and imaging through a spatial filter

Longitudinal Pulse Shaping

- Saturable absorber.
- Pulse stacking.
- Longitudinal Pulse shaping in frequency domain.

Saturable Absorber

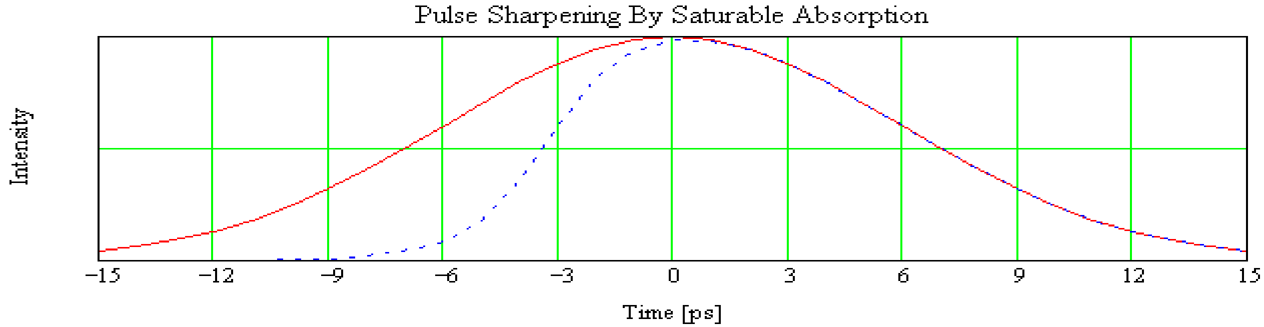
Properties of F_2^-:LiF color center saturable absorber:

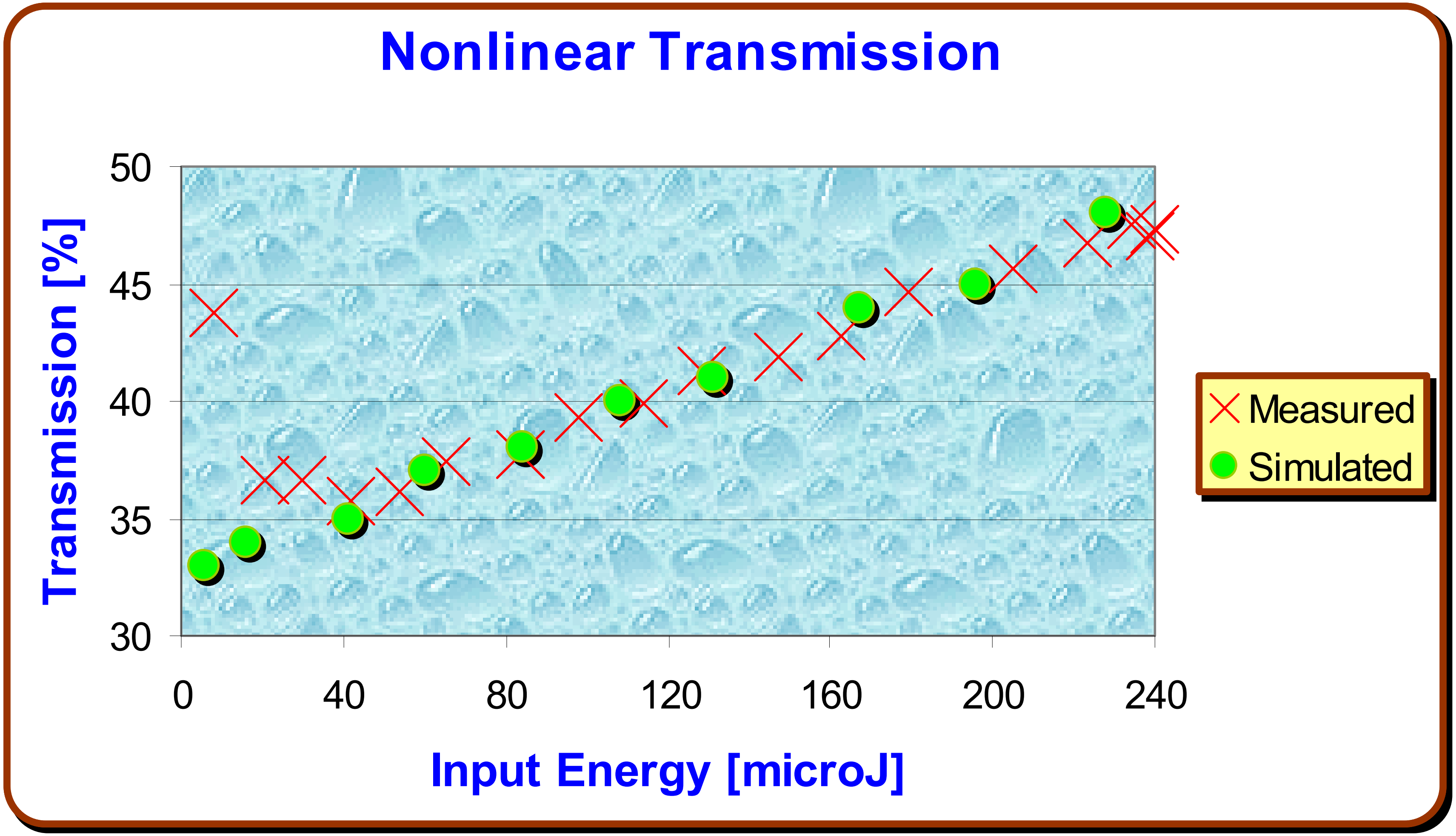
$\alpha := 0.6 \cdot cm^{-1}$ $L := 7.5 \cdot cm$ $T_0 := \exp(-\alpha \cdot L)$ $T_0 = 0.011$ $\sigma := 1.7 \cdot 10^{-17} \cdot cm^2$

$F_{sat} := \frac{h \cdot \nu}{2 \cdot \sigma}$ for a 3-level system $F_{sat} = 5.495 \cdot 10^4 \cdot mass \cdot time^{-2}$

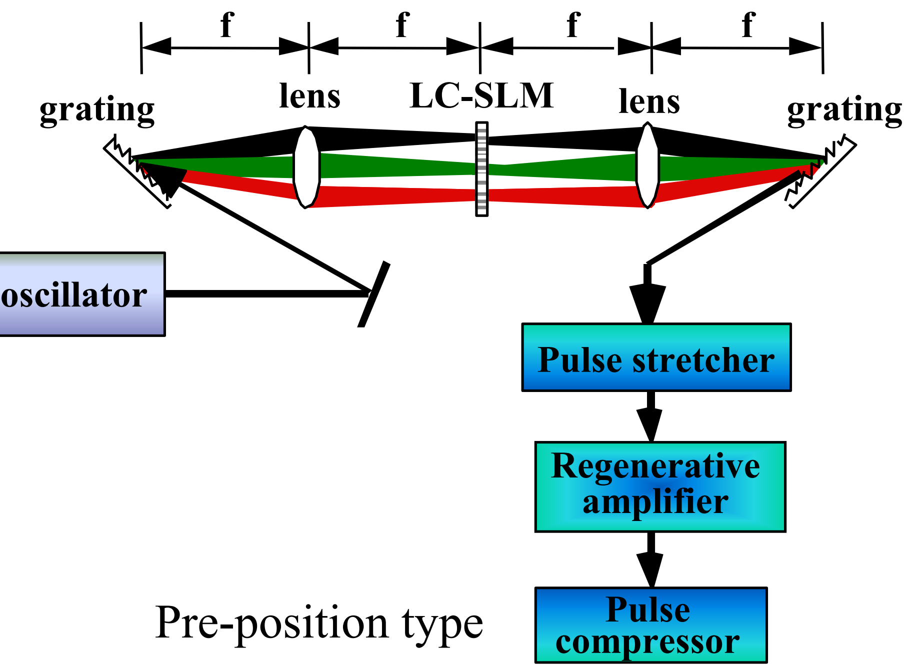
Calculate the shape of the output pulse in the presence of the saturable absorber using a "thin-slab" transmission formula:

$$I_{out_{ps}} := Intensity\left[(ps - 40) \cdot 10^{-12} \cdot sec\right] \cdot \left[\frac{T_0 \cdot \exp\left(\frac{fluence\_exposure_{ps}}{F_{sat}}\right)}{1 + T_0 \cdot \left(\exp\left(\frac{fluence\_exposure_{ps}}{F_{sat}}\right) - 1\right)} \right]$$

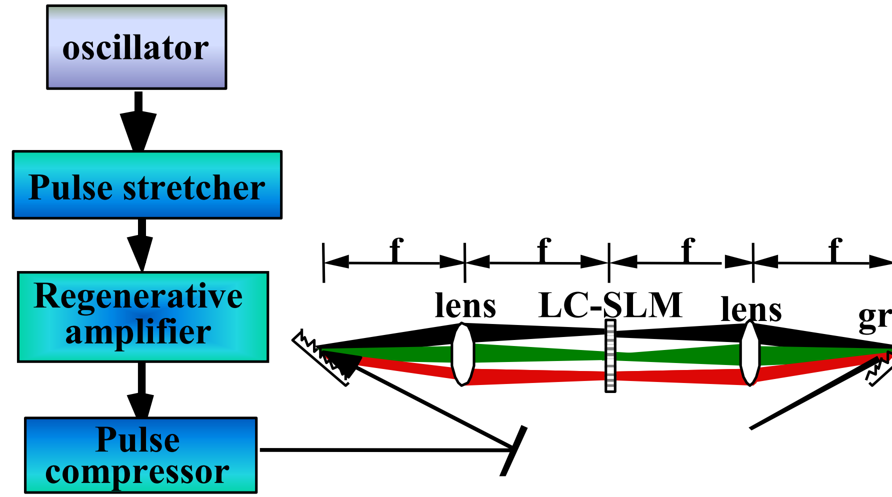



Nonlinear Transmission
Transmission [%]
50
45
40
35
30
0
40
80
120
160
200
240
Input Energy [microJ]
Measured
Simulated

Femtosecond pulse shaper and an amplifier FESTA



Pre-position type



Post-position type

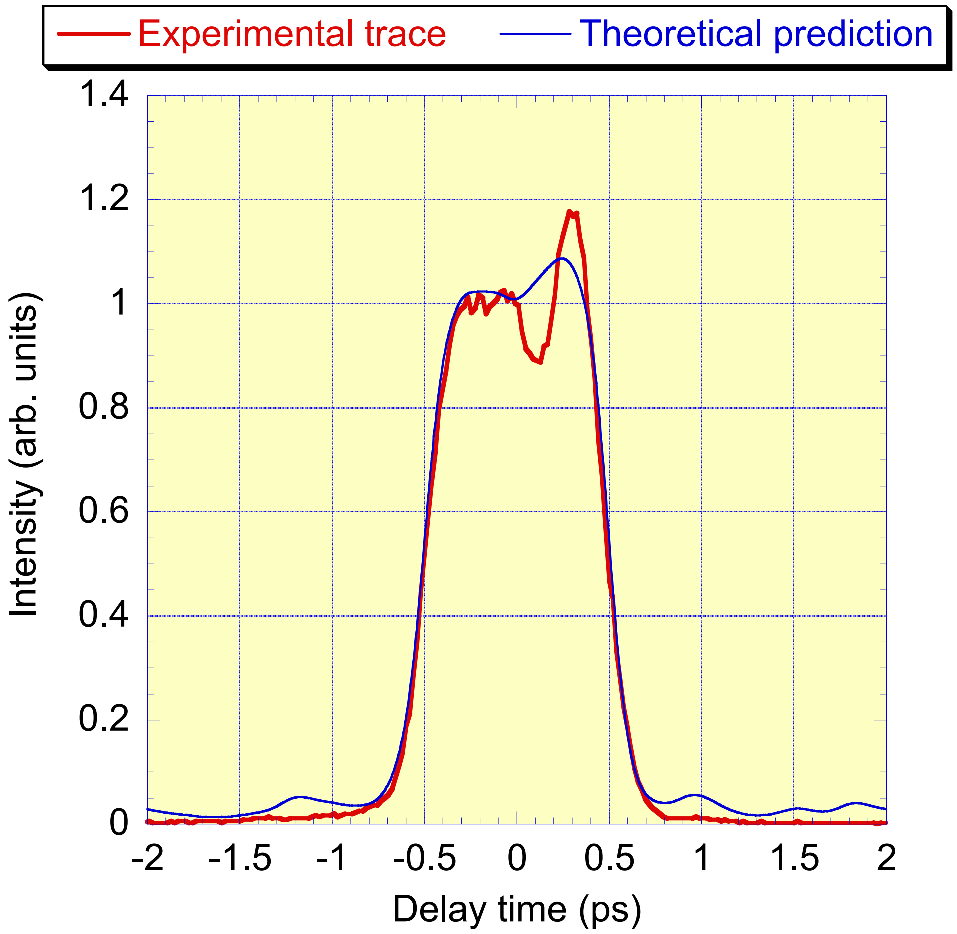
Characteristics：

Neglect of insertion loss in a pulse shaper
No damage of the modulation device
Pulse distortion by an amplifier which is placed after a pulse shaper
Damage of optical elements in an amplifier induced by pulse distortion

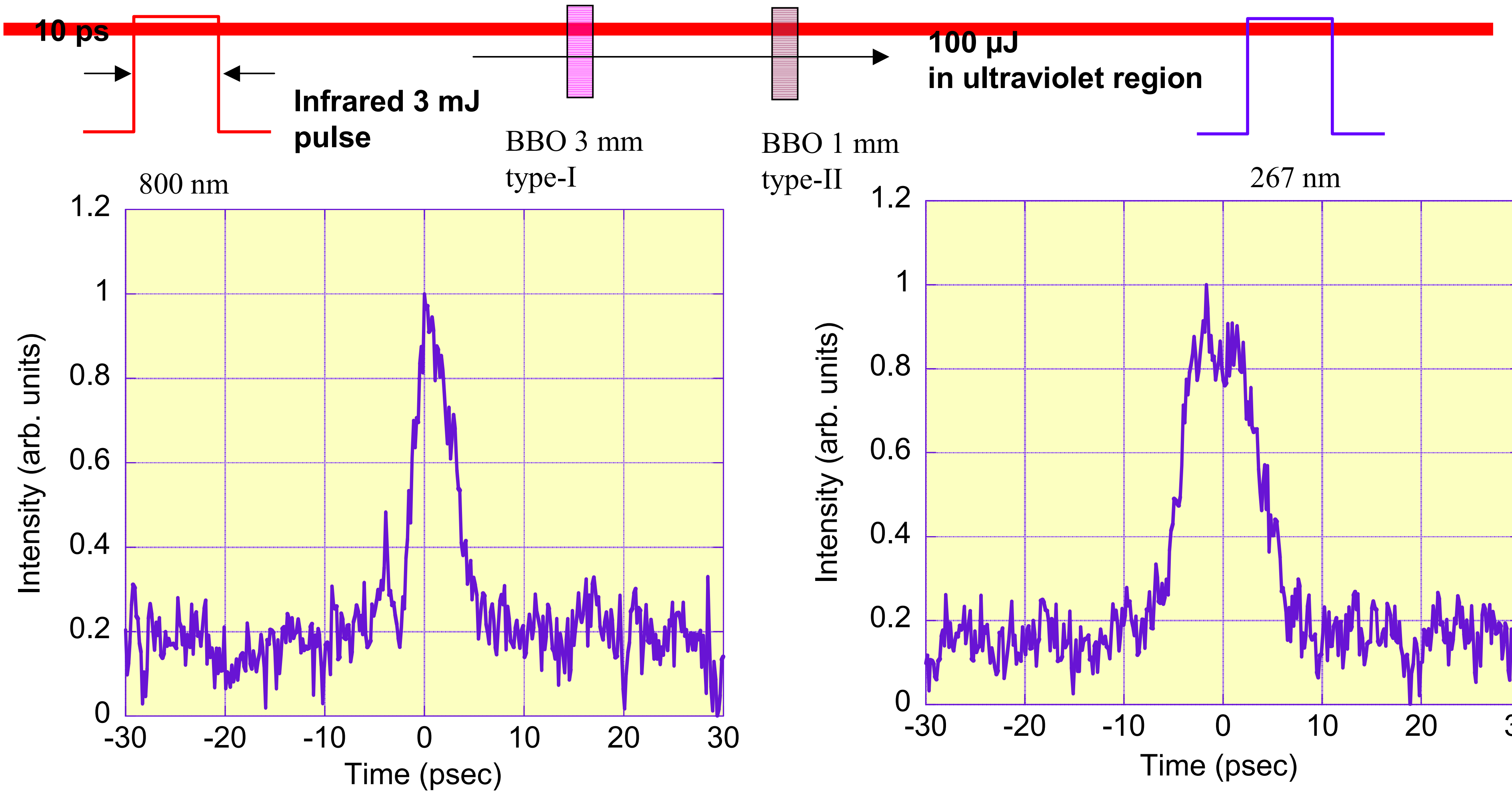
Characteristics：

Simplicity to design of frequency modulation
Damage of the modulation device
Insertion loss of the pulse shaper

Experimental Results



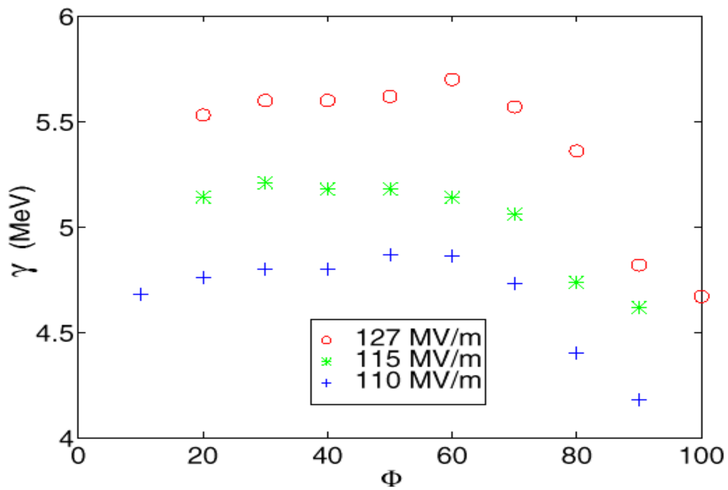
Temporal shaping of the ultra violet square pulses measured by X-ray streak camera

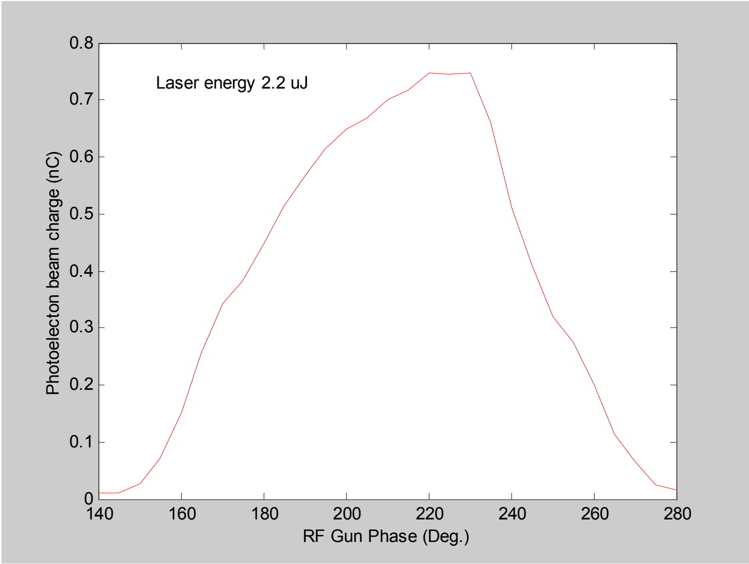


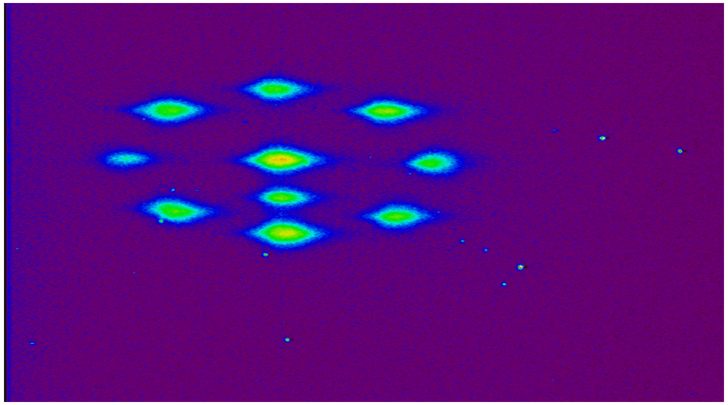
Temporal intensity profile of unshaped femtosecond pulses measured by streak camera (FWHM ~4.4 ps)

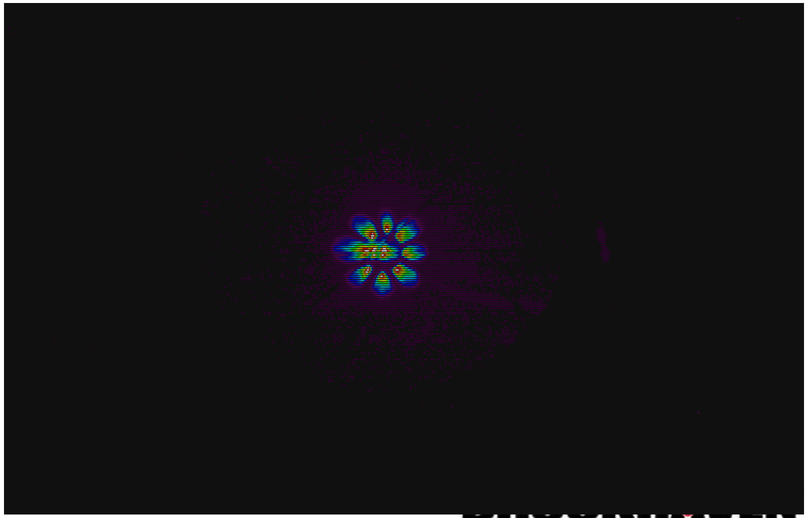
Temporal intensity profile of shaped pulses measured by streak camera (FWHM ~8 ps)

Electron Beam and Laser Diagnostics

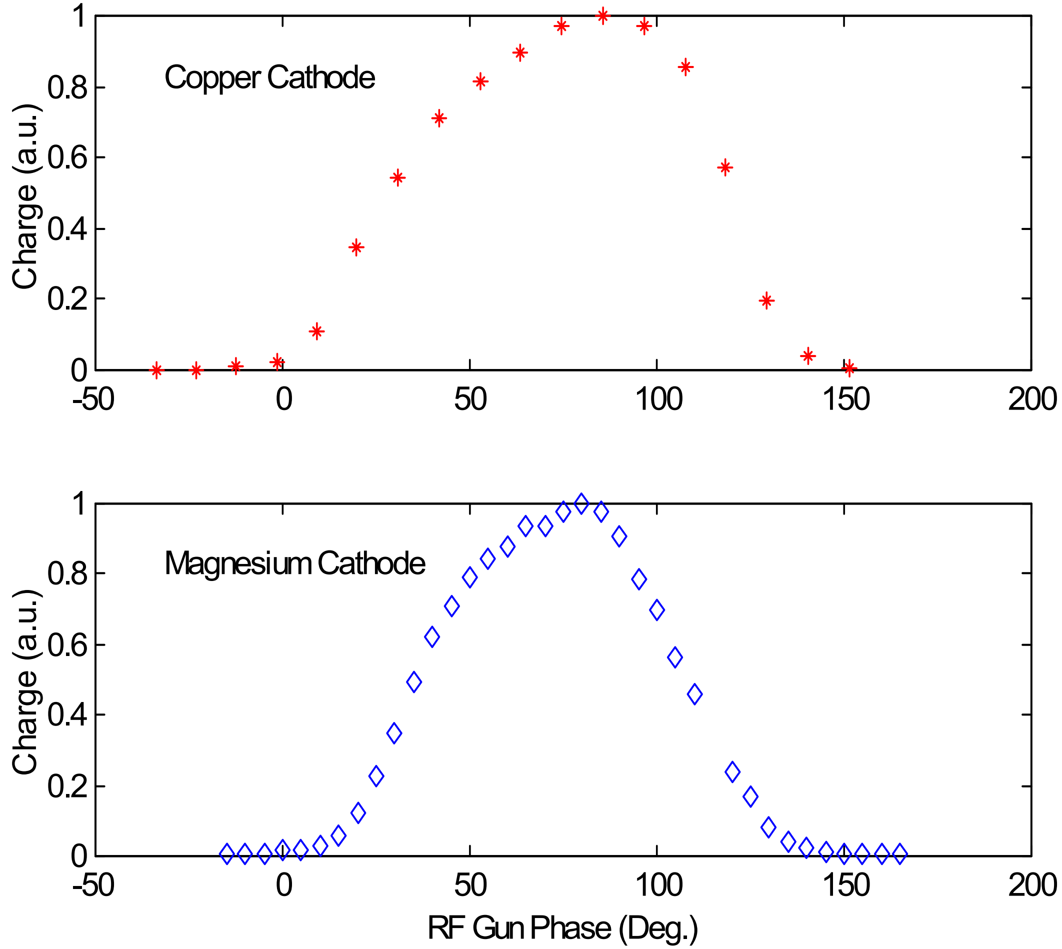








Thermal Emittance-Mg



Thermal Emittance -W. Graves

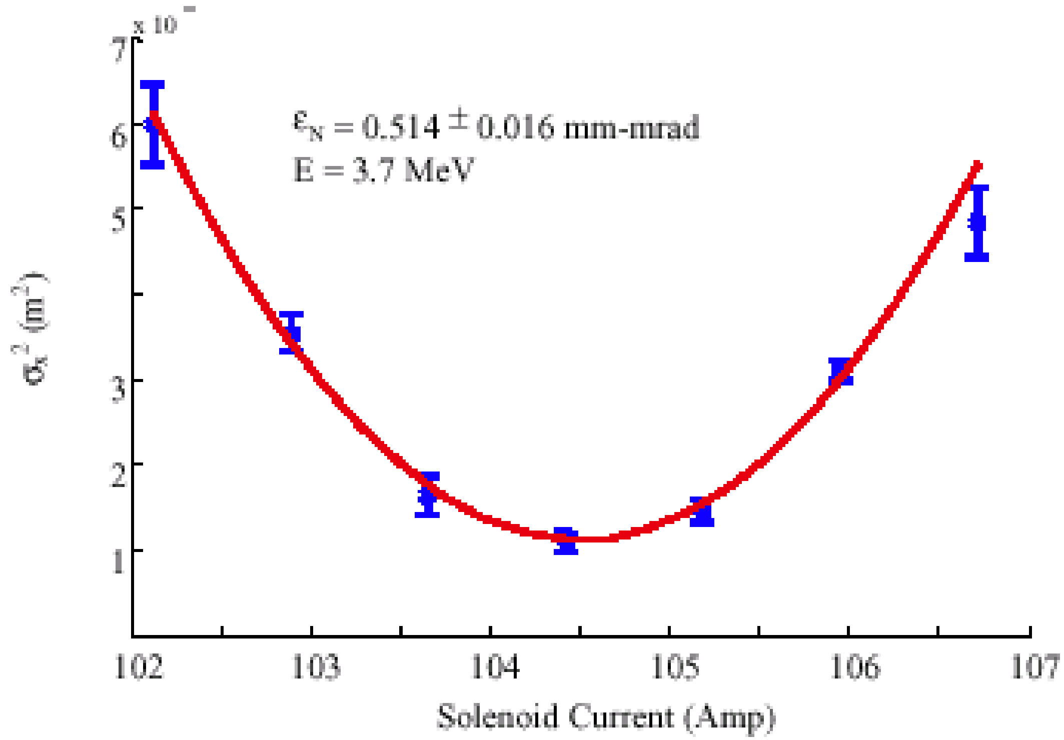
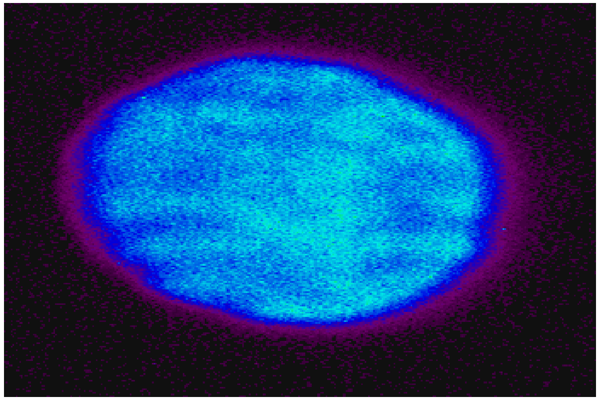
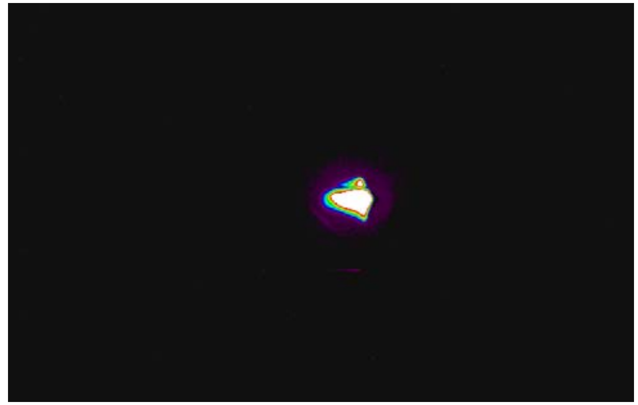


Figure 2: Data from a typical solenoid scan. Charge = 2 pC, bunch length = 2.5 ps FWHM.

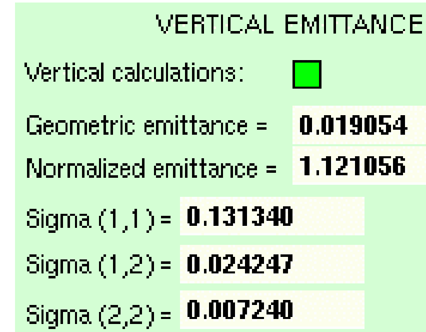
Performance of Photocathode RF gun Injector at the ATF

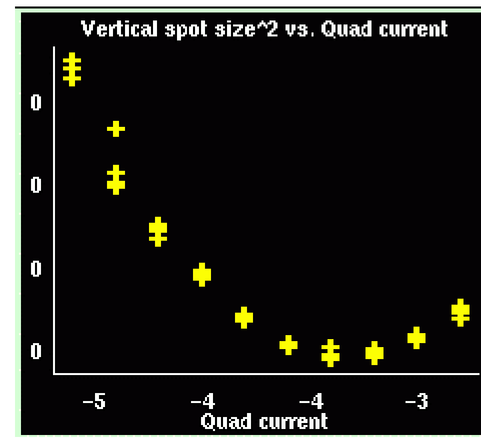


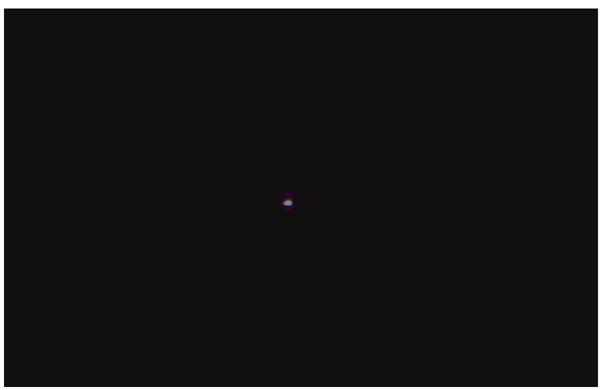
Laser profile on the cathode.



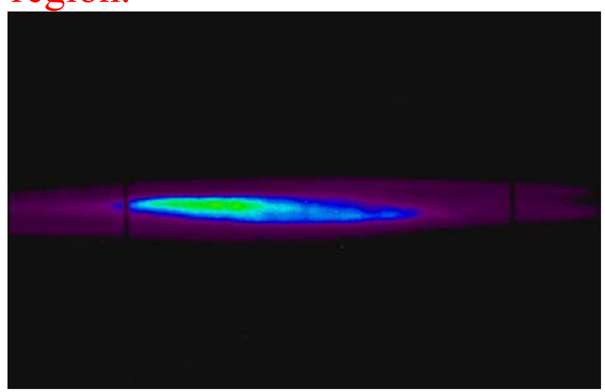
Electron beam at dispersion region.







Electron beam focus after the gun.



Electron beam profile on the measurement screen.

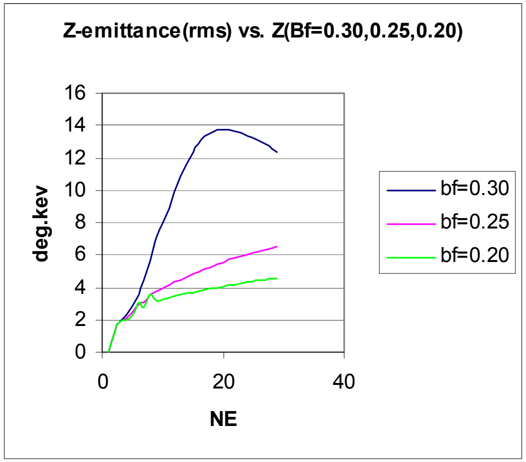
Q-scan data for a 30 MeV beam, 200 pC charge with rms normalized emittance 1.1 mm-mrad, bunch length 4 ps FWHM

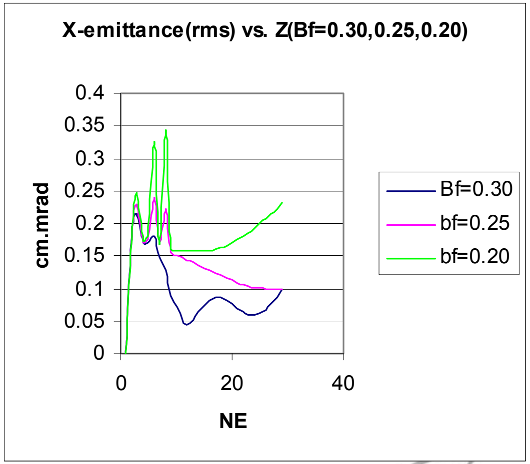
$$B = \frac{Ne}{2\pi\ell\,\varepsilon_{n,x}\varepsilon_{n,y}}$$

$$x'' + k\ (s)x - \frac{2r_e N/\ell}{a^2\gamma^3}x = 0$$

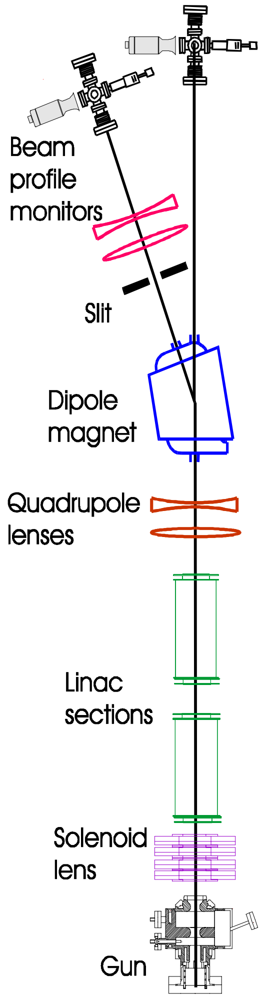
$$z' = \frac{\delta}{\gamma^2}$$

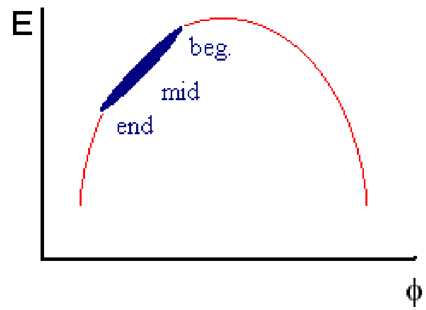
$$\delta' = \frac{3r_0 N}{\gamma^3\beta^2\ell_b{}^3} f(a,b)z$$

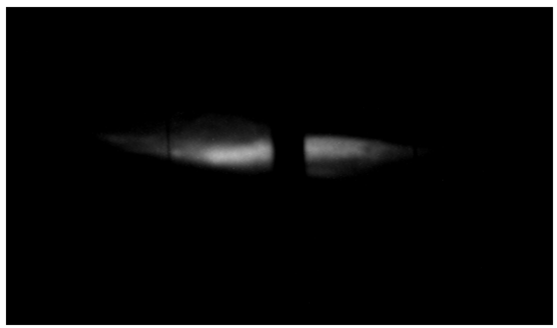


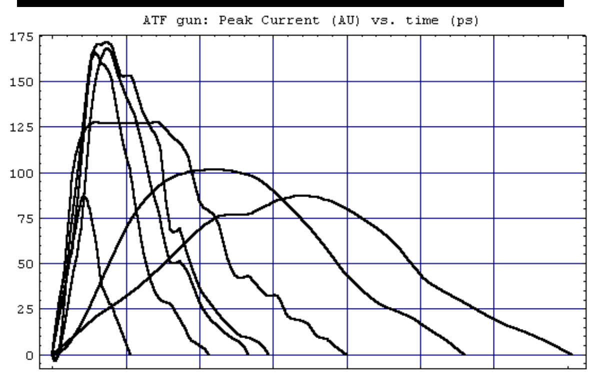


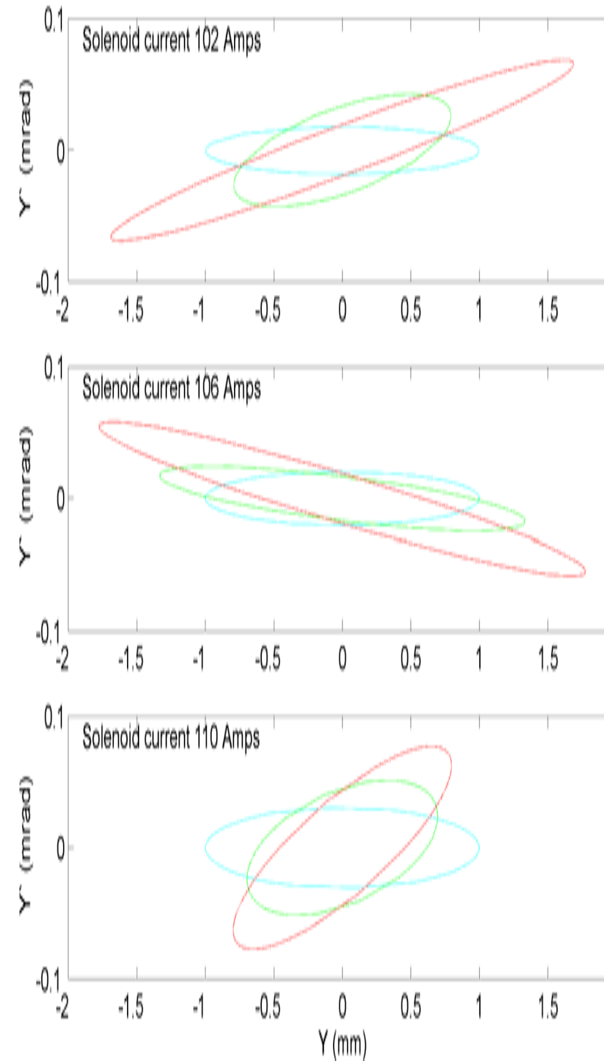
Transverse Space-charge Emittance Compnesation



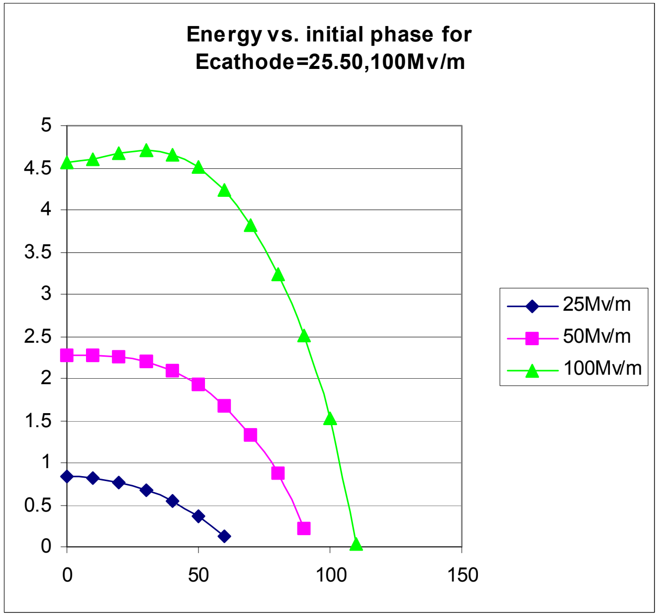


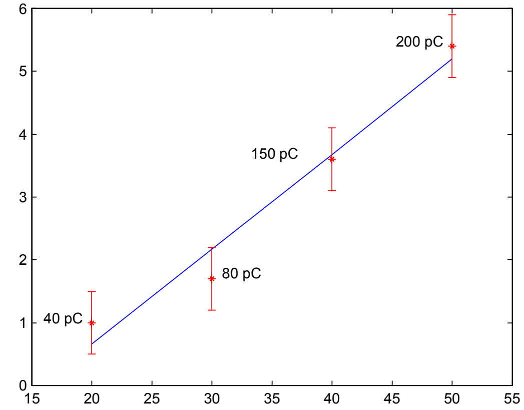


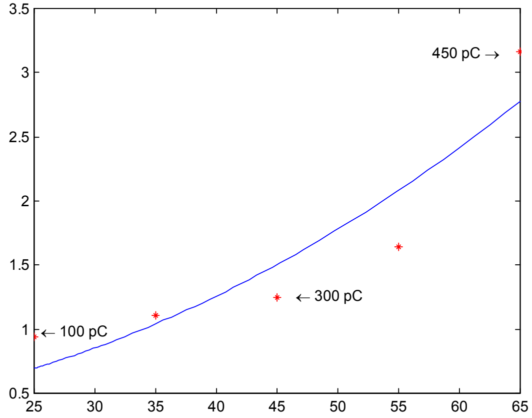




Longitudinal Emittance Compensation

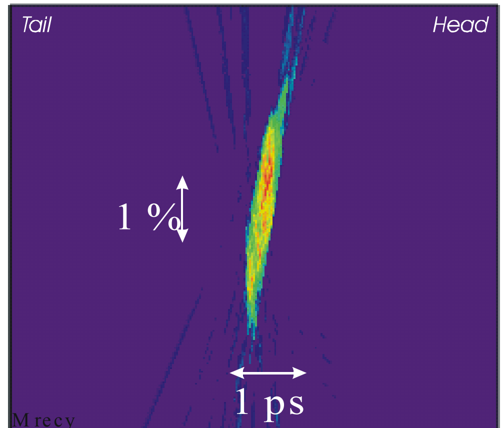


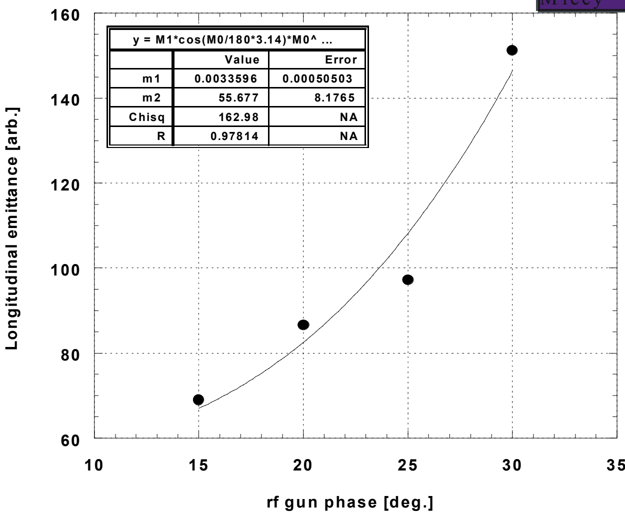


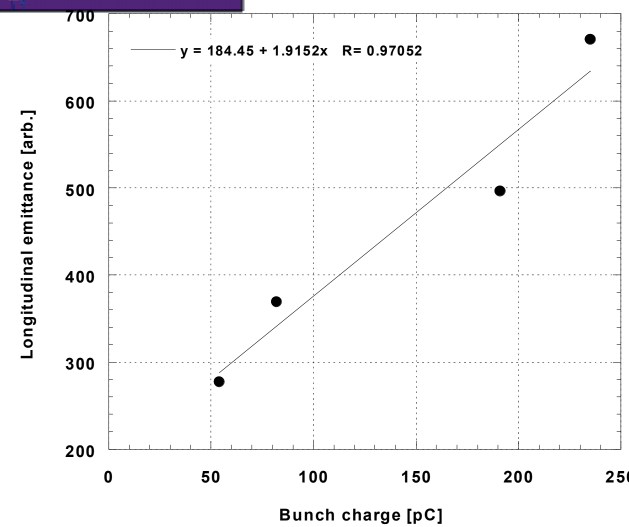


- *Phys. Rev. E. 54, R3121 (1996)*
- *PAC 97*

Longitudinal Emittance

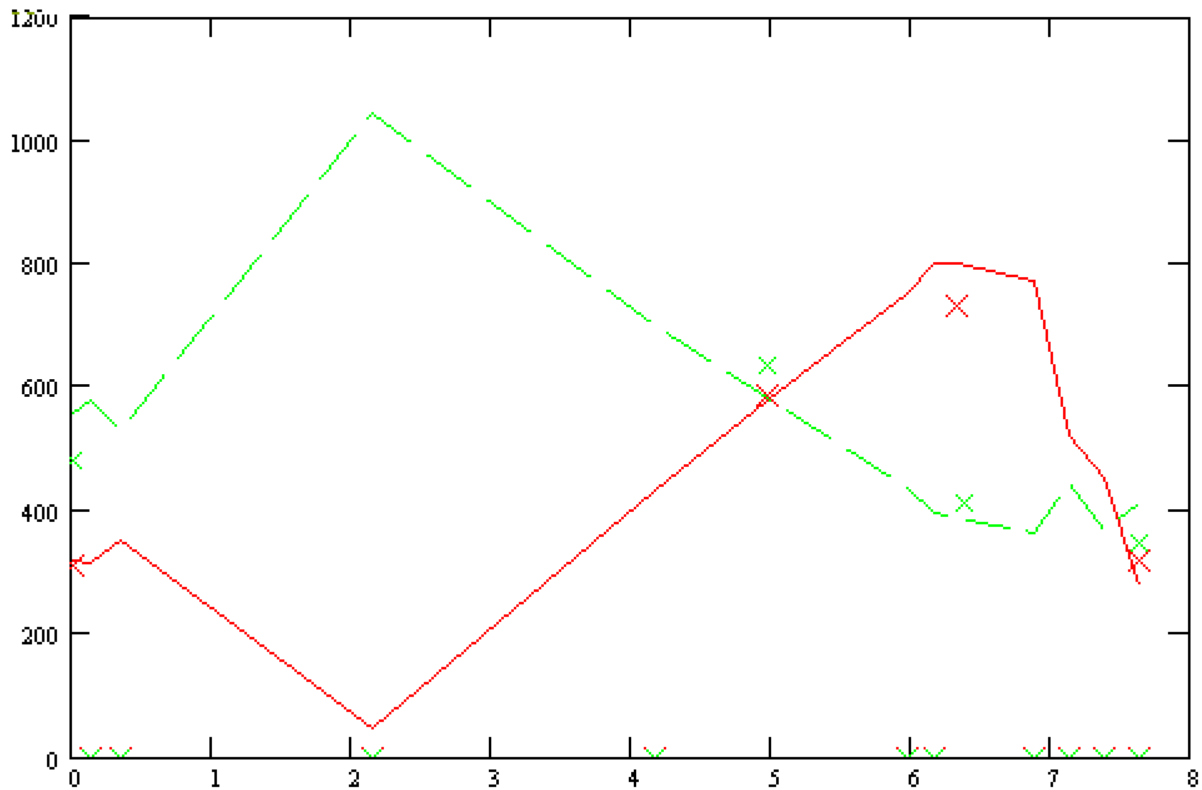


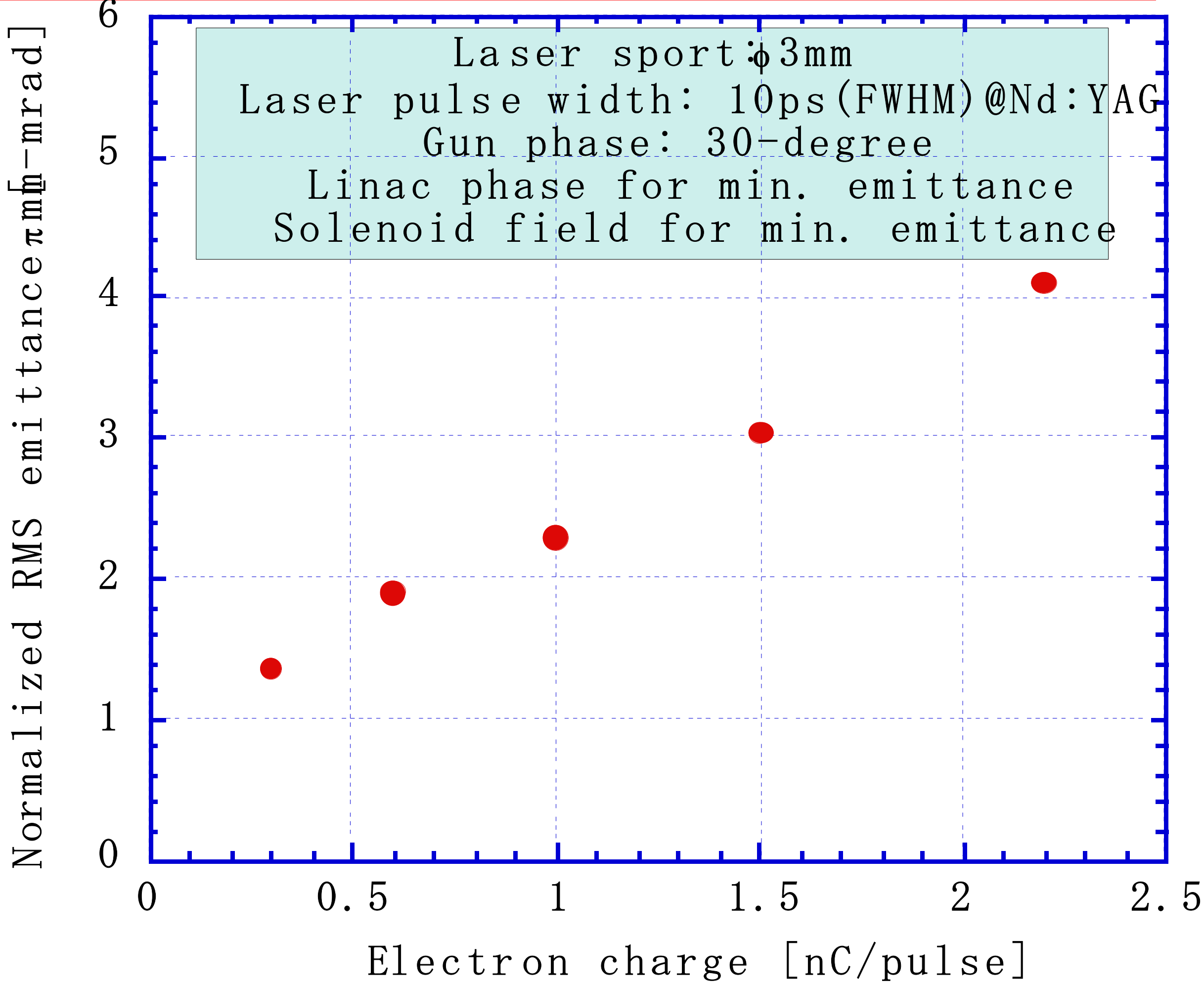




Experimental Results of 0.5 nC

$$\begin{bmatrix} \beta x \\ \alpha x \\ \varepsilon x \end{bmatrix} = \begin{bmatrix} 14.139 \\ 2.194 \\ 7.088 \cdot 10^3 \end{bmatrix} \qquad \frac{\varepsilon x \cdot \gamma}{10^6} = 0.843$$

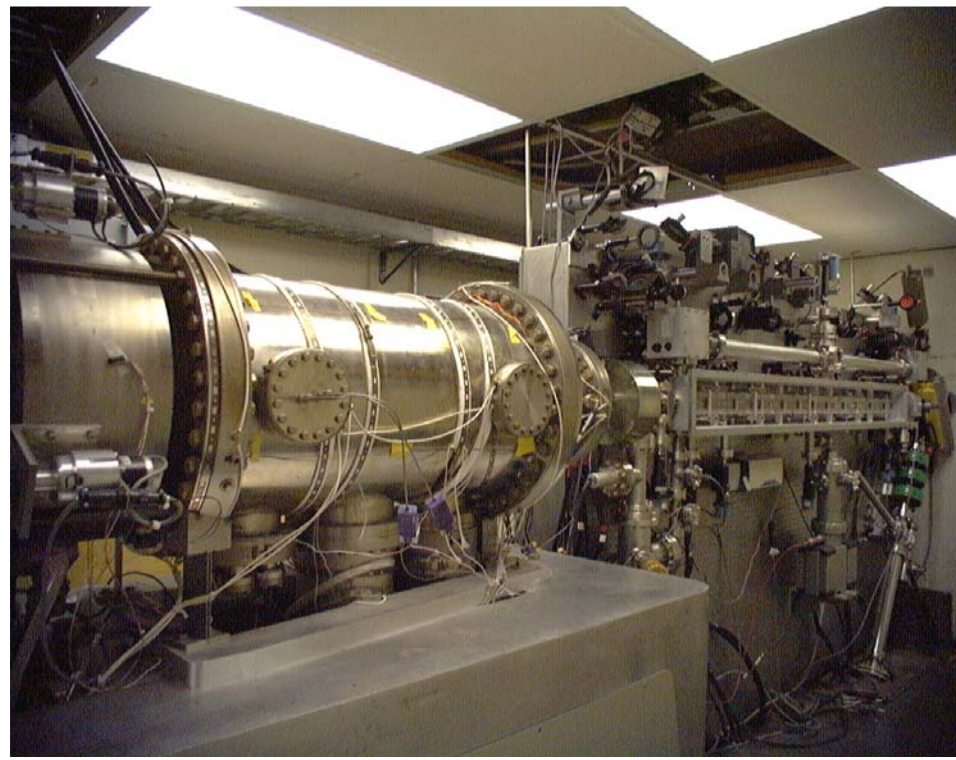




Laser sport:ϕ3mm
Laser pulse width: 10ps(FWHM)@Nd:YAG
Gun phase: 30-degree
Linac phase for min. emittance
Solenoid field for min. emittance
Normalized RMS emittance[πmm-mrad]
Electron charge [nC/pulse]
0
1
2
3
4
5
6
0
0.5
1
1.5
2
2.5

The Advanced FEL Photoinjector Operates at 20 MV/m Gradient and 200 mA Average Current

- 1300 MHz
- E_b = 15-20 MeV
- $\bar{I}_{macro}$ = 100-400 mA
- Q = 1-4 nC
- ε_{rms} = 1.6 mm-mrad
- $\Delta\gamma/\gamma$ = 0.2%
- Injection $\phi = 30^o$
- Solenoid = 300A
- Bucking Sol. = 310A



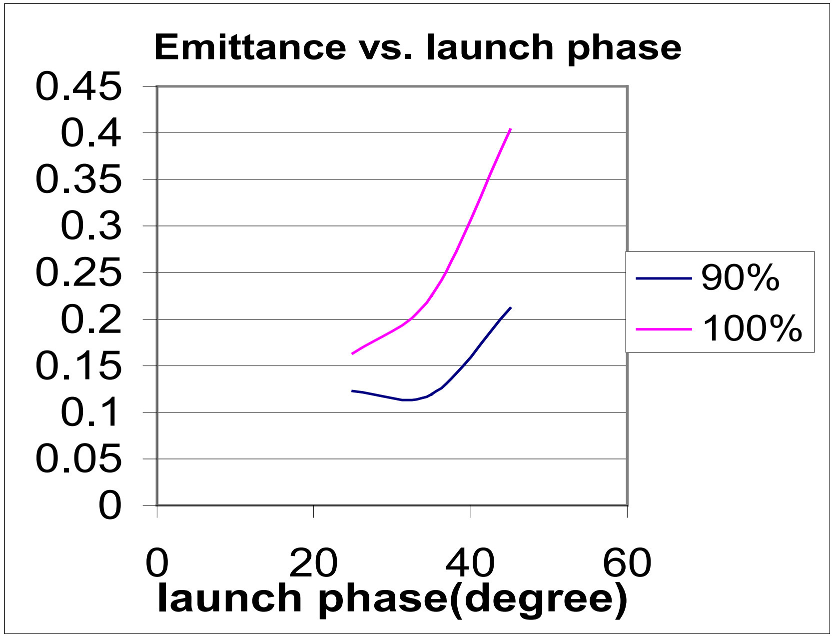
Kwang-Je Kim model

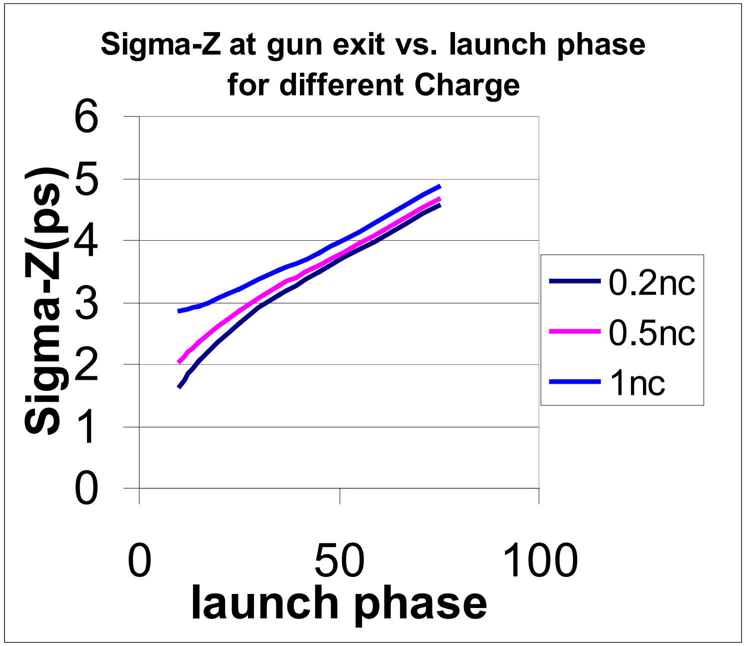
$$\varepsilon_{sc} \approx \frac{3.8\,10^{3}\,q}{\left(2\sigma_x + \sigma_z\right)E_0 Sin\phi_0}$$

$$\varepsilon^{tr}{}_{rf} \approx 2.7\,10^{-5}\,E_0 \mathrm{f}^{2}\sigma_x^{2}\sigma_z^{2}$$

$$\varepsilon^{z}{}_{rf} \approx \sqrt{3}(\gamma_f - 1)k^{2}\sigma_z{}^{3}$$

Simulation Studies





4. LCLS LoadLock

Bob Kirby and Gerry Collet

SLAC

Physical Electronics Group

Order of Slide Presentation

- **Motivations for a LoadLock**
- **Proposed Gun Changes**
- **Top Ass'y and Elevation views**
- **Major components with details**

Motivations For A LoadLock

- Install PCs under vacuum with no exposure to the gun vault environment

- Ex-vault pre-process cathodes (e.g., bakeout) or deposit cathodes (e.g., Cs_2Te) off-site, transfer and load without breaking vacuum

- Through the use of “transport/storage” vessels, PCs can be prepared/processed and stored long-term under vacuum, then installed immediately as needed

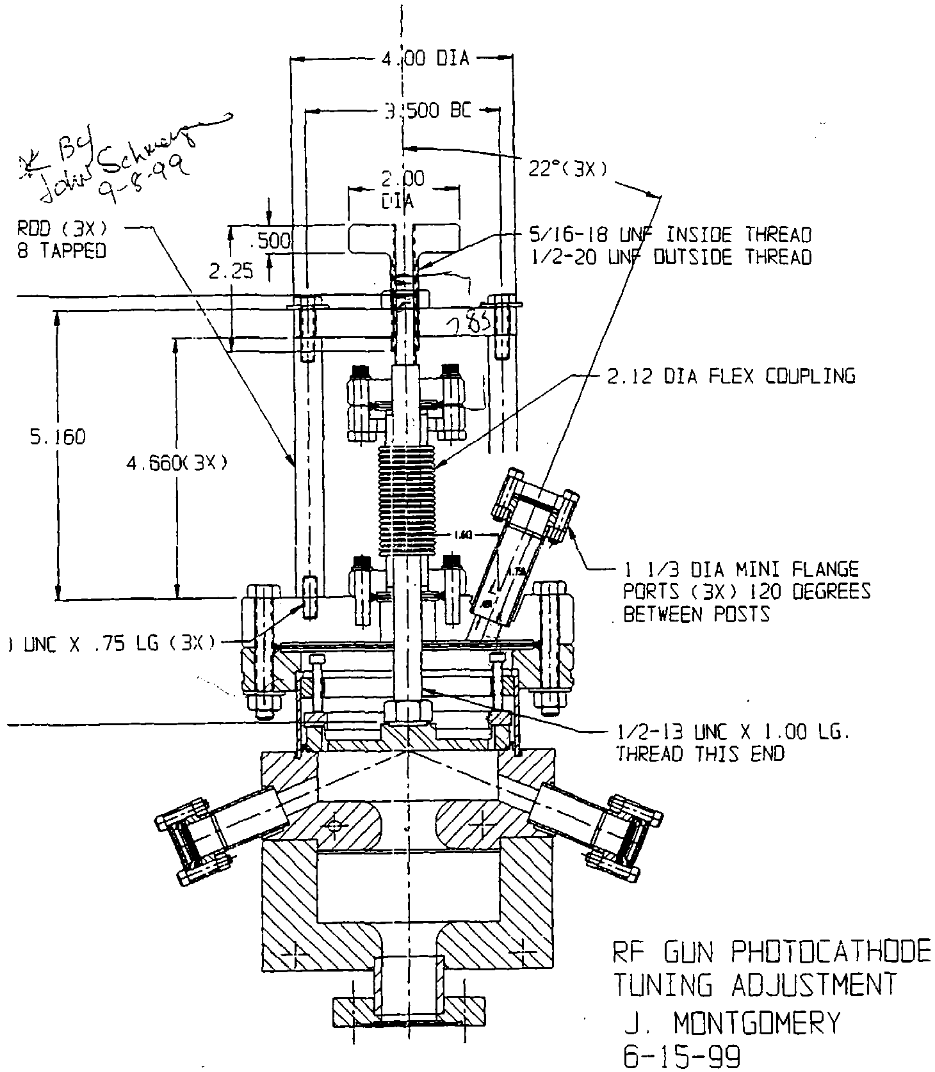
Gun Design Modifications

- Beef-up the mechanics that apply the PC mating pressure and frequency tuning

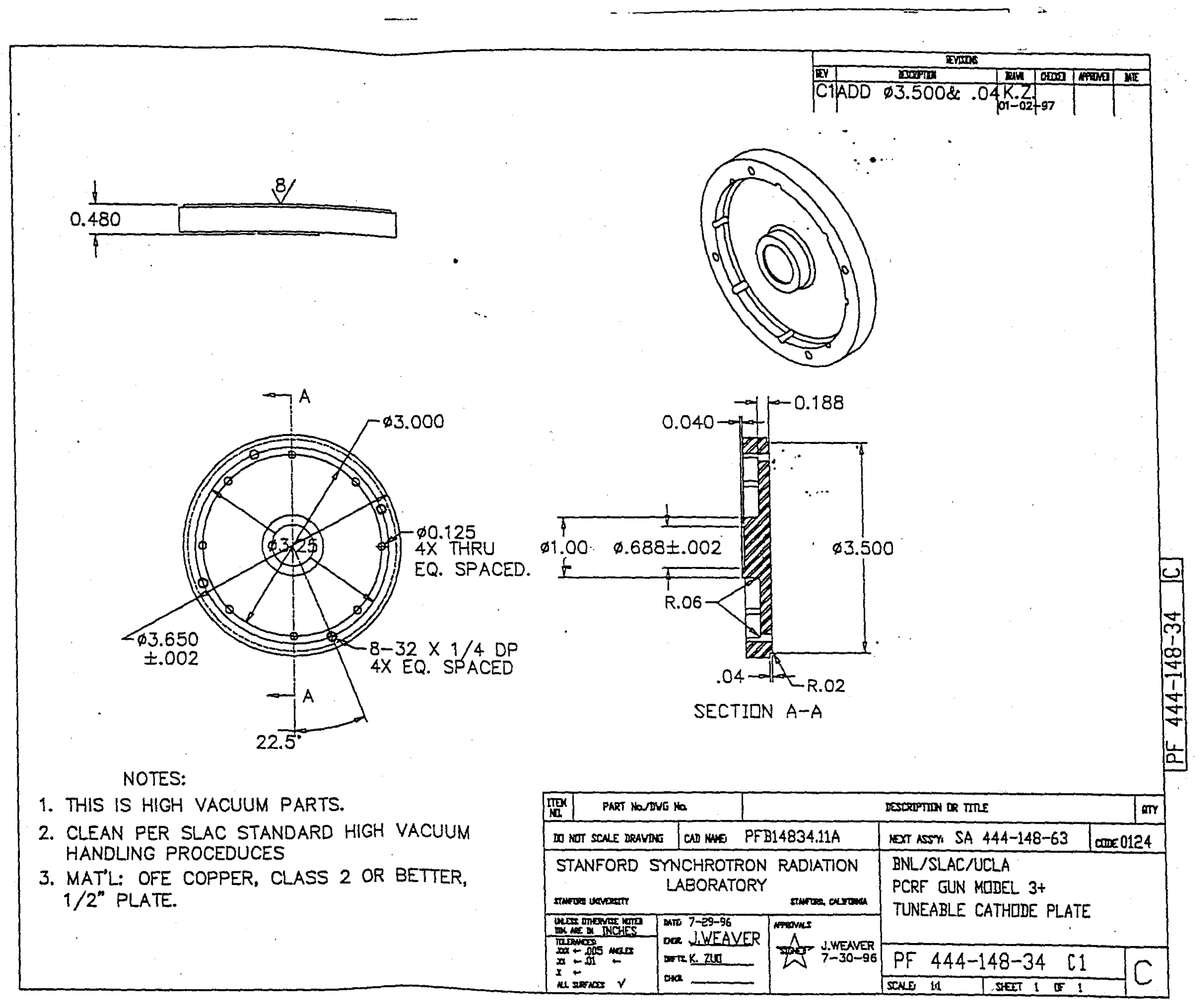
- Braze a stainless cap to the PC mating surface for scratch/deformation resistance

- Move location of rear gun UHV flange downstream to expose and allow final step (after brazing operations) lapping of the PC mating surface and provide a solid anchor for applying the cathode mating pressure

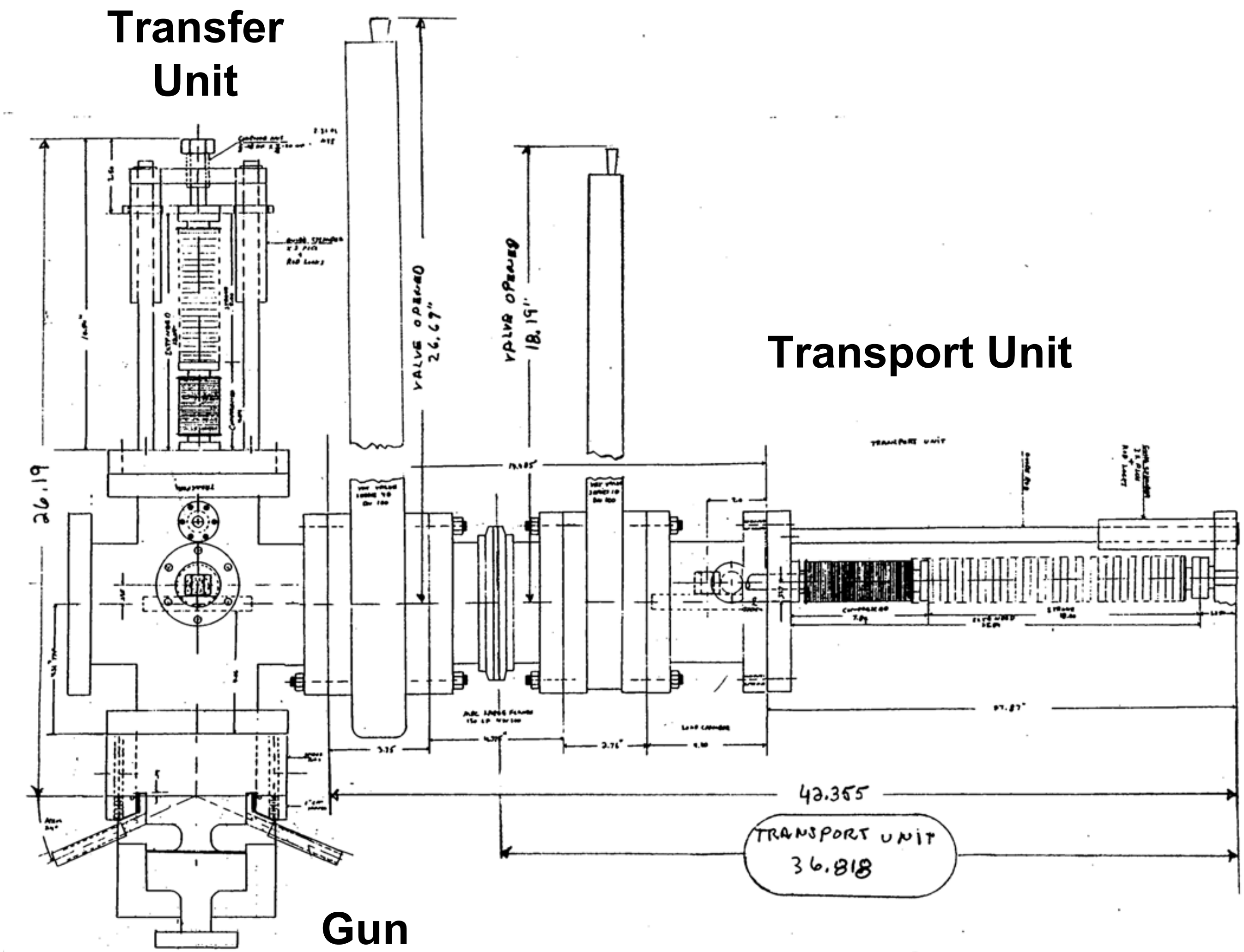
GTF RF Photo Injector Gun



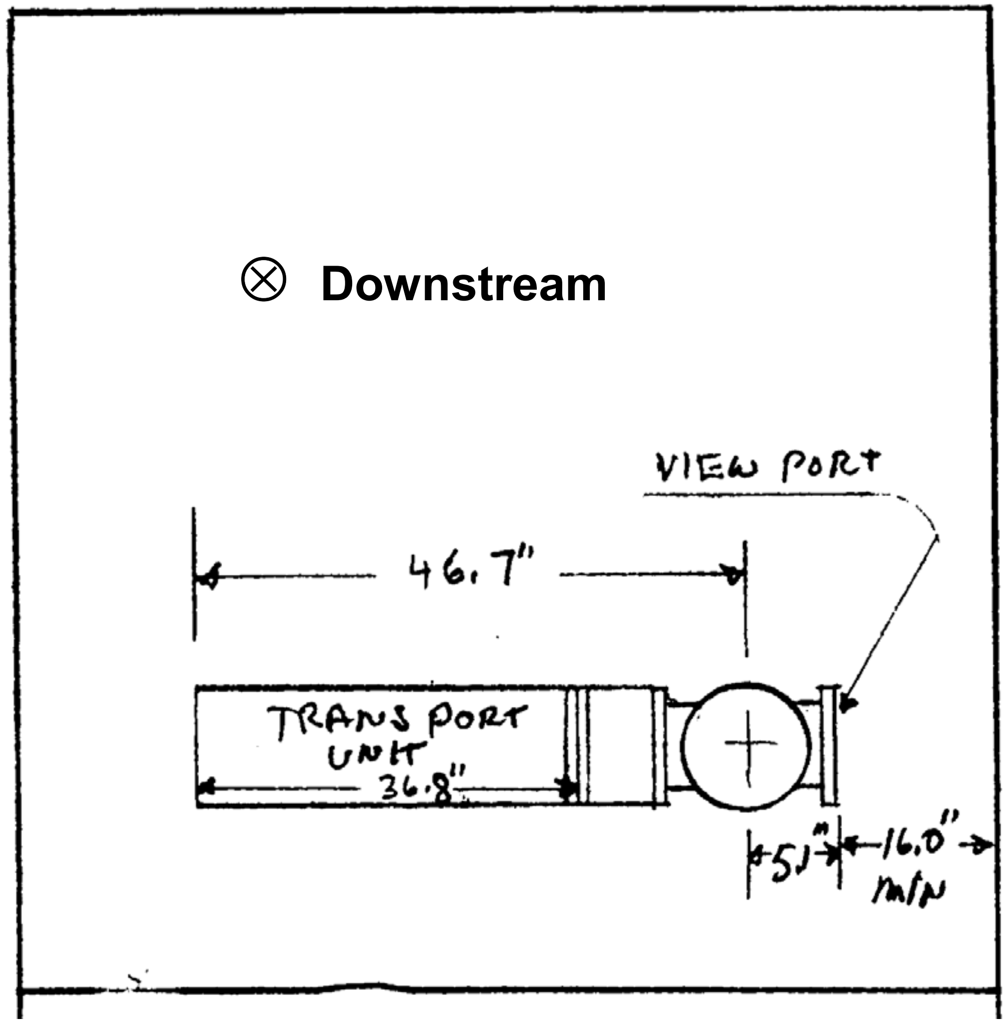
GTF RF Photocathode



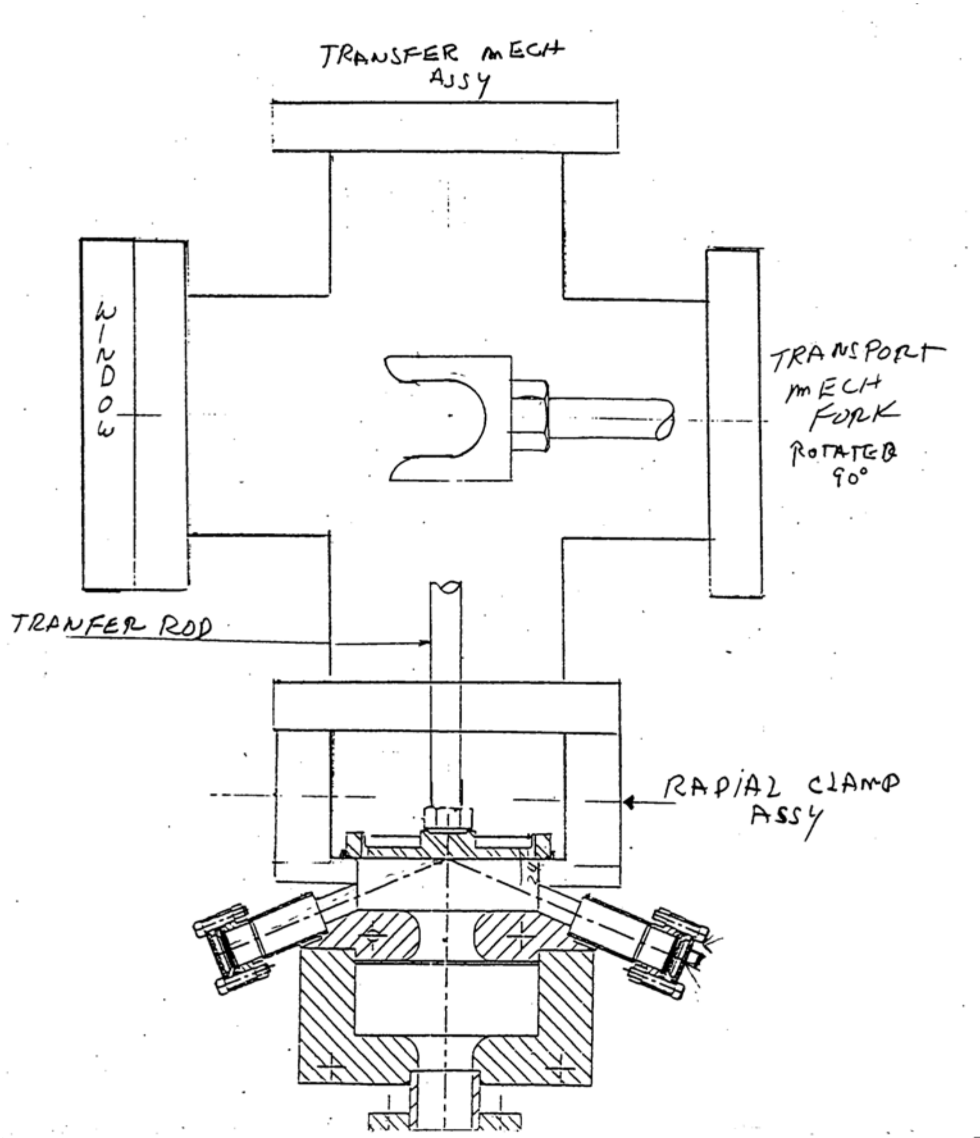
LoadLock & Gun, Top View



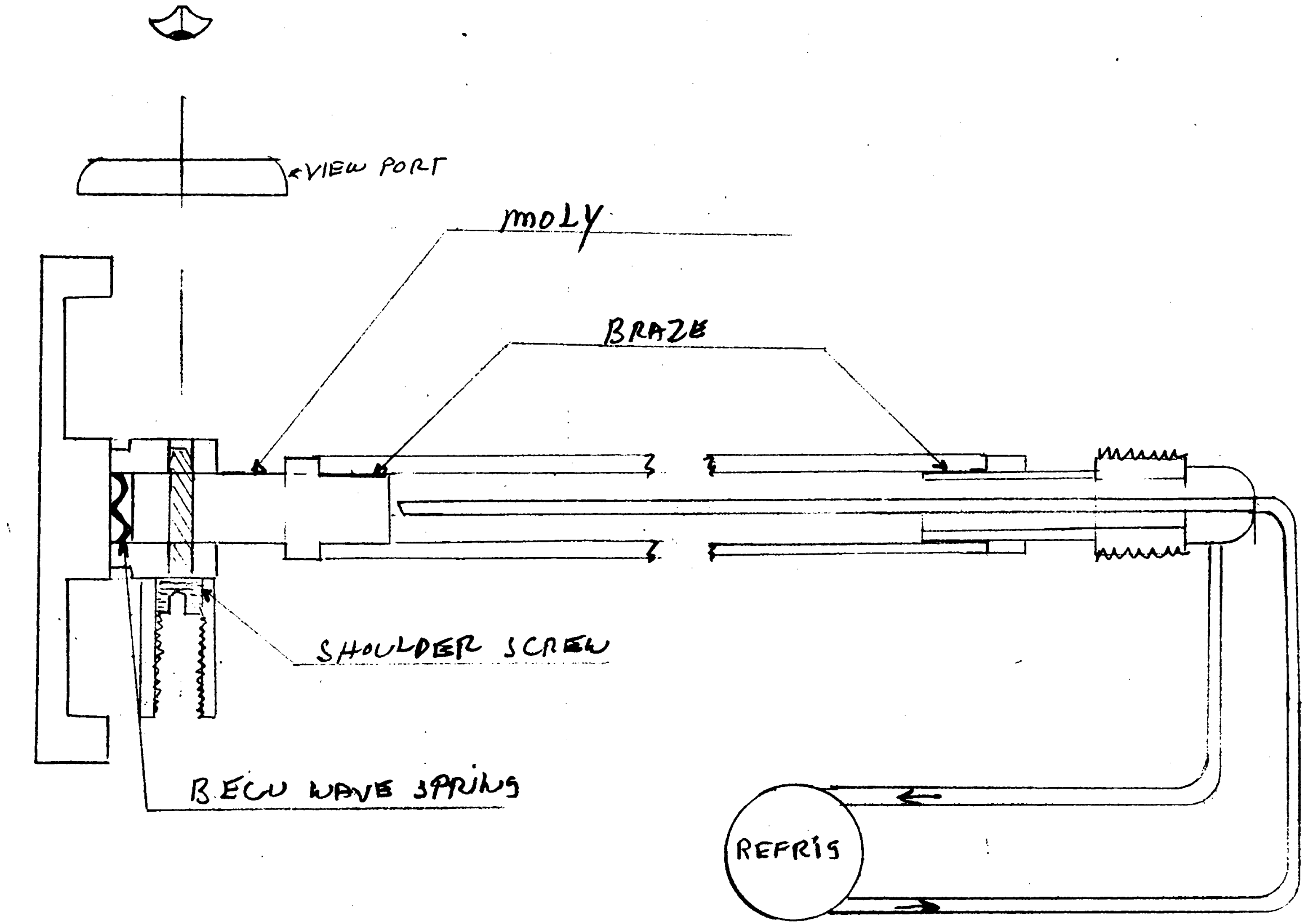
LoadLock and Gun, Elevation View



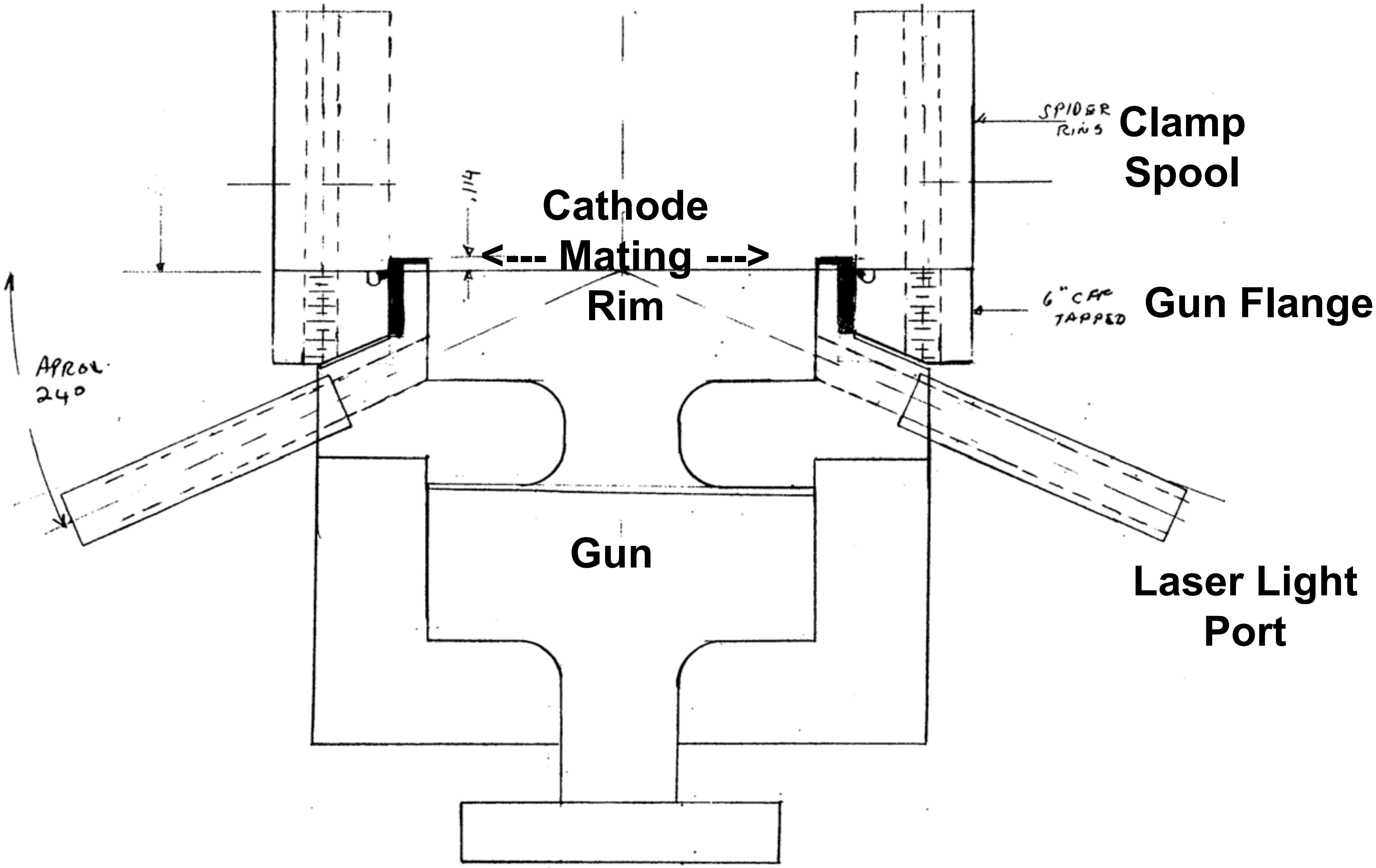
Cathode Exchange Chamber



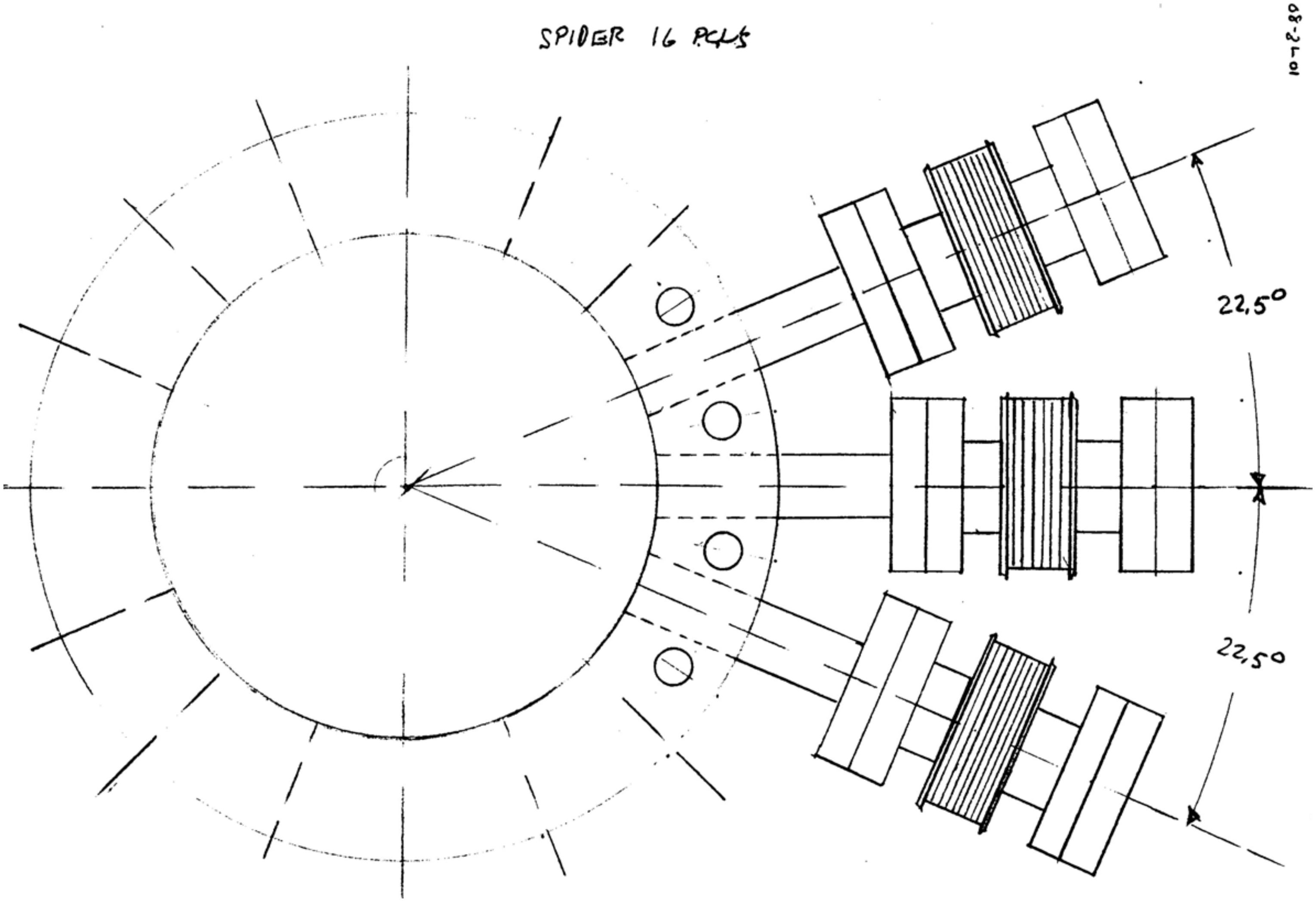
Cathode Exchange Detail, Side Crossection



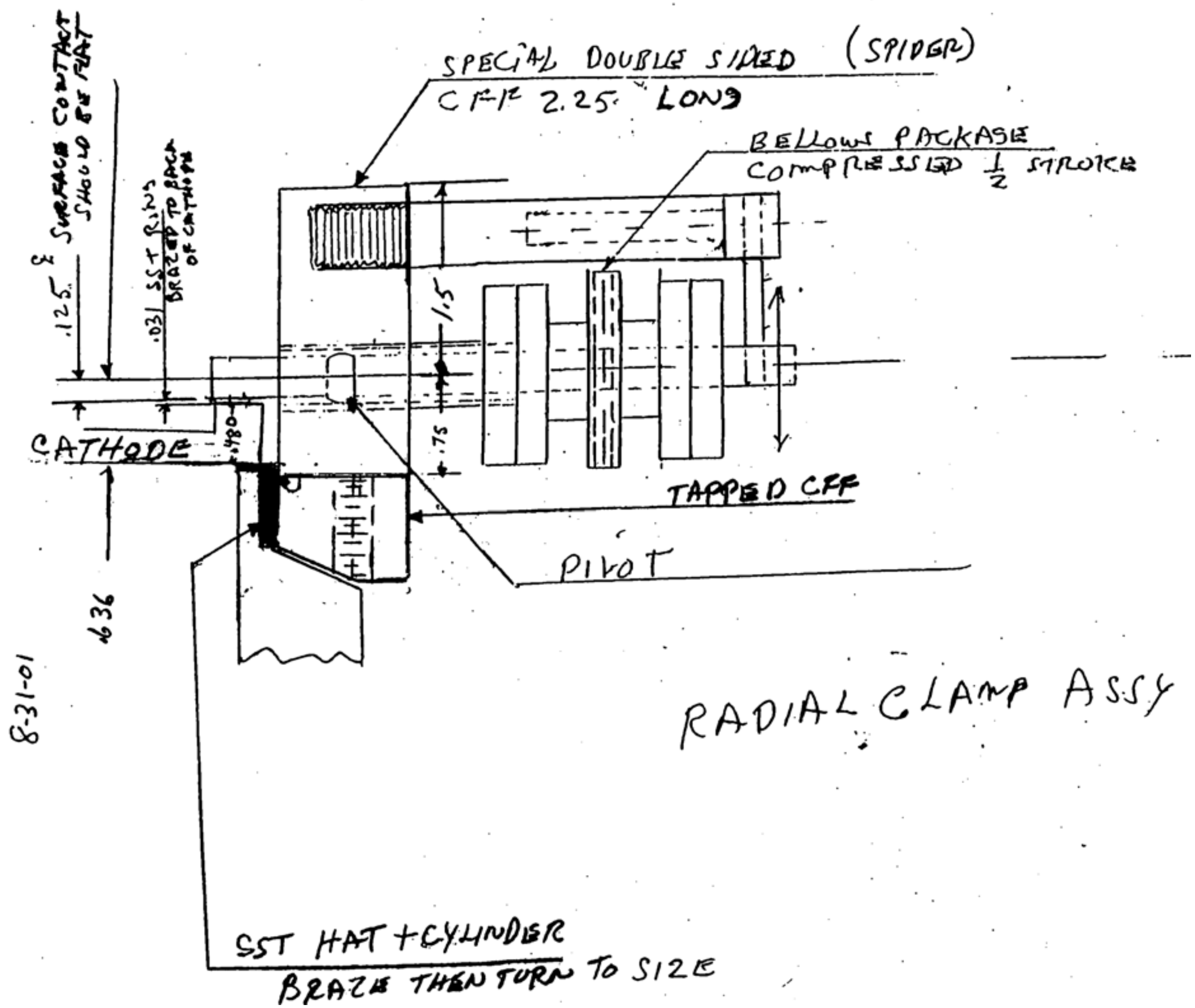
Cathode/Gun Mating



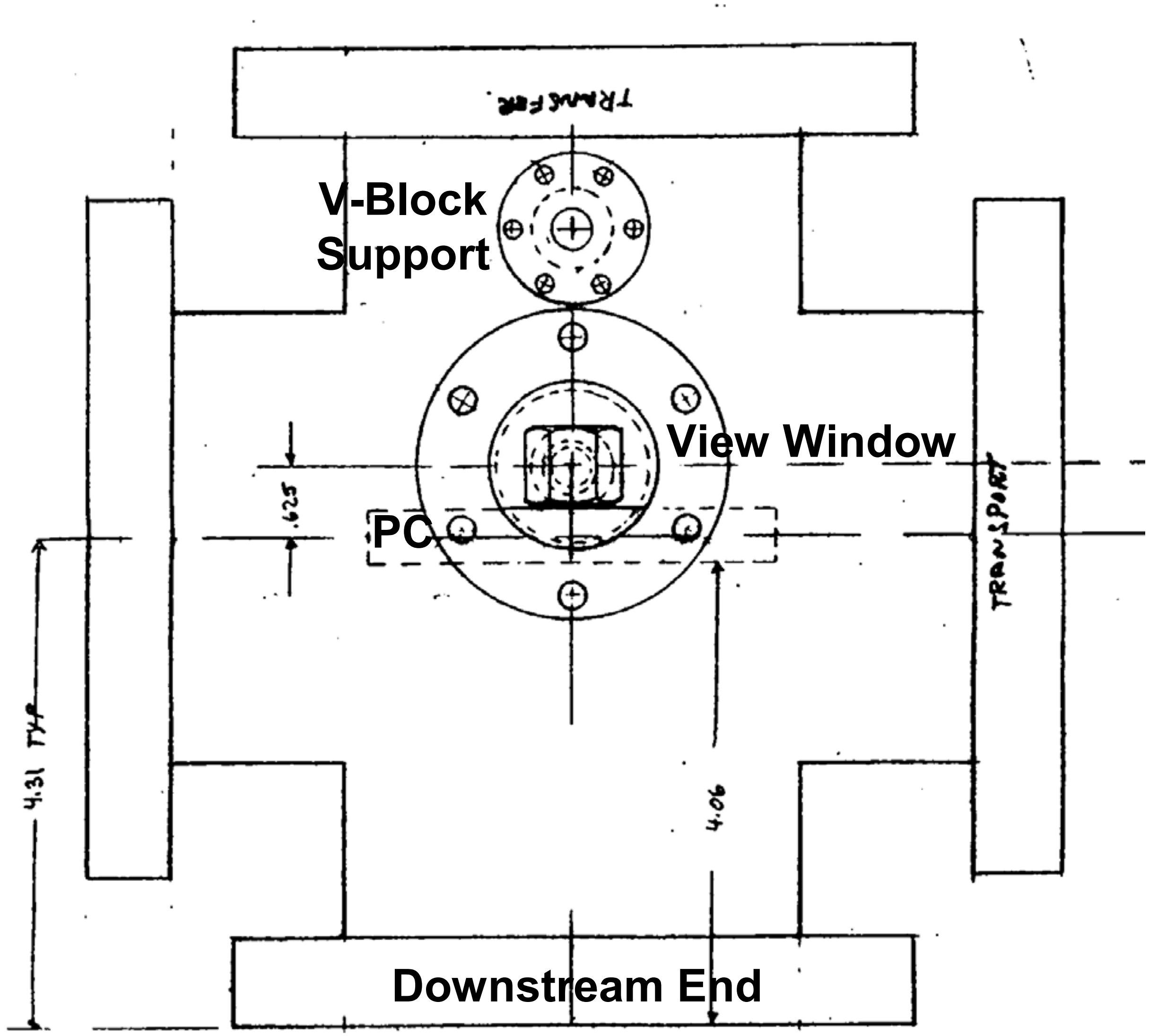
PC Clamp, Elevation View



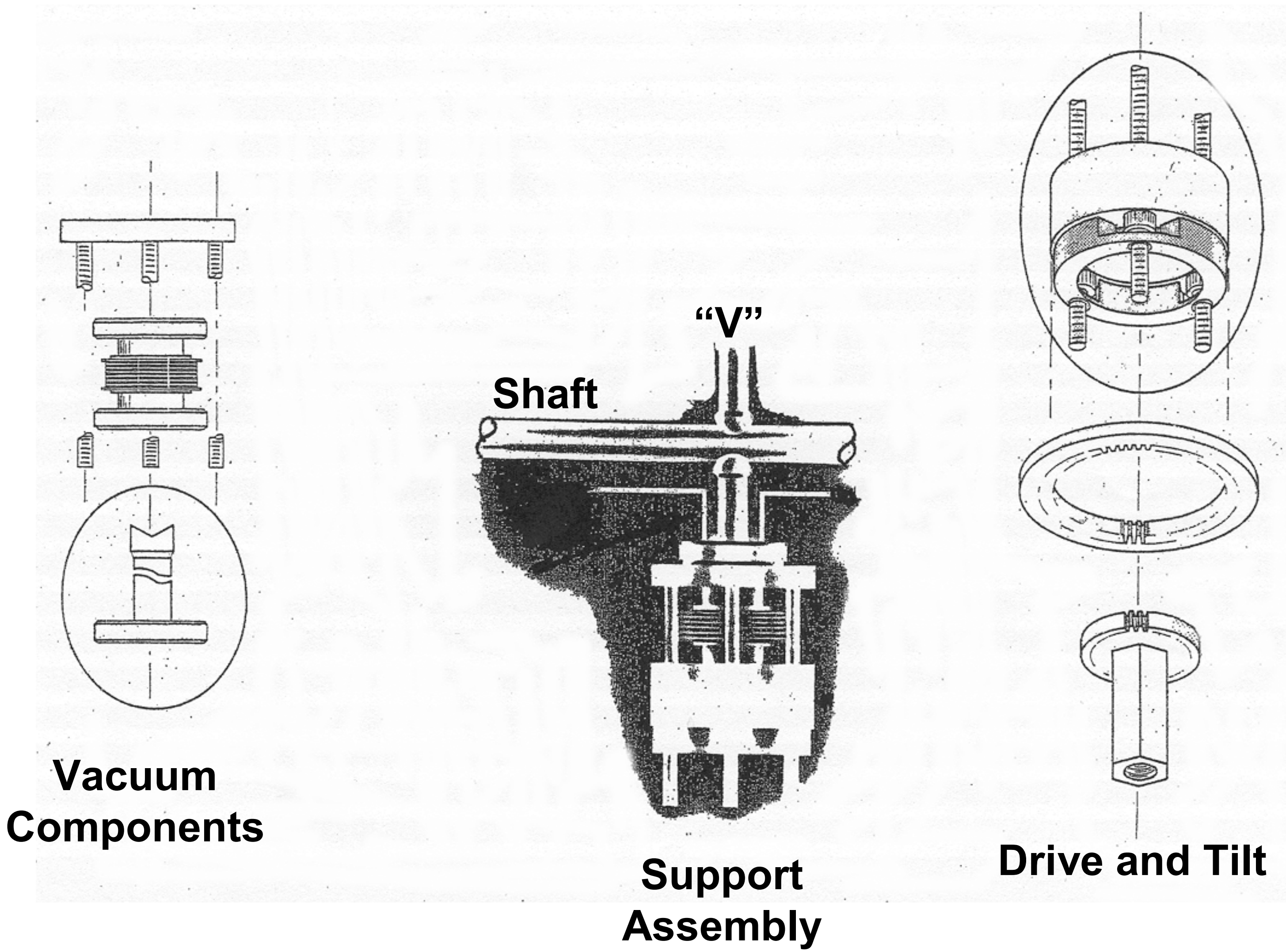
PC Clamp, Actuator Detail



Exchange Chamber, Top View

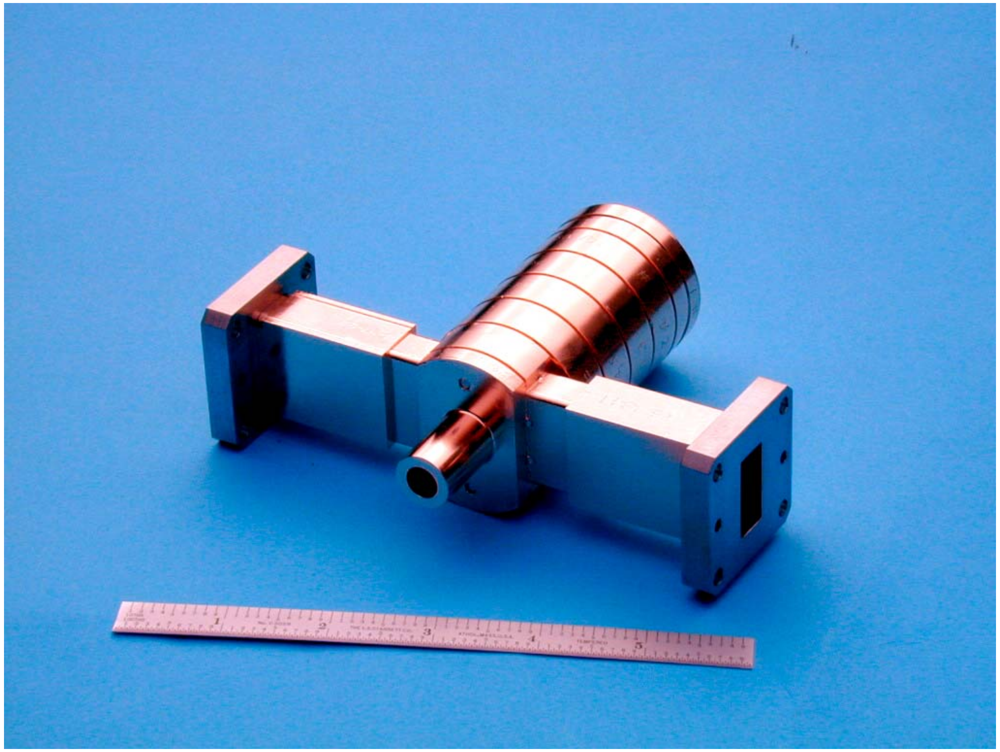


V-Block Shaft Support

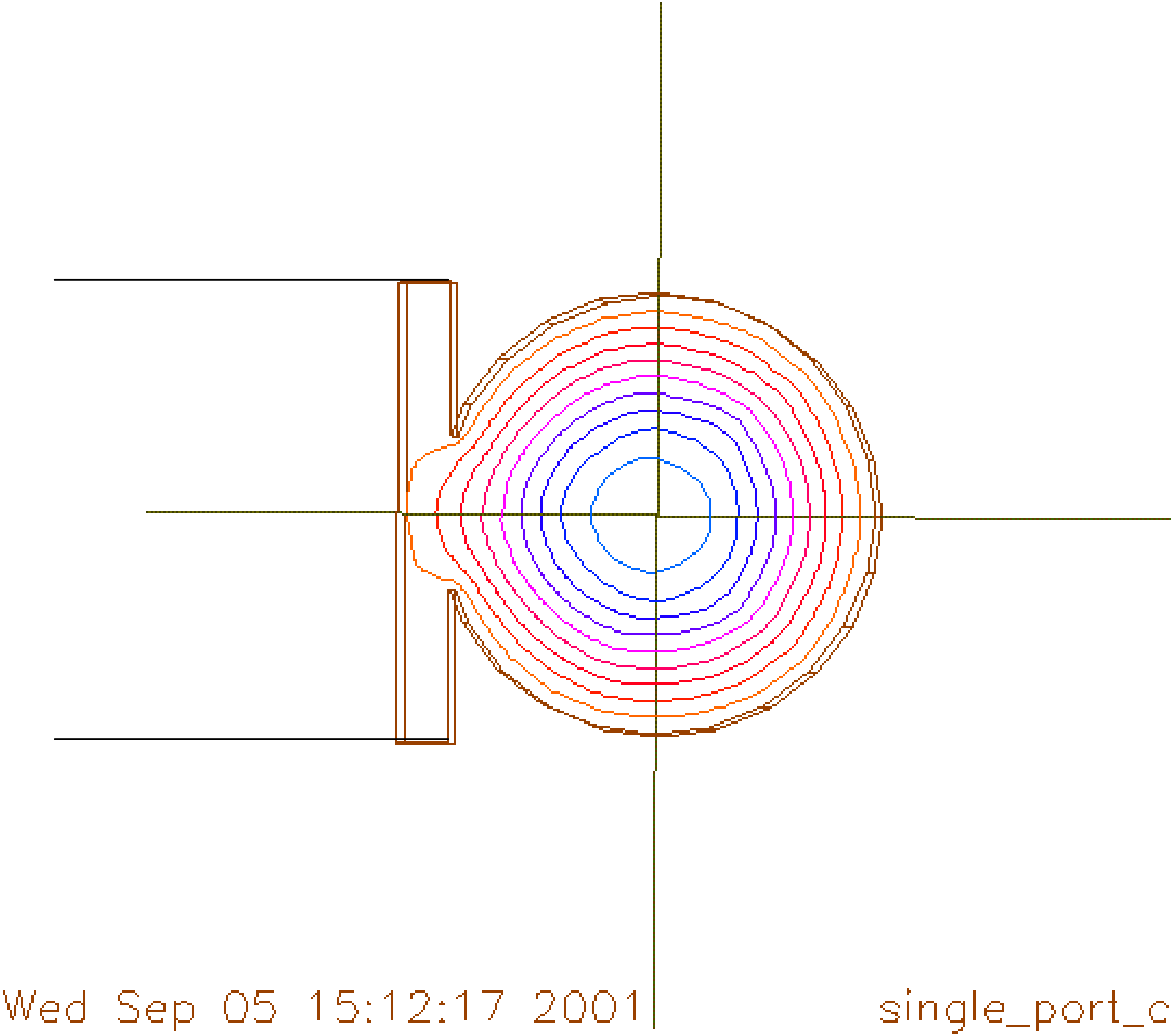


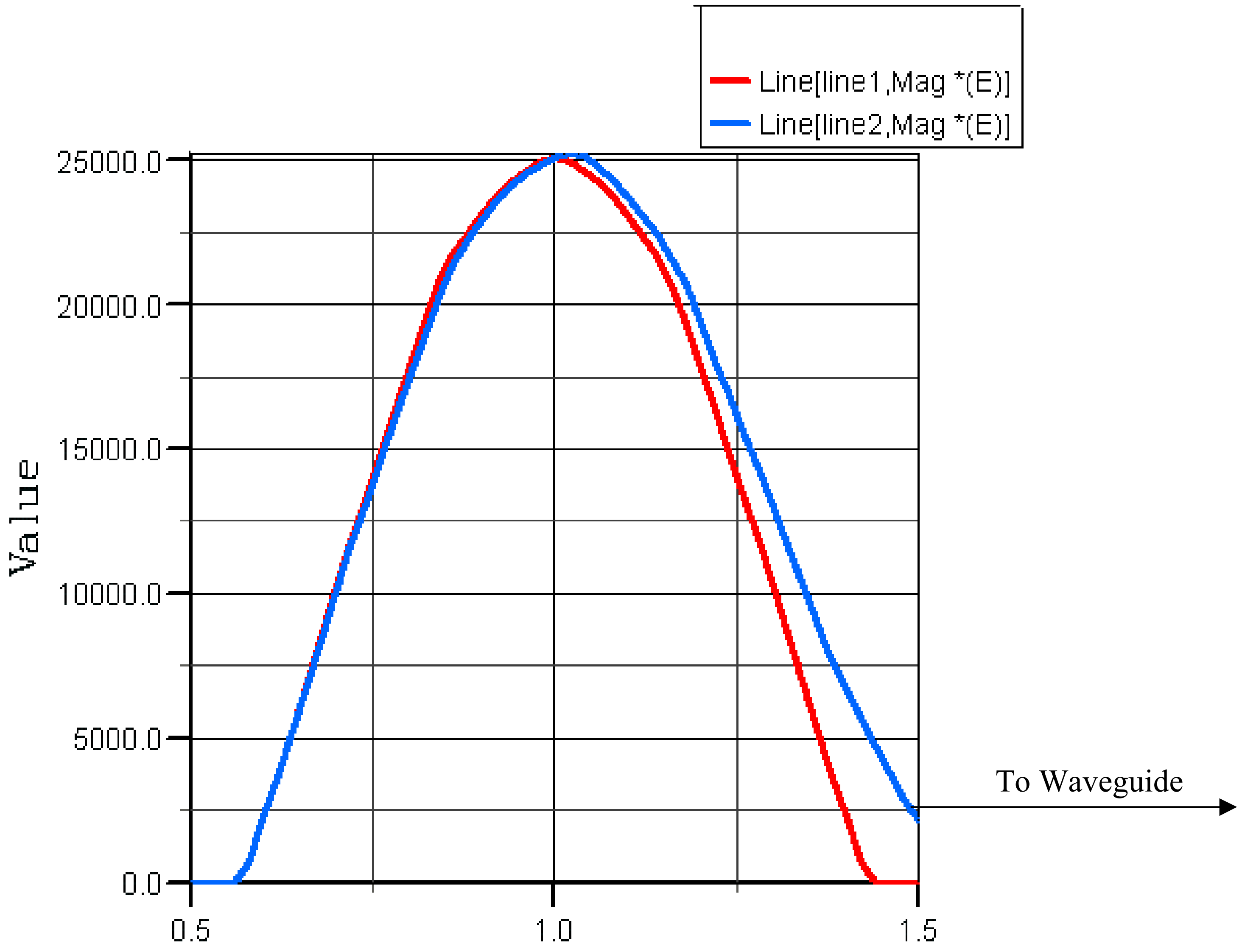
5. Symmetrical Feed Design Considerations

A.E.Vlieks

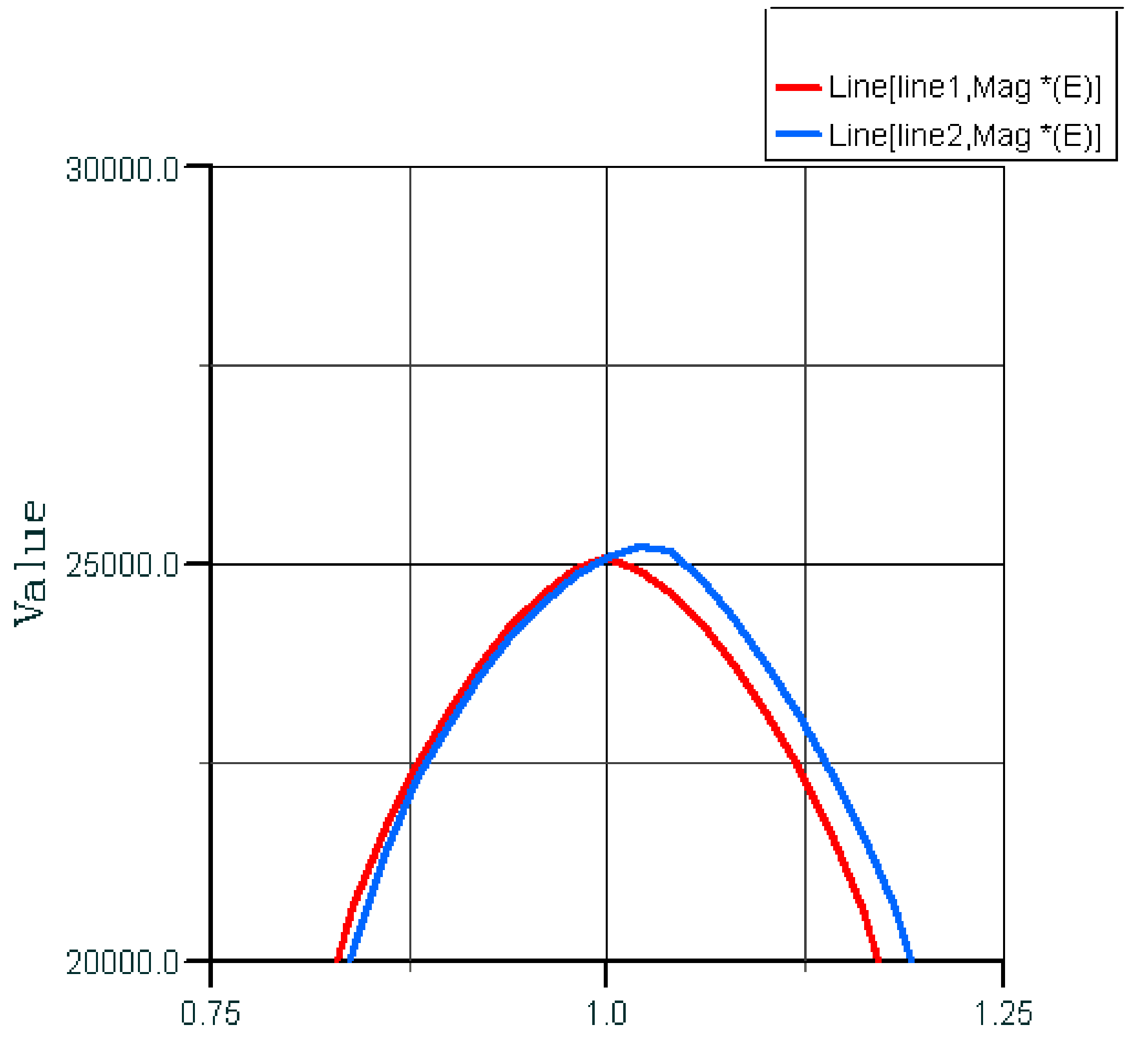


Single Port Cavity





Line[line1,Mag *(E)]
Line[line2,Mag *(E)]
25000.0
20000.0
15000.0
10000.0
5000.0
0.0
Value
0.5
1.0
1.5
To Waveguide



Line[line1,Mag *(E)]
Line[line2,Mag *(E)]
30000.0
25000.0
20000.0
Value
0.75
1.0
1.25

The presence of a single waveguide feed introduces an two types of transverse asymmetries

- **Amplitude-Fields deformed by hole in wall.**
- **Phase- caused by transverse traveling wave.**

We can introduce these transverse asymmetries into the longitudinal accelerating field as perturbations:

$$E_z = \left(E_{z0} + \frac{\Delta E \cdot y}{h}\right)\sin\left(\omega \cdot t + \varphi_0 + \Delta\varphi \cdot y/h\right)$$

Where ***h*** is some characteristic distance over which the amplitude and phase perturbations are measured

$$\frac{\partial B_x}{\partial t} = -\frac{\partial E_z}{\partial y}$$

$$B_x(t) \approx \frac{\Delta E}{\omega \cdot h} \cdot \cos(\omega \cdot t + \varphi_0) - \frac{E_{z0}}{\omega \cdot h} \cdot \Delta\varphi \cdot \sin(\omega \cdot t + \varphi_0)$$

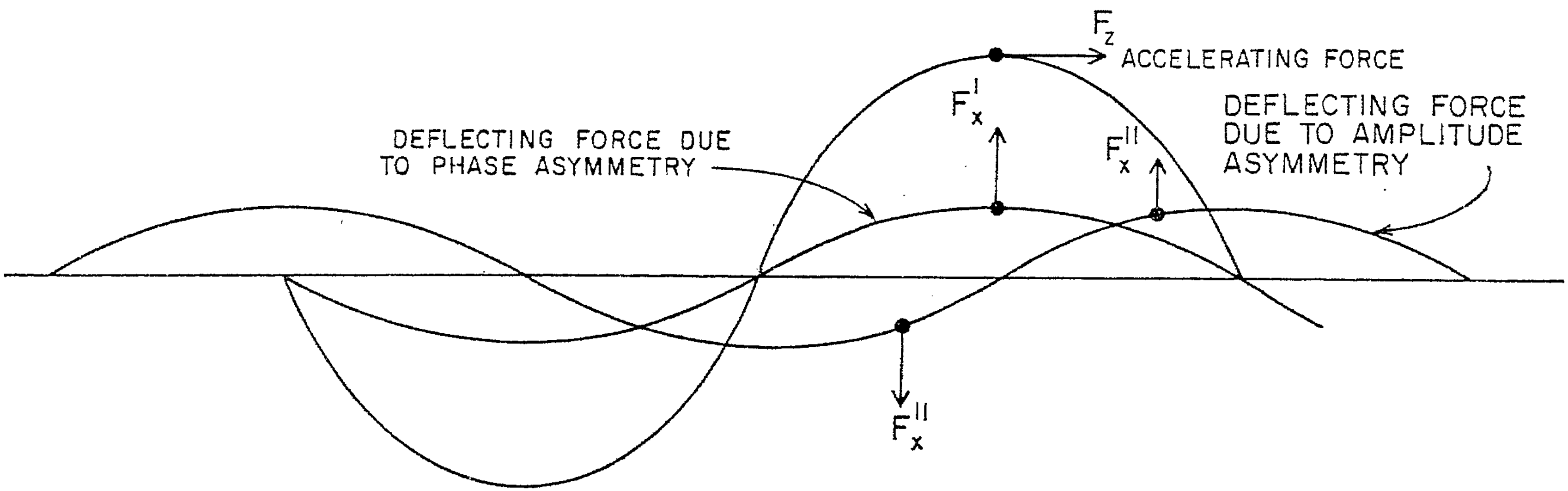
This enters into a transverse Force term…

$$F_y = q \cdot v_z \cdot B_x$$

G.A.Loew and R.B.Neal, LINEAR ACCELERATORS, LaPostolle and Septier ed. (1970) and

R. Chojnacki et Al, AGN-7, February 21, 1991

Relationship between accelerating force and forces caused by asymmetries



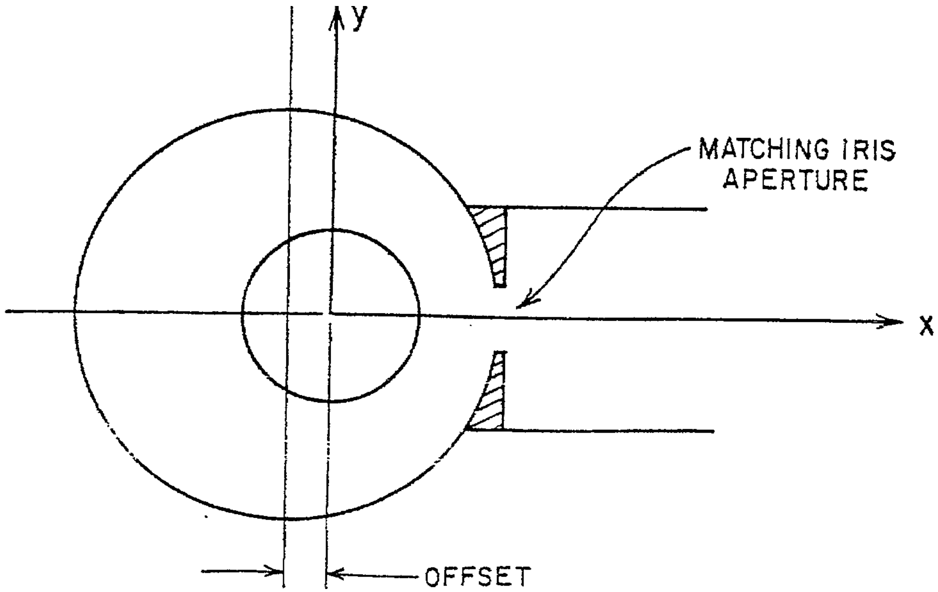
From G.A.Loew and R.B.Neal, LINEAR ACCELERATORS, LaPostolle and Septier ed. (1970) and R. Chojnacki et Al, AGN-7, February 21, 1991

Ways to Reduce Asymmetries

- Use offset cavity
- Use undercoupled Iris
- Use “dummy” symmetrizing waveguide
- Use symmetric Feeds
- Use symmetric Feeds with “racetrack” waveguide shape

Reduction of Dipole Effect by offsetting Cavity

Relative to beam



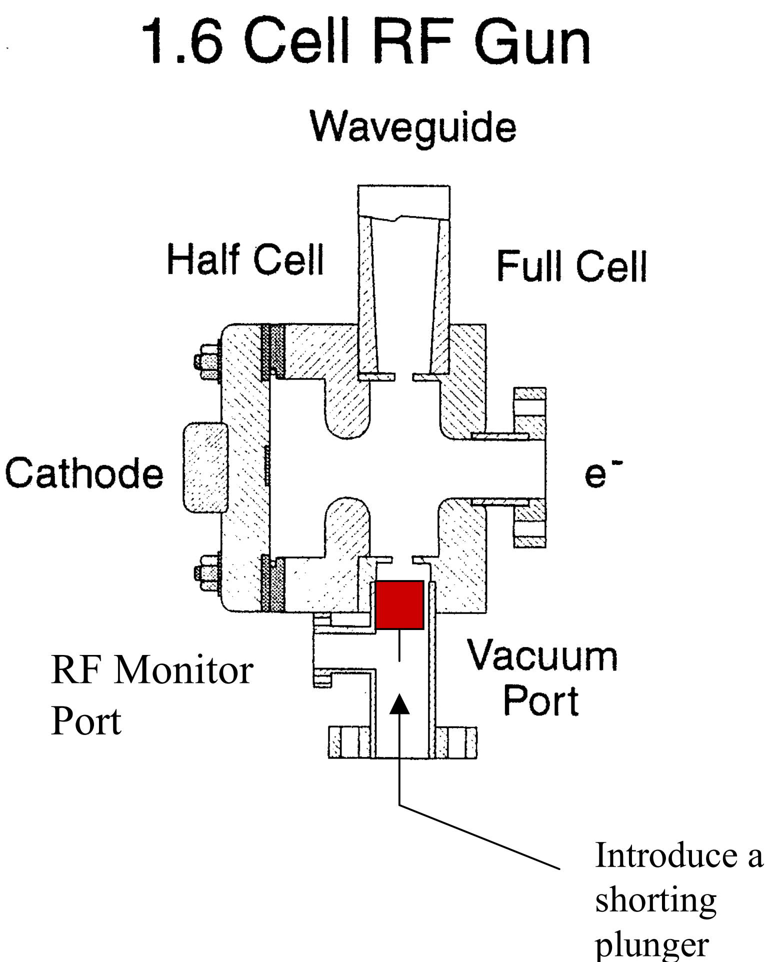
From G.A.Loew and R.B.Neal , LINEAR ACCELERATORS,
LaPostolle and Septier ed. (1970)

Under-coupled Iris

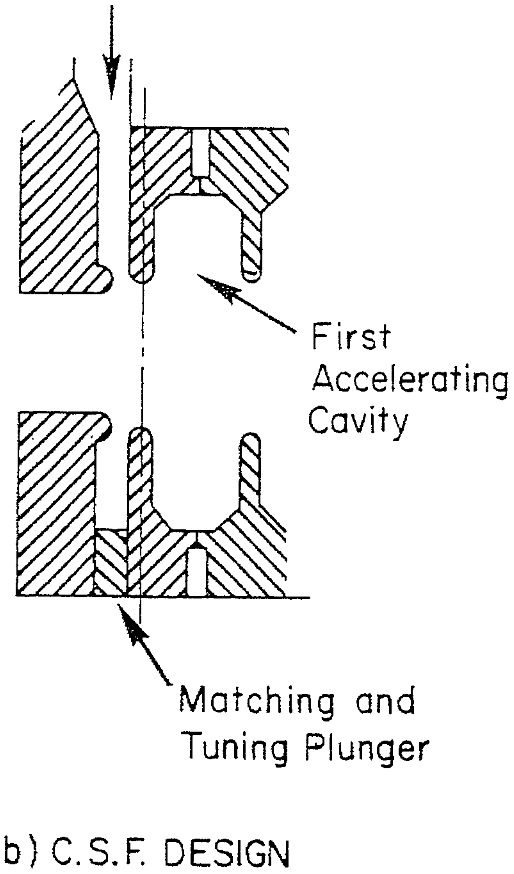
W.J.Brown et Al from MIT recently reported that they were reducing the effect of the asymmetric coupling iris' by deliberately under coupling the cavities with a β of 0.56. (Their RF gun is a 17 GHz 1.5 cell gun)

W.J.Brown et Al, Phys Rev Special Topics-Accel and Beams,Vol **4**, 083501 (2001)

Symmetrized Coupler Cavity Designs

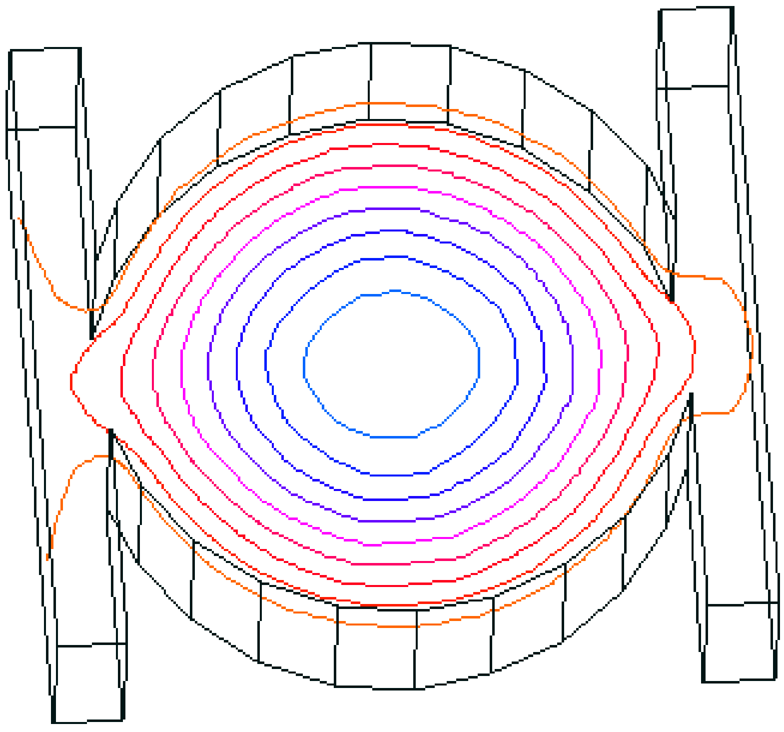


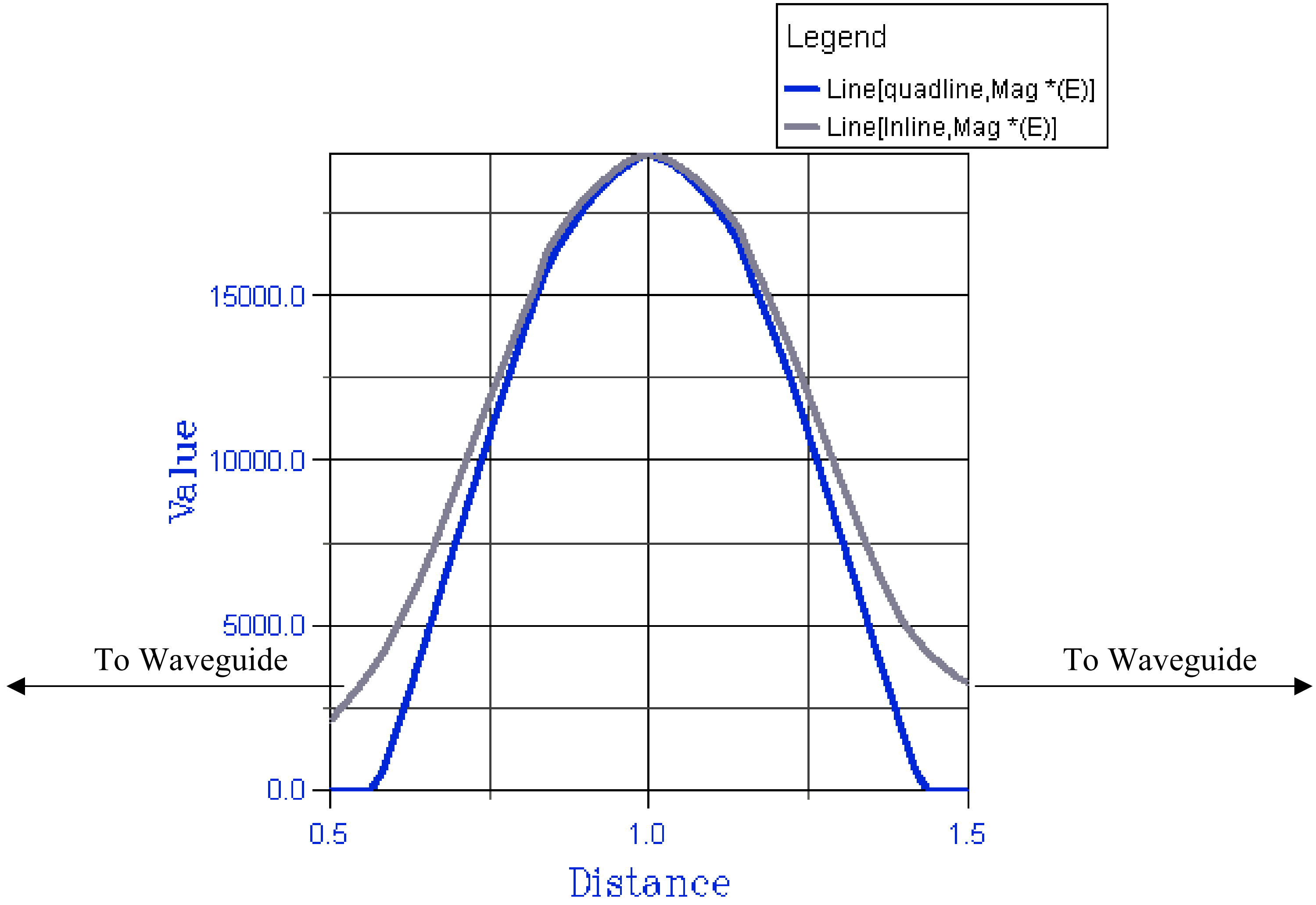
From Dennis Palmer, "The Next Generation Photo Injector" Stanford University Thesis (1998) and Palmer et Al, SLAC-PUB 7420 (May 1997)



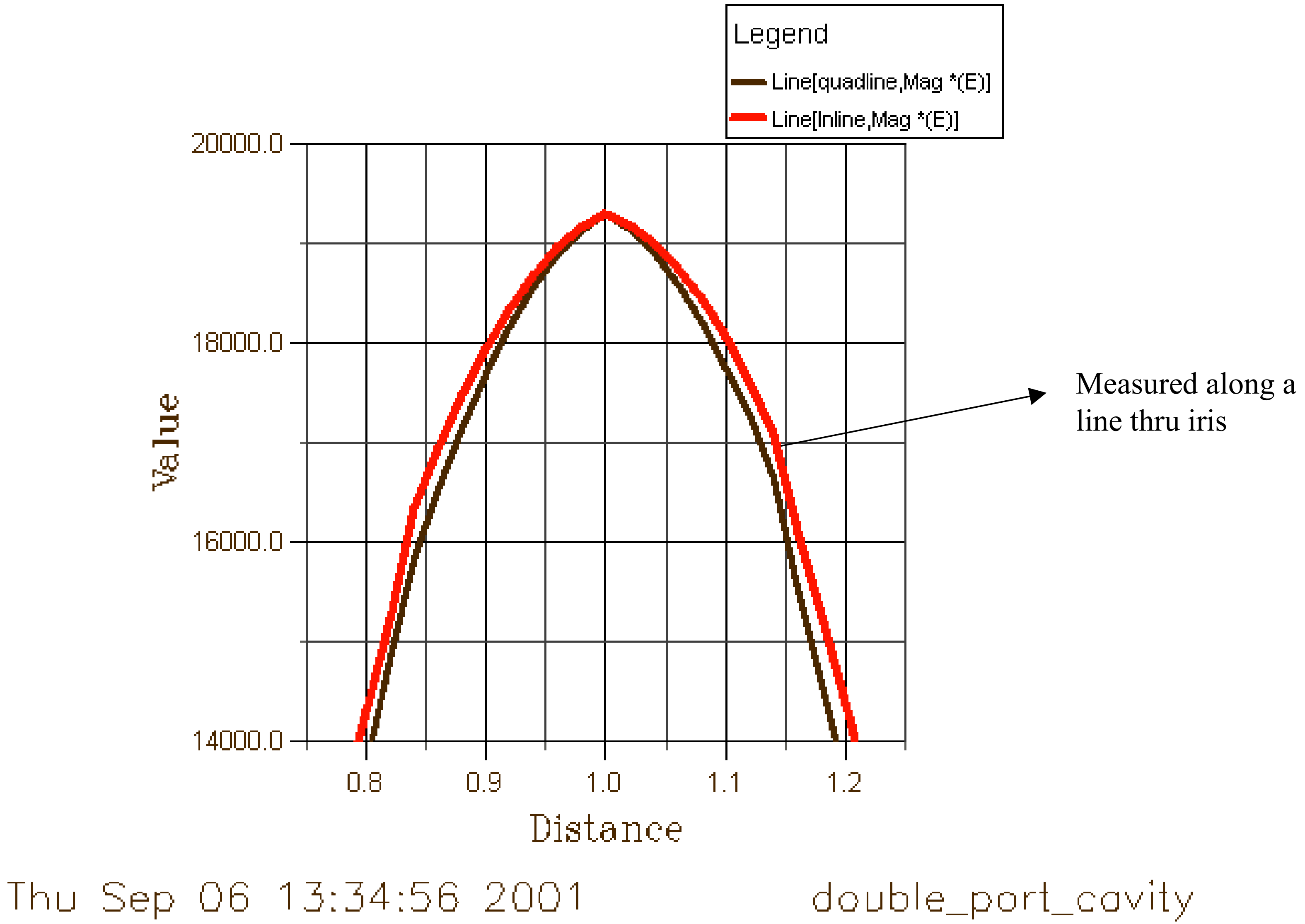
From G.A.Loew and R.B.Neal, LINEAR ACCELERATORS, LaPostolle and Septier ed. (1970)

Dual-Port Cavity



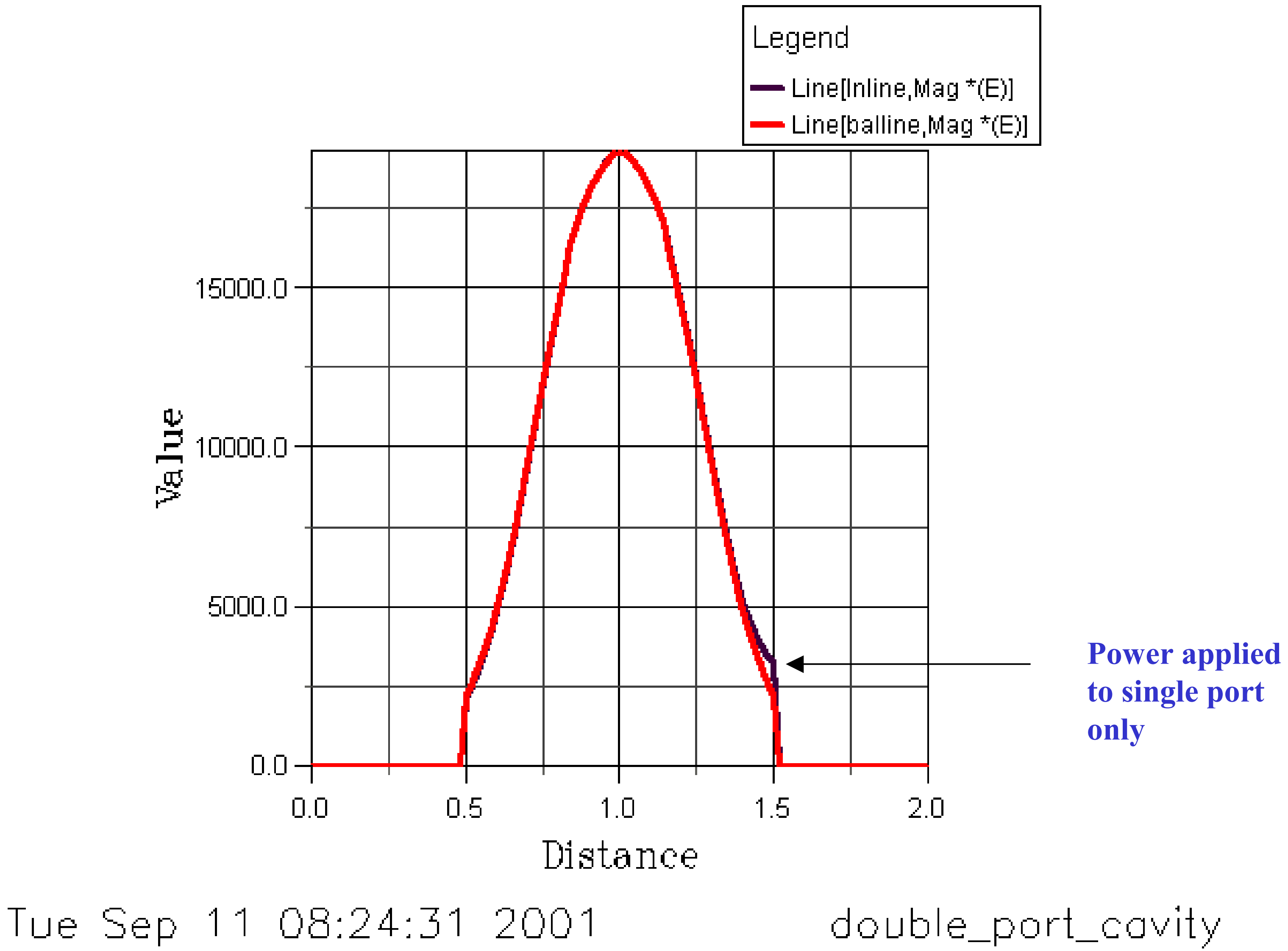


Legend
Line[quadline,Mag *(E)]
Line[Inline,Mag *(E)]
15000.0
10000.0
5000.0
0.0
Value
0.5
1.0
1.5
Distance
To Waveguide
To Waveguide

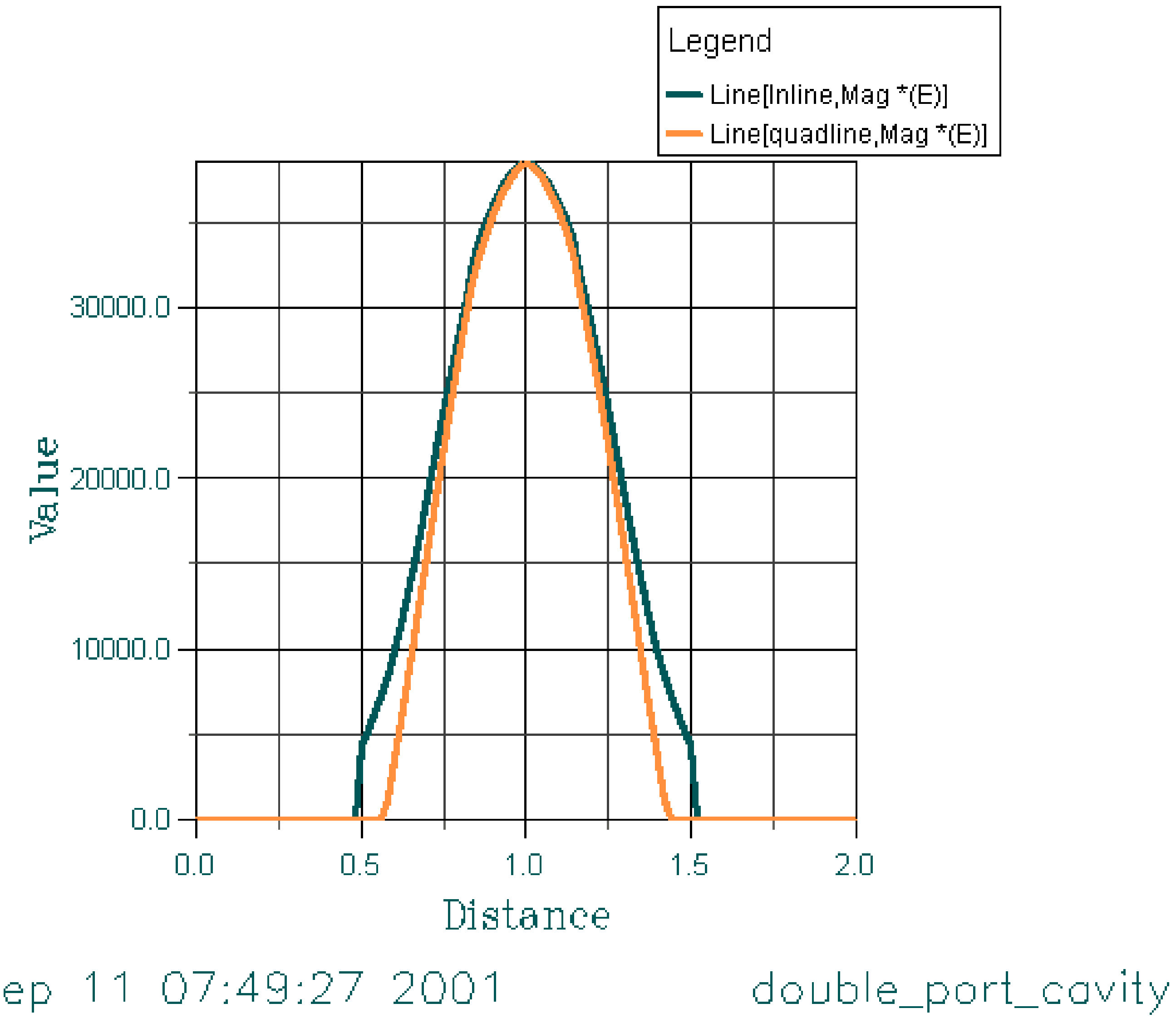


Legend
Line[quadline,Mag *(E)]
Line[lnline,Mag *(E)]
20000.0
18000.0
16000.0
14000.0
Value
0.8
0.9
1.0
1.1
1.2
Distance
Measured along a line thru iris
Thu Sep 06 13:34:56 2001
double_port_cavity

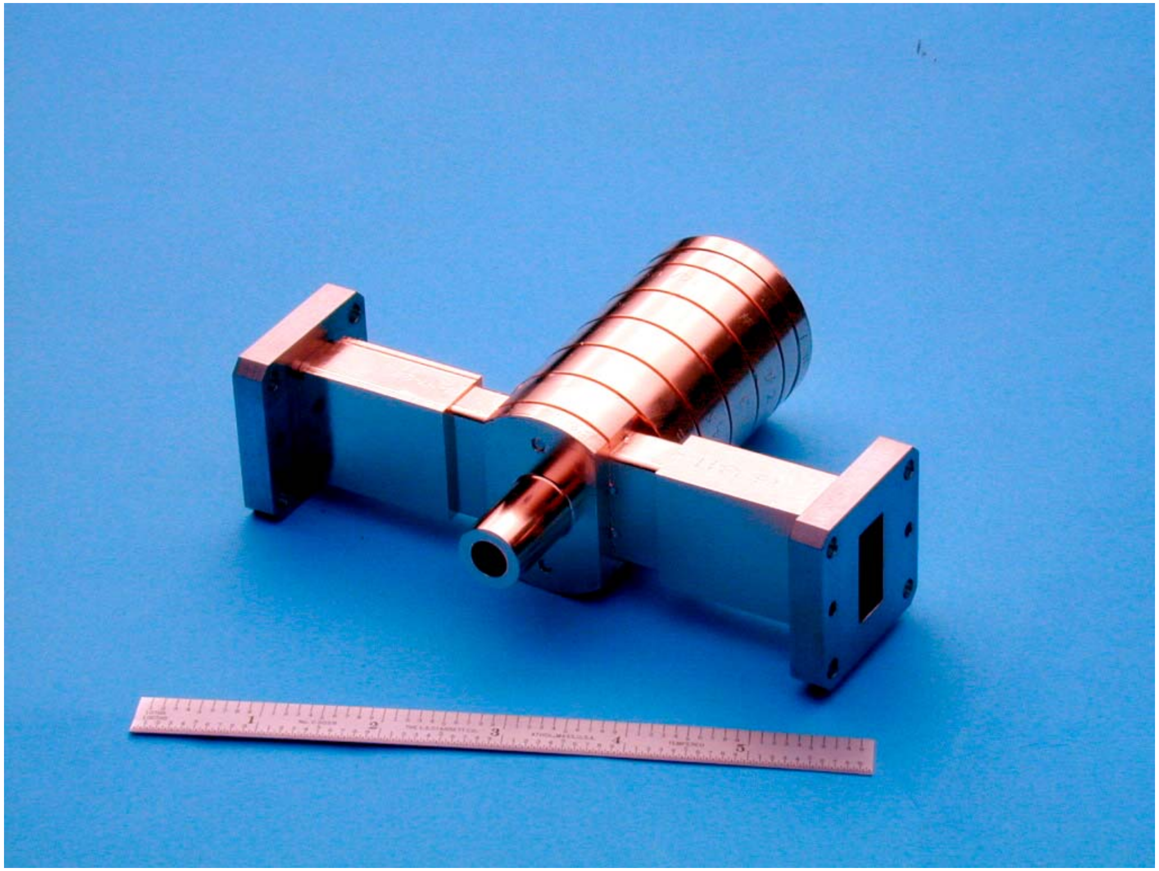
Symmetric Cavity –Comparison of balanced and unbalanced Input Drive



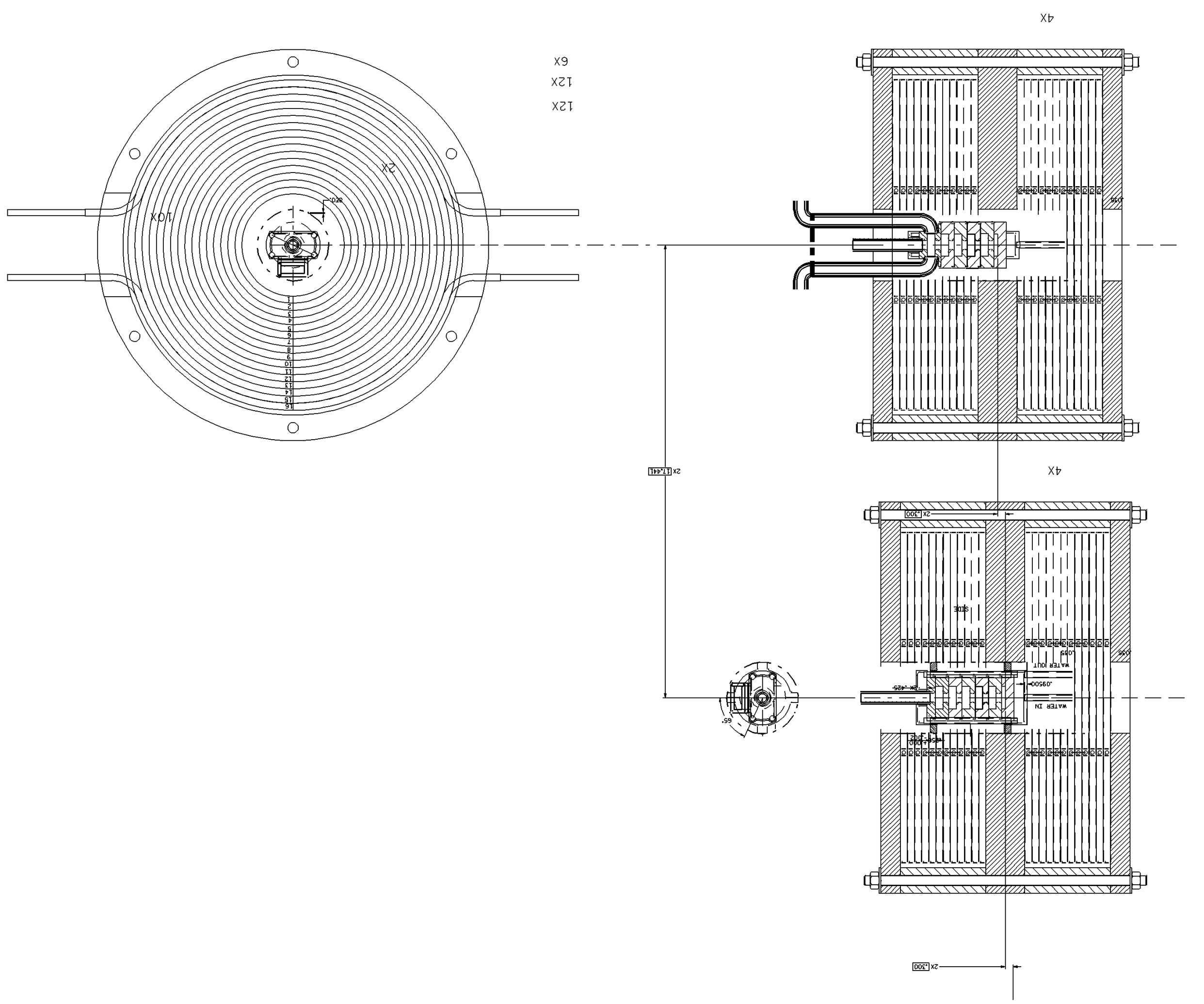
Symmetric cavity with balanced Input power



Assembled and Bonded 5.5 Cell Cold-Test Model



View of Gun in Magnet



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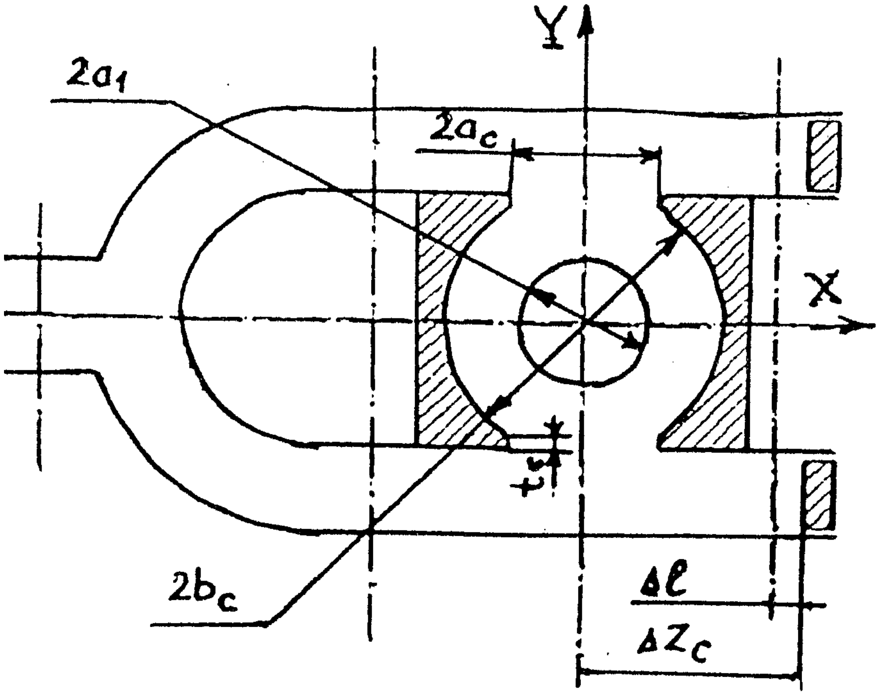
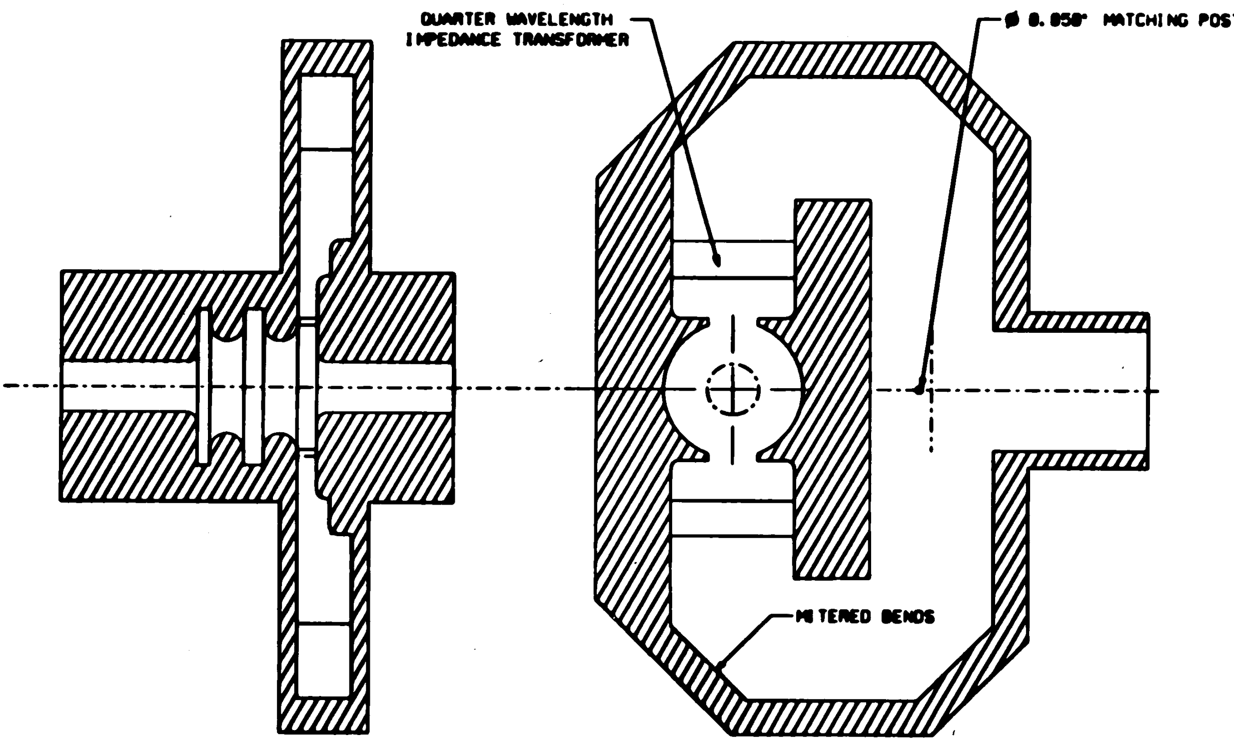
Dual-Feed Design for DESY Input coupler*

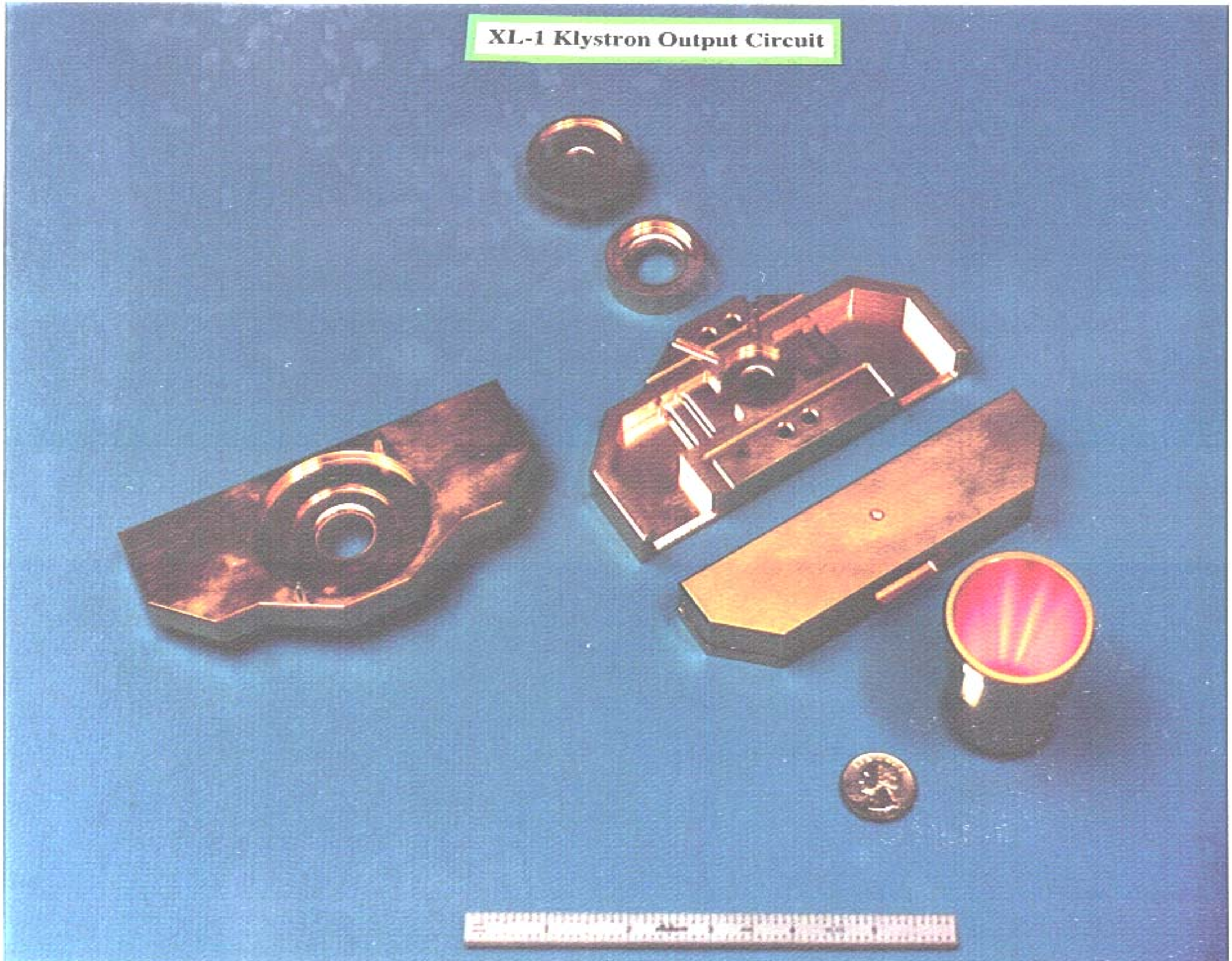


* N.Sobenin-LC95

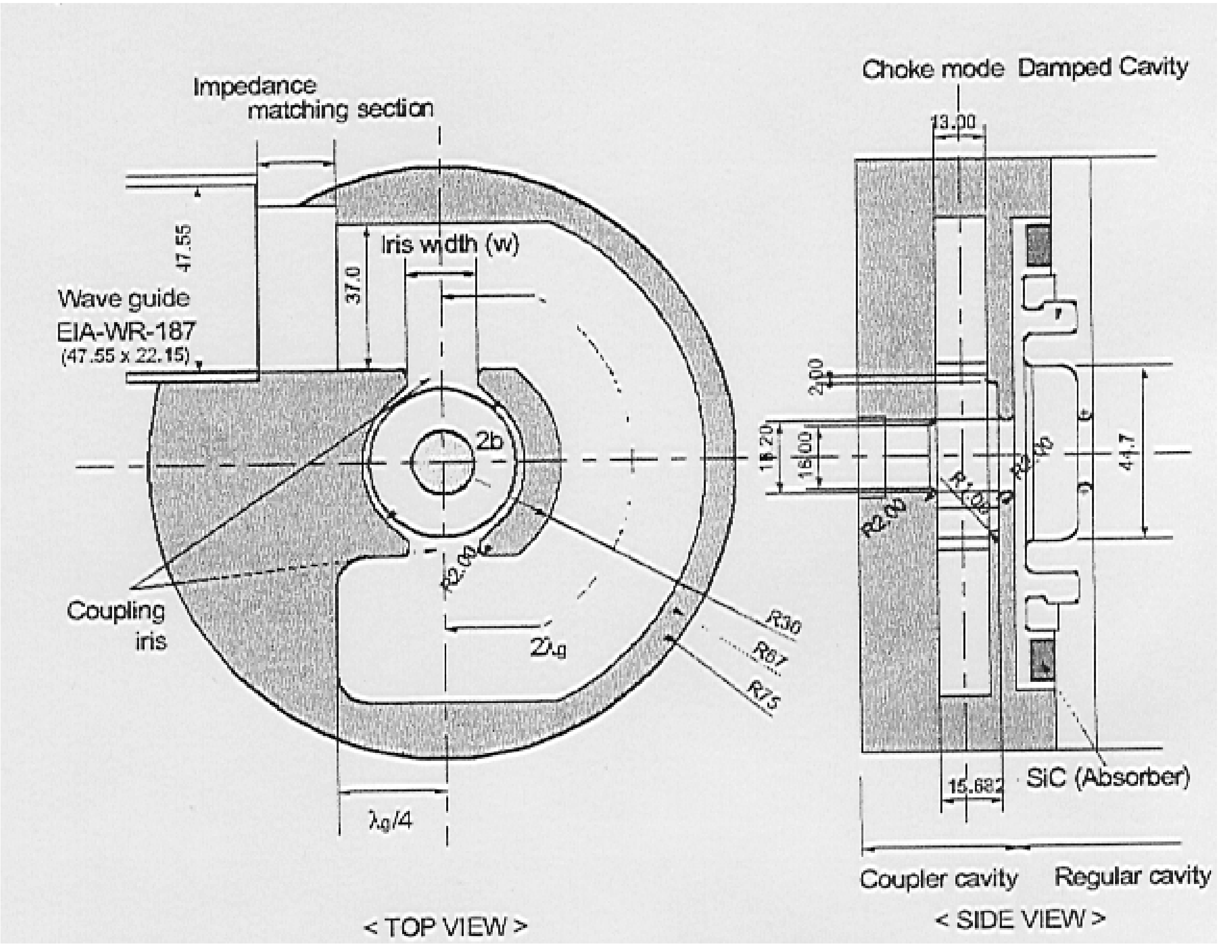
X-Band Klystron Dual-Output Cavity



XL1 3-CELL STANDING WAVE OUTPUT CIRCUIT

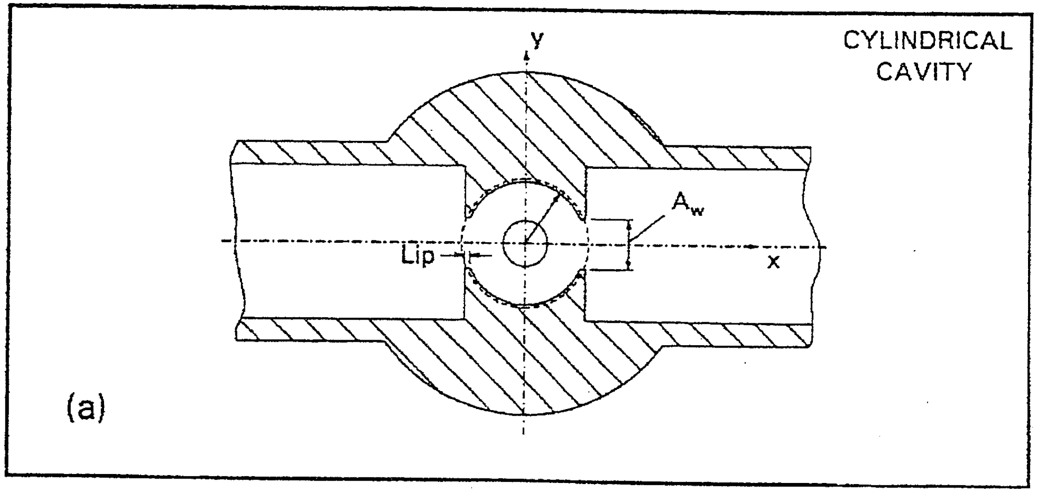

XL-1 Klystron Output Circuit

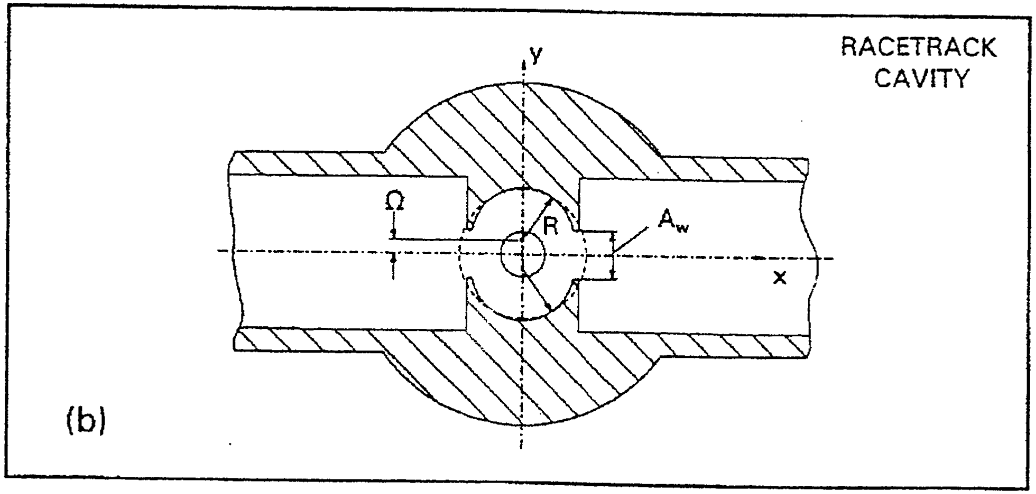
*Matsumoto "J-Coupler"



*C. Suzuki et Al, PAC97

…A further Improvement can be had by using a "*Racetrack**" Configuration





Advantages:

- Removes quadrupolar asymmetry
- Removes field enhancement at irises

* "Haimson et Al, Adv. Accel Concepts Proceedings p653,1998"

Summary

- A single input feed inherently causes a dipolar asymmetry which contributes to a degradation in emittance.
- There are a variety of ways to ameliorate the transverse asymmetry caused by a single feed.
- A symmetrizing iris coupled to a shorted piece of waveguide can remove the dipole asymmetry but may enhance the transverse kick due to the transverse (phase) power flow.
- Symmetrically placed dual inputs remove the dipole asymmetry and greatly reduces the effects of transverse power flow . Need to pay more attention to symmetry at higher frequencies because of difficulty in scaling spot size with frequency.
- A racetrack design reduces field enhancement at the irises and removes the quadrupole asymmetry.

The "down-side" of dual inputs is complexity:

1. Waveguides take up space.
2. Magnet bore may have to be larger.