Technology Challenges for RF Guns as ERL Sources

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Technical Challenges are Everywhere!

- RF Gun
  - NCRF
  - SRF
- Cathodes
- Drive Laser
- Bunch Compression
- Beam Transport

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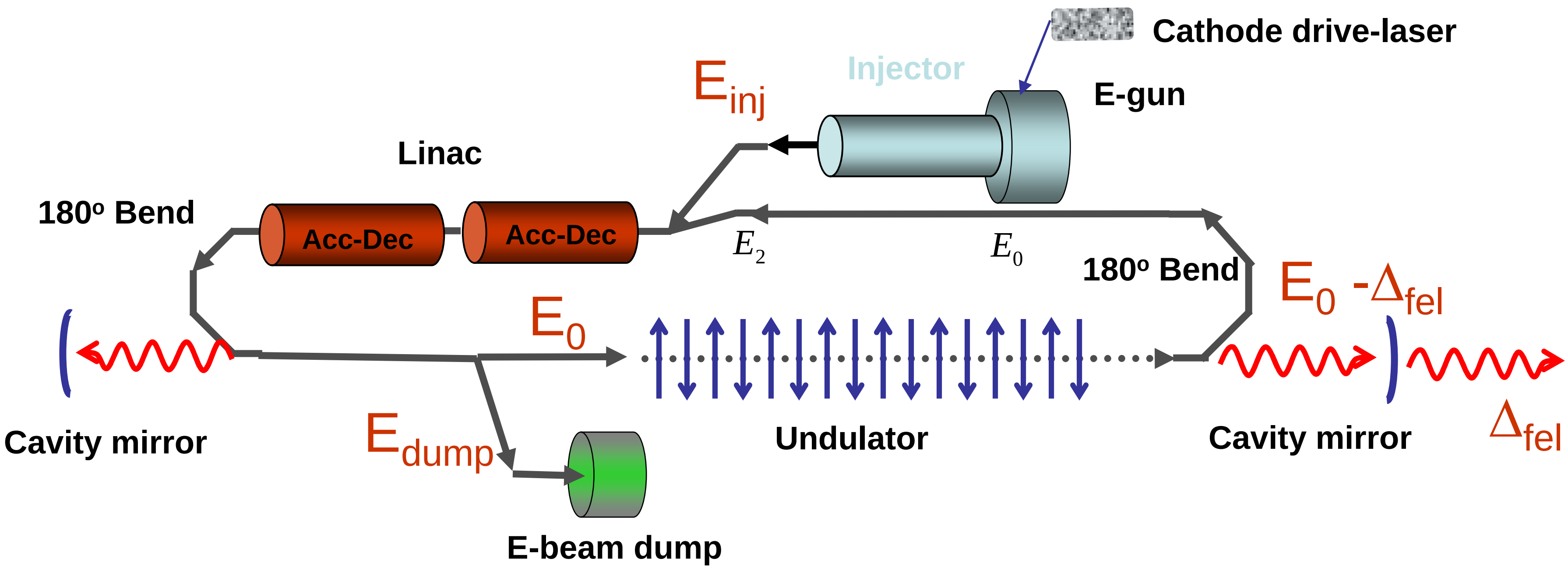
Basic Layout of ERL Free Electron Laser



E-Beam make 2 passes thought the linac:
1: Acceleration and lasing
2: Deceleration and energy recovery

$E_{inj} \approx$ 10 MeV **$\Delta \approx$ 3 MeV**

$E_0 \approx$ 100 MeV **$E_{dump} \approx$ 7 MeV**

slice compliments of P. O'Shea, UMd

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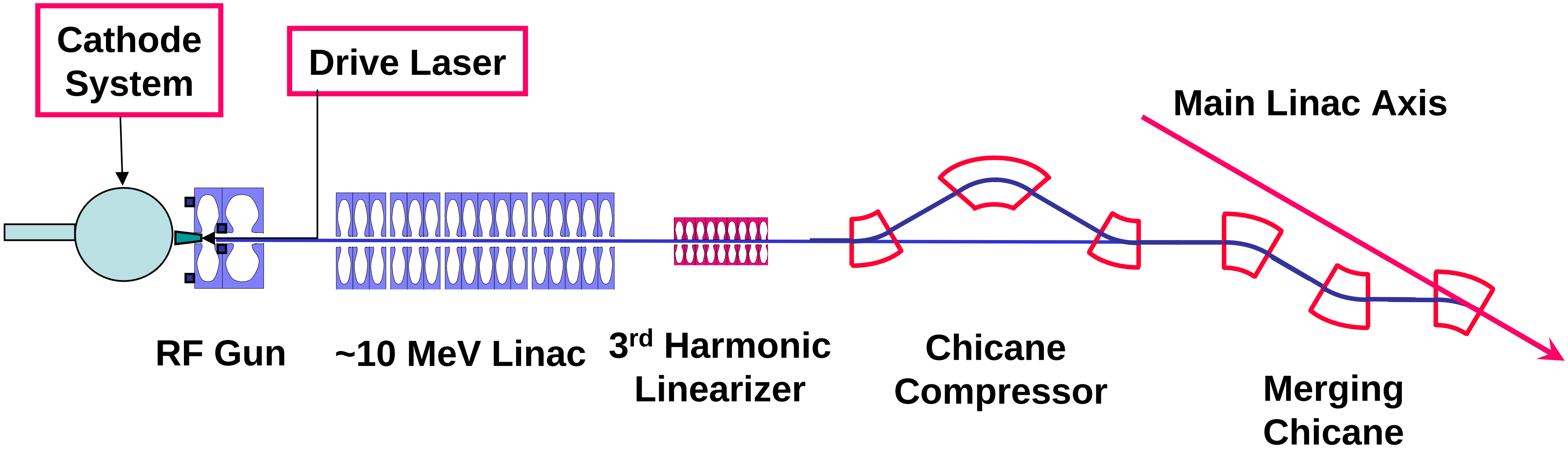
Basic Components of the RF Gun Injector



+ Laser Heater to Suppress Beam Instabilities?

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The Gun

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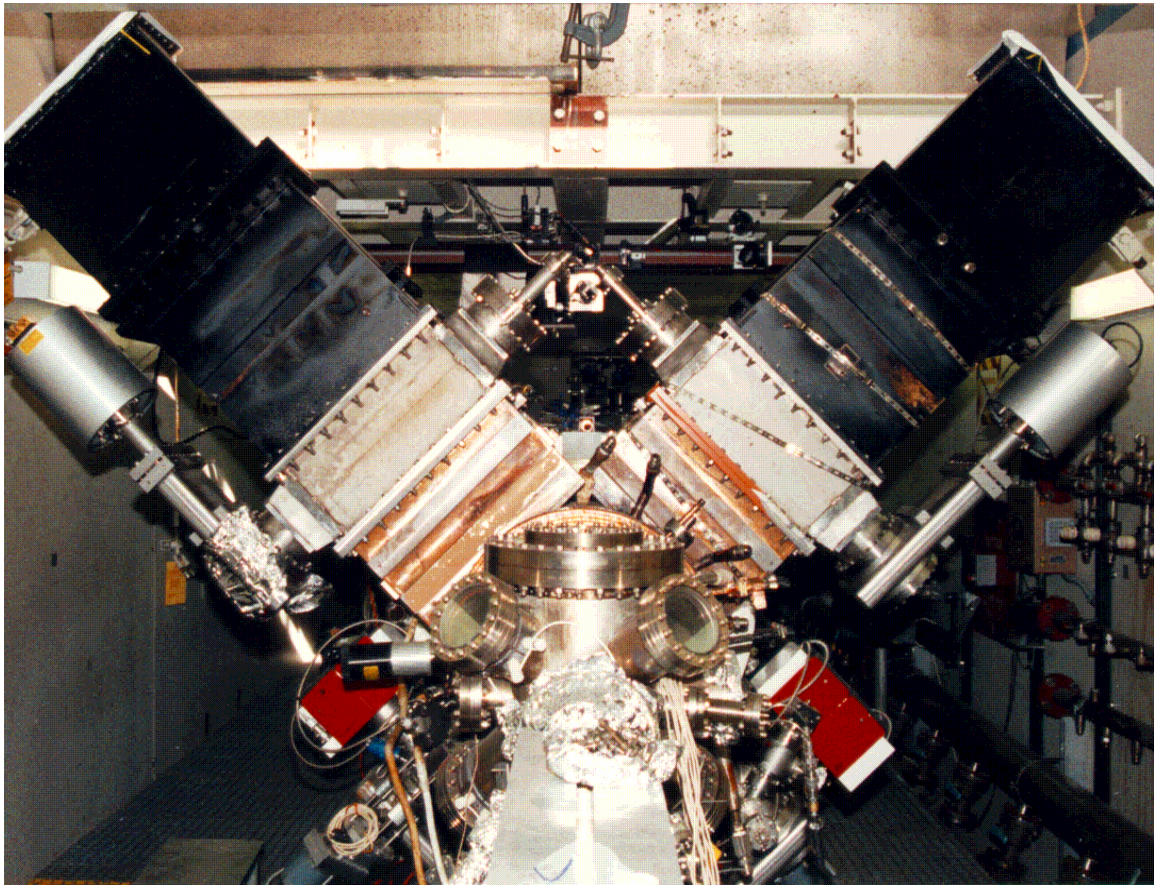
The Boeing 433 MHz RF Photocathode Gun



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Demonstrated Performance of 433 MHz Photocathode Gun, 1992 H-D Test

Photocathode Performance:	
Photosensitive Material:	K_2CsSb Multialkali
Quantum Efficiency:	5% to 12%
Peak Current:	45 to 132 amperes
Cathode Lifetime:	1 to 10 hours
Angle of Incidence:	near normal incidence
Gun Parameters:	
Cathode Gradient:	26 MV/meter
Cavity Type:	Water-cooled copper
Number of cells:	4
RF Frequency:	433 $\times 10^6$ Hertz
Final Energy:	5 MeV(4-cells)
RF Power:	600 $\times 10^3$ Watts
Duty Factor:	25%, 30 Hertz and 8.3 ms
Laser Parameters:	
Micropulse Length:	53 ps, FWHM
Micropulse Frequency:	27 $\times 10^6$ Hertz
Macropulse Length:	10 ms
Macropulse frequency:	30 Hertz
Wavelength:	527 nm
Cathode Spot Size:	3-5 mm FWHM
Temporal and Transverse Distribution:	gaussian, gaussian
Micropulse Energy:	0.47 microjoule
Energy Stability:	1% to 5%
Pulse-to-pulse separation:	37 ns
Micropulse Frequency:	27 $\times 10^6$ Hertz
Gun Performance:	
Emittance (microns, RMS):	5 to 10 for 1 to 7 nCoulomb
Charge:	1 to 7 nCoulomb
Energy:	5 MeV
Energy Spread:	100 to 150 keV

Applied Physics Letters, 63 (15), 11 October 1993, pp. 2035-2037.

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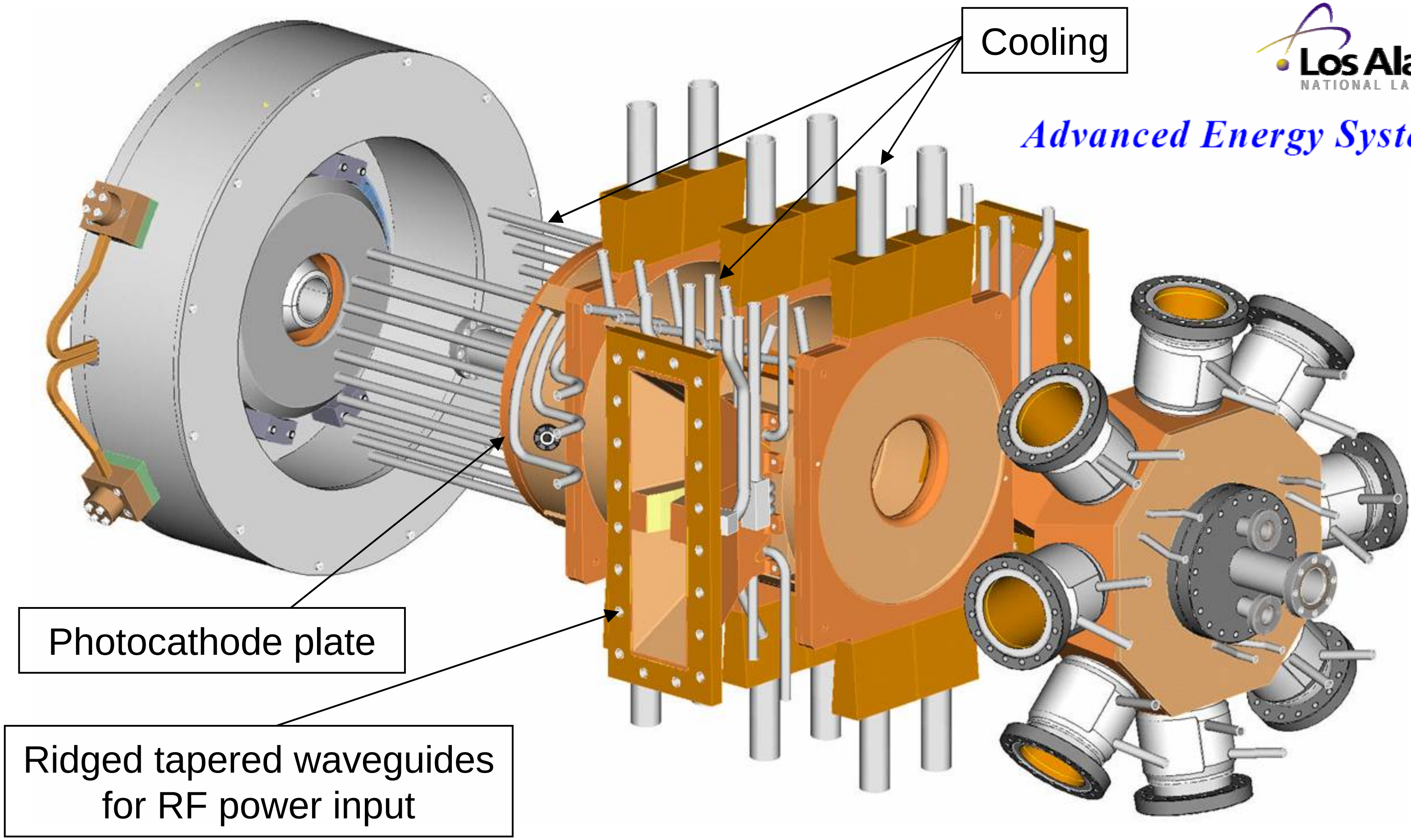
Normal-Conducting RF Photoinjector



2.5-cell PI with emittance-compensating magnets (left) and vacuum plenum (right)

complements of D. Nguyen, LANL

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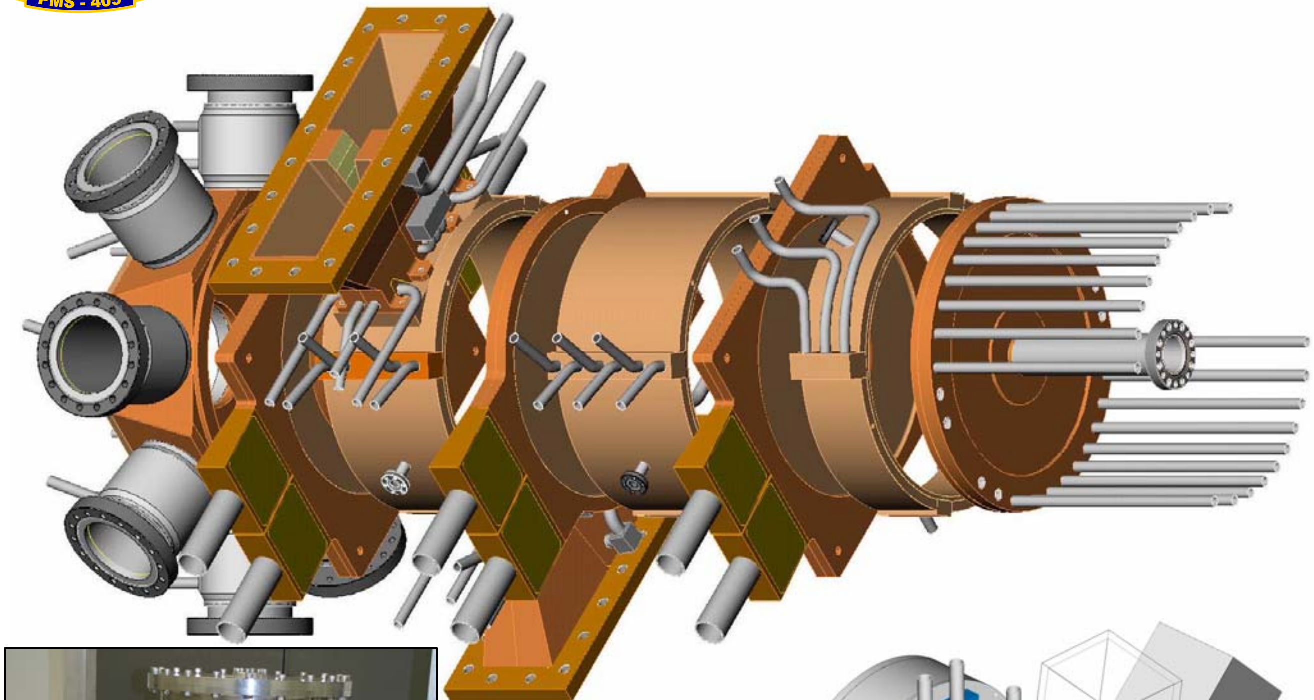
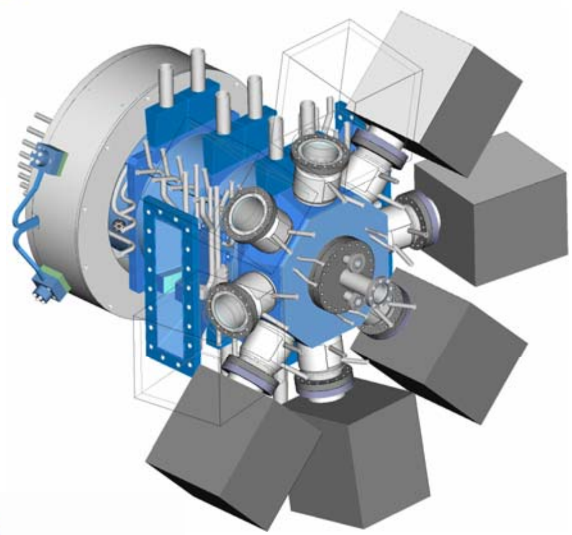
RF Photoinjector Summary





Gun Type	RF
Injector and ERL	
RF Frequency (MHz)	700
PRF (MHz)	33.3 (350)
Charge/Bunch (nC)	3.0
Current (mA)	100 (1050)
Injector Energy (MeV)	2.5
Transverse RMS Normalized Emittance (	6
Longitudinal RMS Emittance (keV-psec)	145
RMS Bunch Length (psec)	
RMS Energy Spread (%)	0.5
ERLP Energy (MeV)	N/A
ERL Energy Goal (MeV)	N/A
Electron Gun	
DC Gun Voltage (kV)	N/A
Gun Accelerating Field (MV/m)	7 / 7 / 5
Cathode Material	Multi-Alkali
Drive Laser FWHM Pulse Length (psec)	16
Laser Wavelength (nm)	527
Laser Power at 5% QE (W)	5 (53)
Booster Accelerator	
Type	N/A
Geometry (Cavities x Cells)	1 x 2.5
Couplers per Cavity / Type	2 / WG
Coupler Power (kW)	500
Status	Fabrication

Los Alamos NATIONAL LABORATORY

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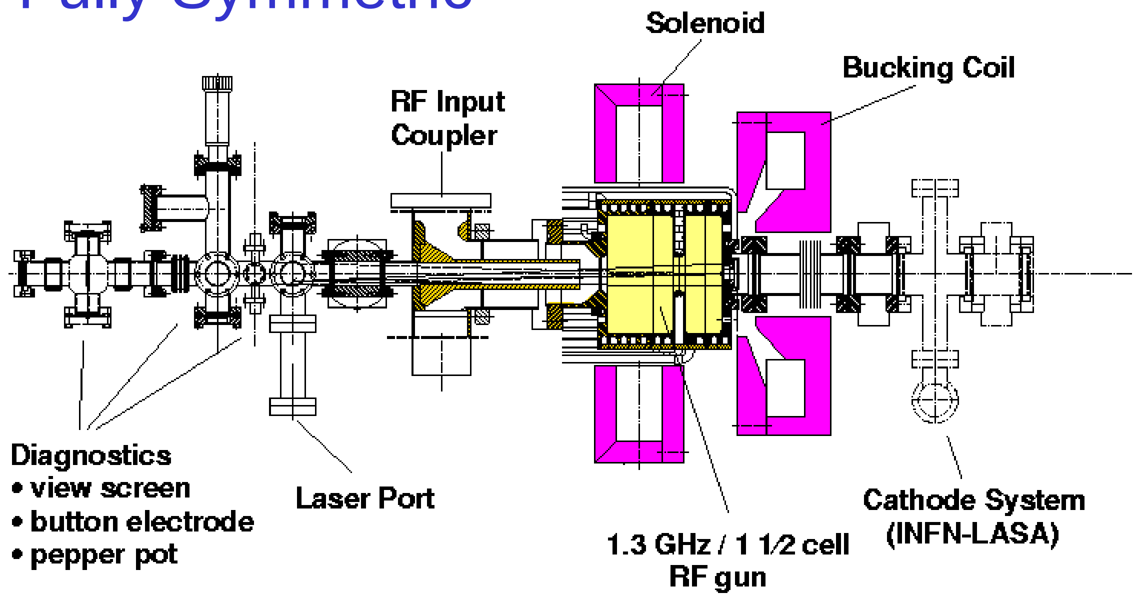
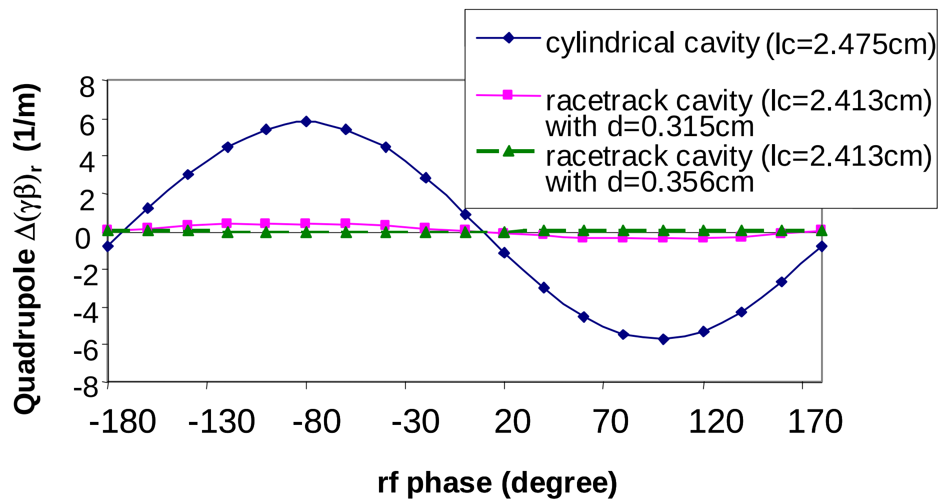
RF Fields Should be Fully Symmetric

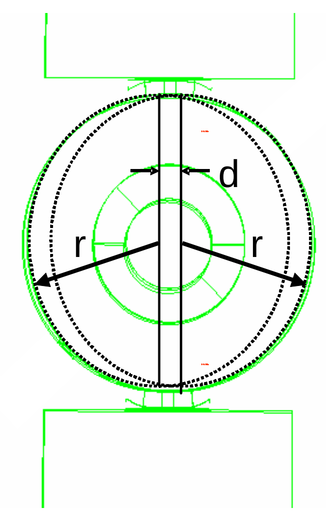
Coaxial RF Feed



DESY TTFII RF Gun
2004 FEL Proceedings

Dual Feed &
Racetrack Shape





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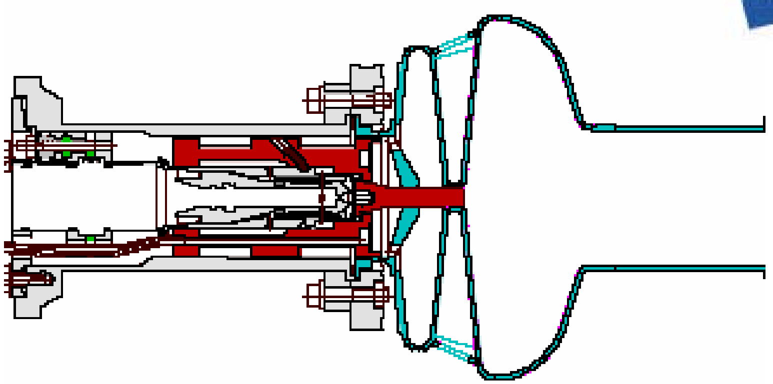
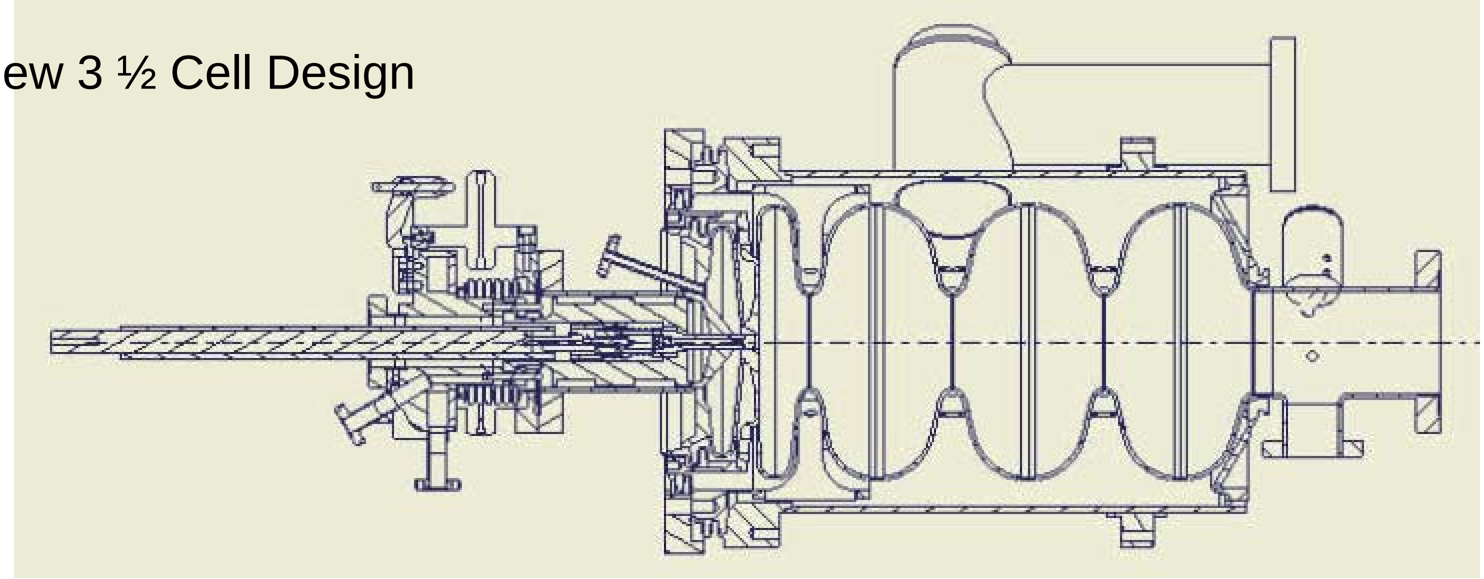
Rossendorf SRF Guns

Forschungszentrum Rossendorf

Original 1-Cell Design



New 3 ½ Cell Design



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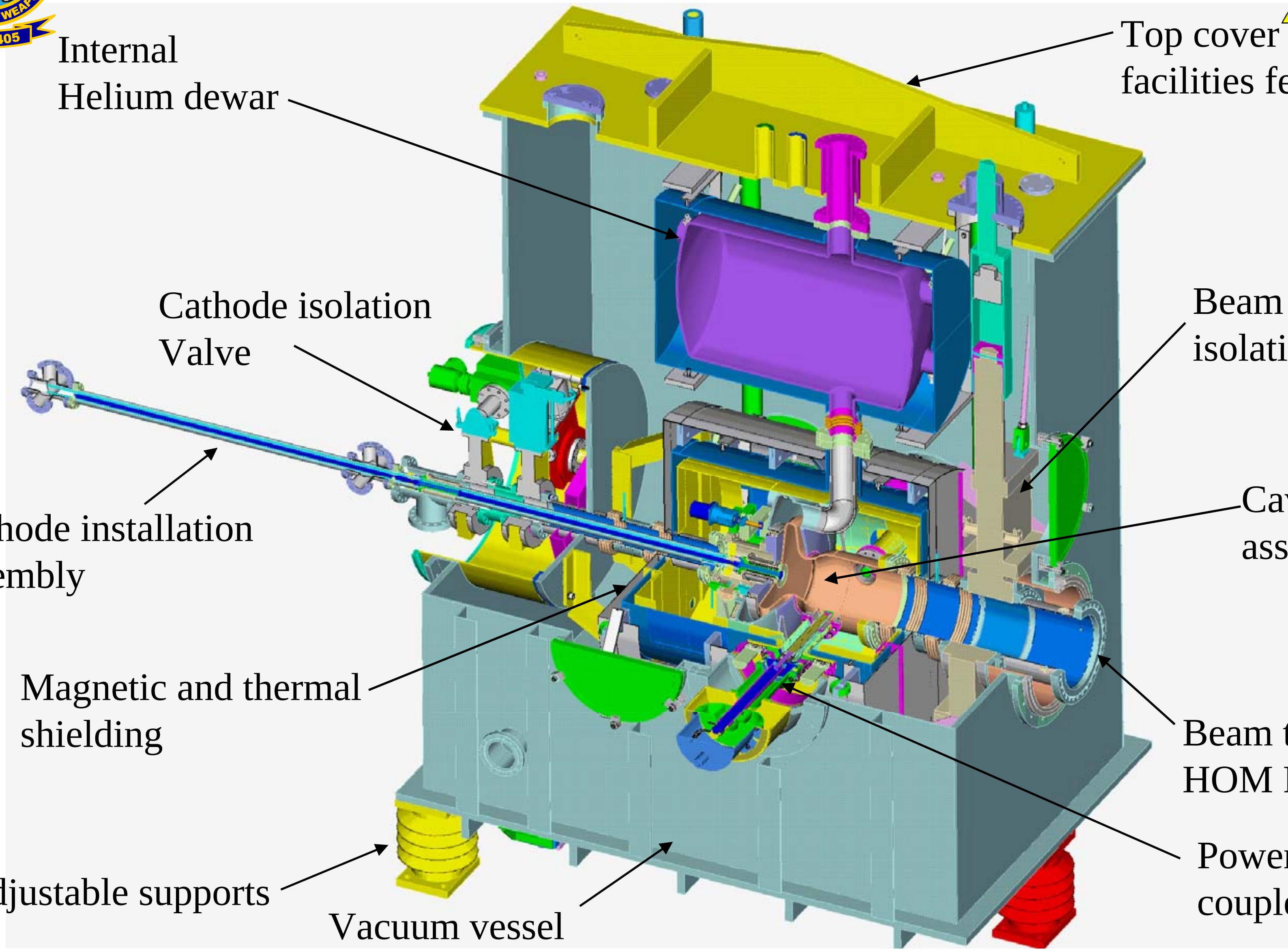
Cryomodule Configuration



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slide compliments of A. Todd

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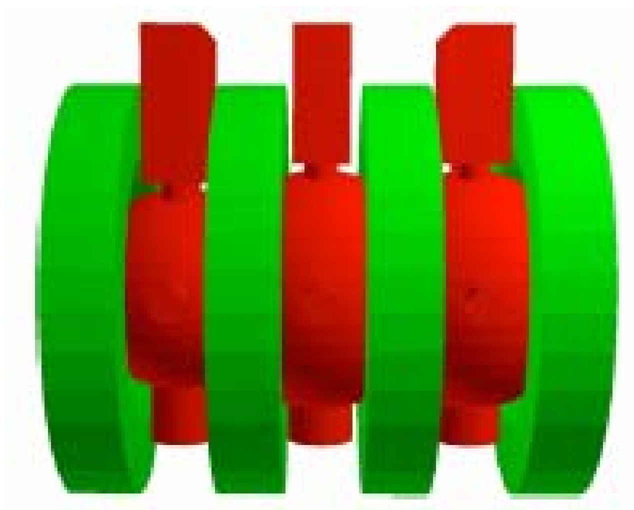
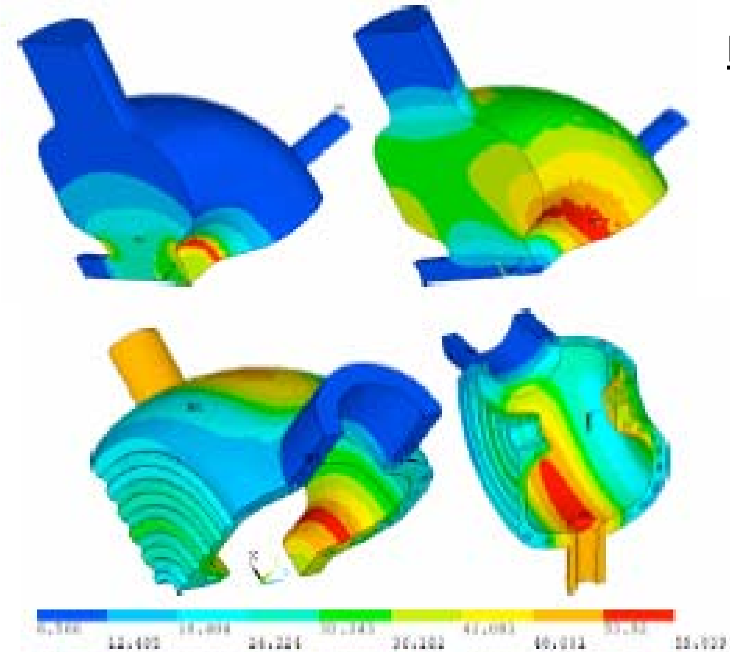
The "LUX" Gun

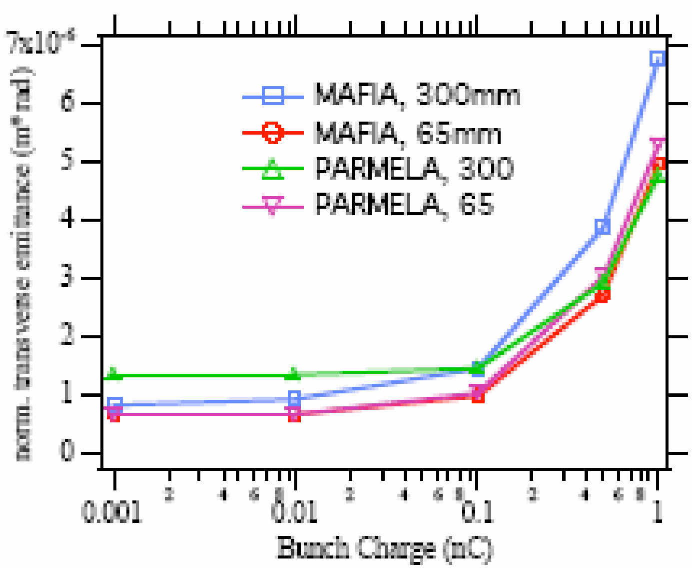


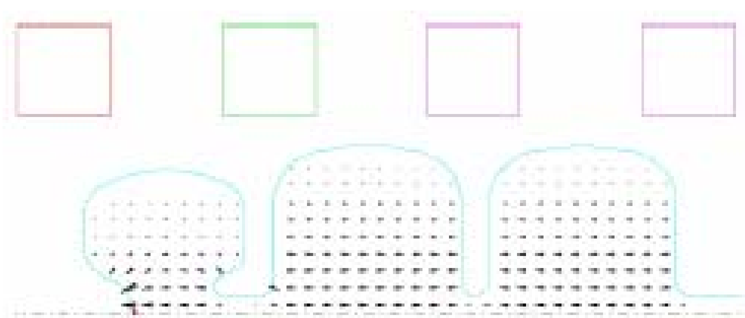


Premise:

Cavity shaping leads to higher impedance and lower thermal loads and stress => can perhaps use OFHC copper instead of Glidcop

Projected CW fields are 20 / 13 /13 MV/m



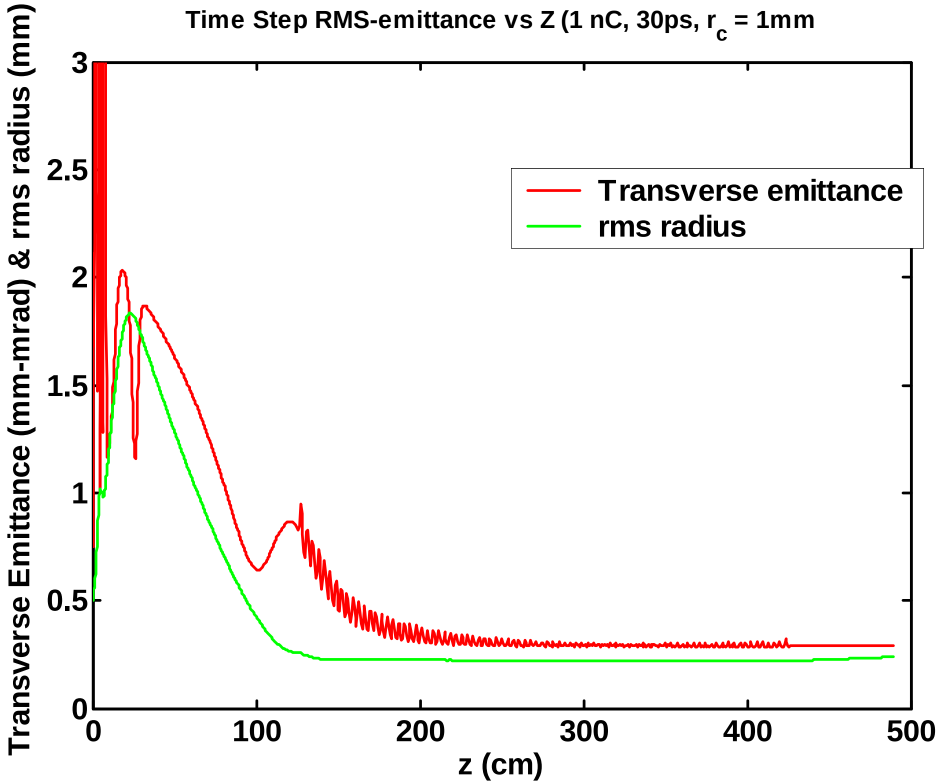


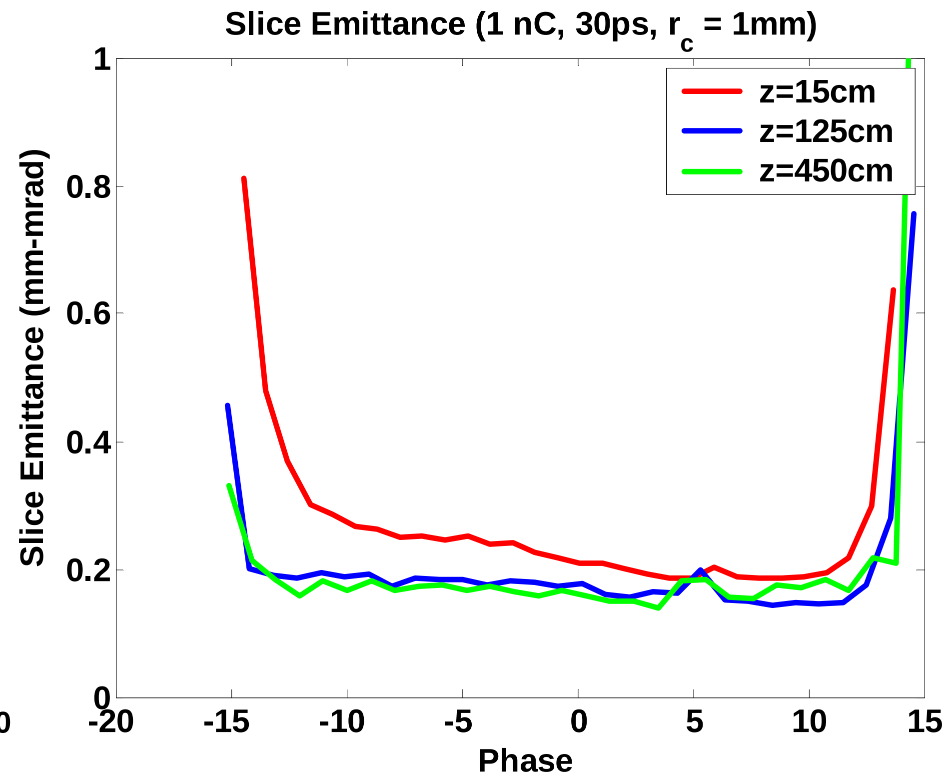
Gun Type	*RF*
Injector and ERL	
RF Frequency (MHz)	*1300*
PRF (MHz)	*1300*
Charge/Bunch (nC)	*1.0*
Current (mA)	*1300*
Injector Energy (MeV)	
Transverse RMS Normalized Emittance (μm)	
Longitudinal RMS Emittance (keV-psec)	
RMS Bunch Length (psec)	
RMS Energy Spread (%)	
ERLP Energy (MeV)	*N/A*
ERL Energy Goal (MeV)	*N/A*
Electron Gun	
DC Gun Voltage (kV)	*N/A*
Gun Accelerating Field (MV/m)	*20 / 13 / 13*
Cathode Material	*TBD*
Drive Laser FWHM Pulse Length (psec)	
Laser Wavelength (nm)	
Laser Power at 5% QE (W)	
Booster Accelerator	
Type	*N/A*
Geometry (Cavities x Cells)	*1 x 2.5*
Couplers per Cavity / Type	*3 / WG*
Coupler Power (kW)	
Status	*Analysis*

slice compliments of A. Todd, AES

Material Courtesy Robert Rimmer

Two-Frequency Gun with Emittance Compensation





D. Jansen suggests using the harmonic TE-mode to magnetically focus in SRF gun

2003 FEL Conference Proceedings

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Photocathodes

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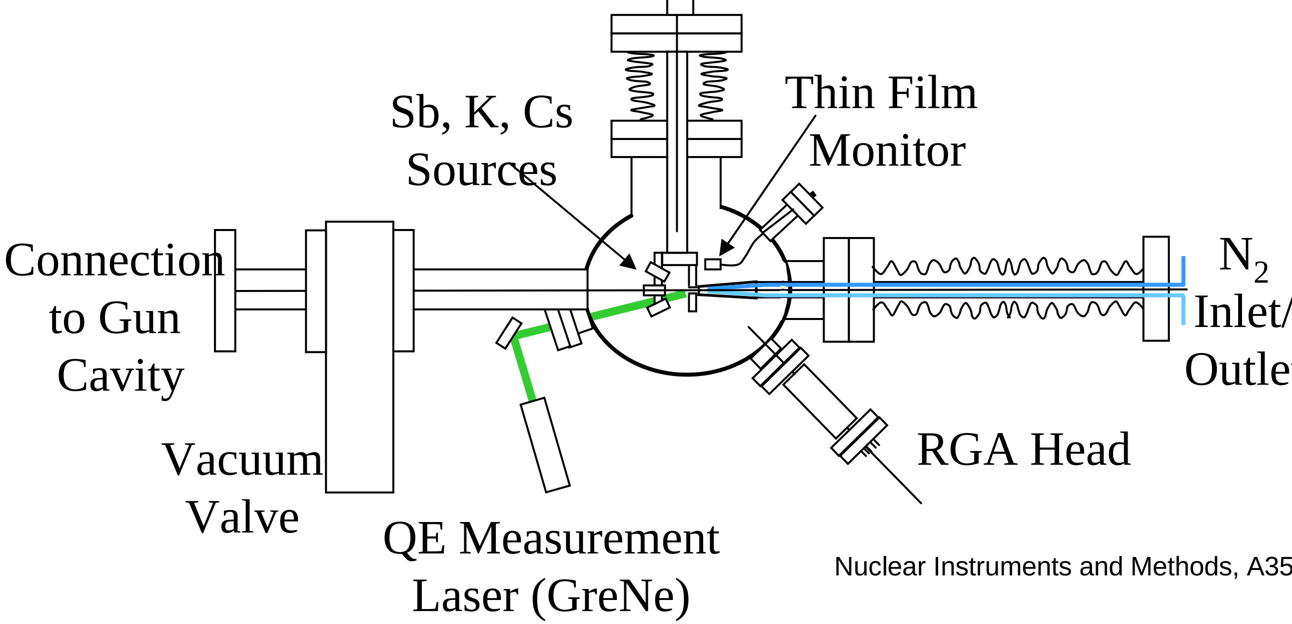
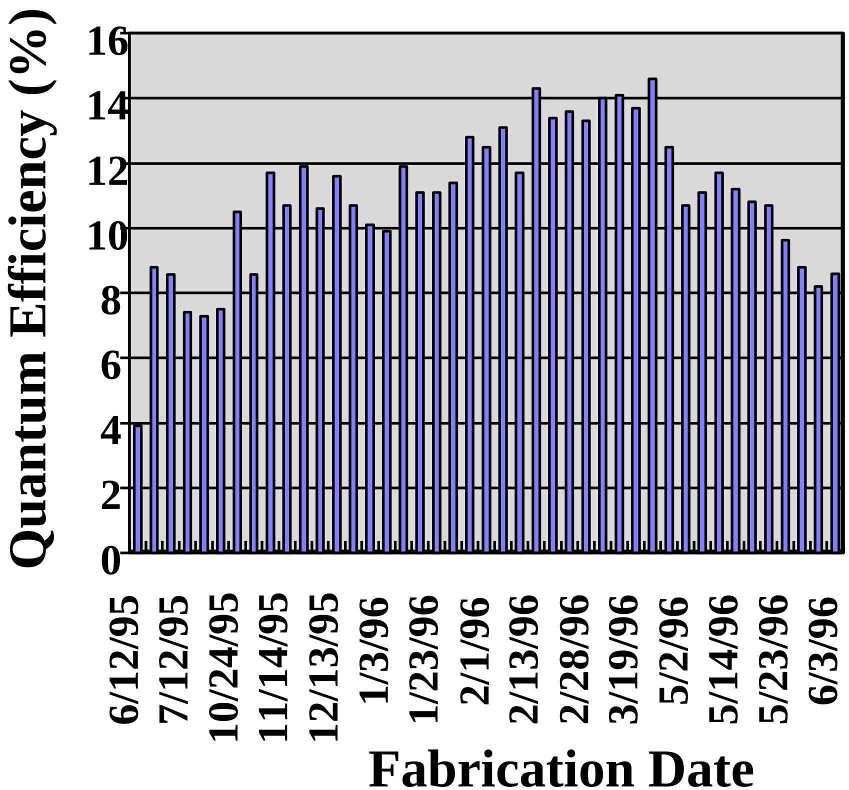


Nuclear Instruments and Methods, A356(1995) pp. 167-176.



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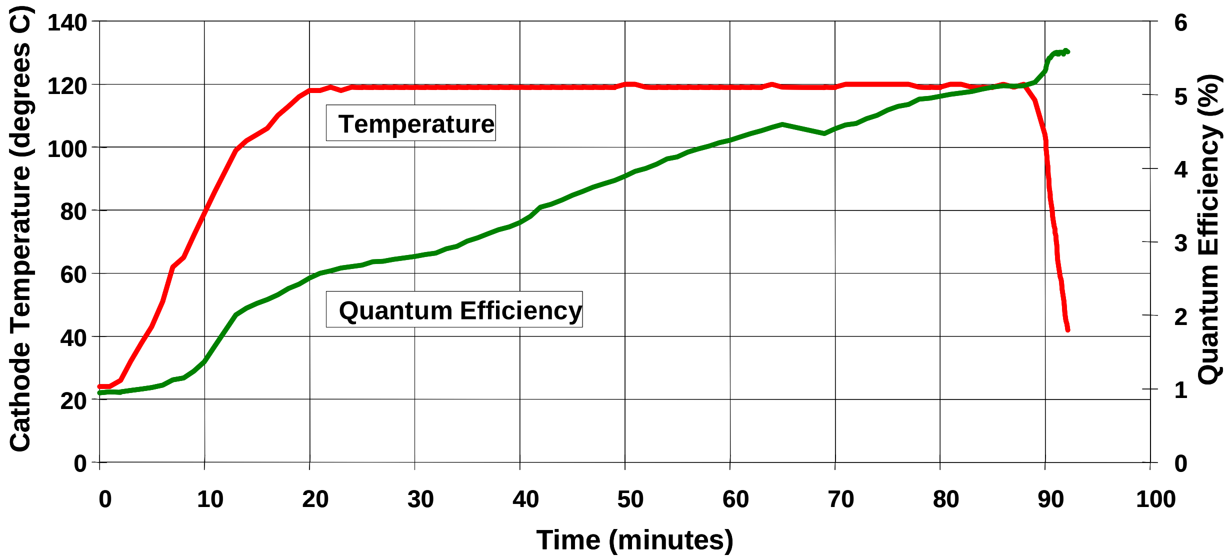

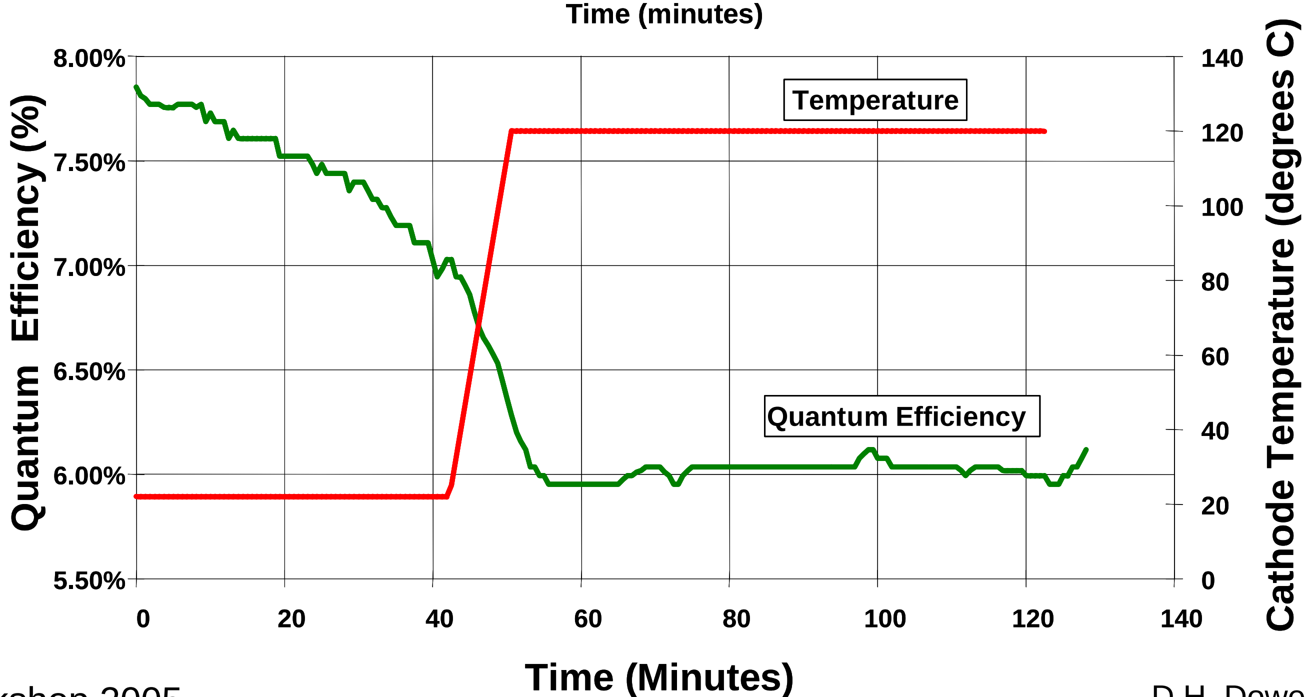

Nuclear Instruments and Methods, A356(1995) pp. 167-176.

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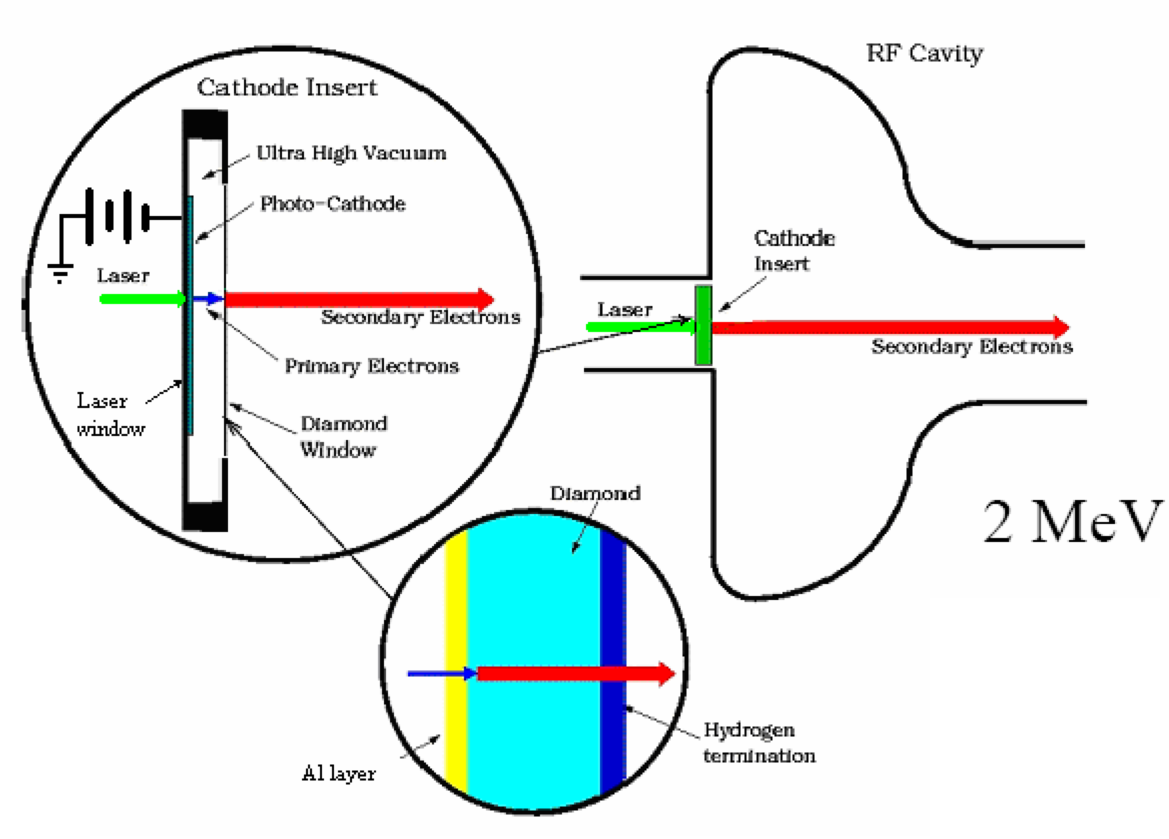
Advanced Diamond Amplified Cathode Being Developed at BNL



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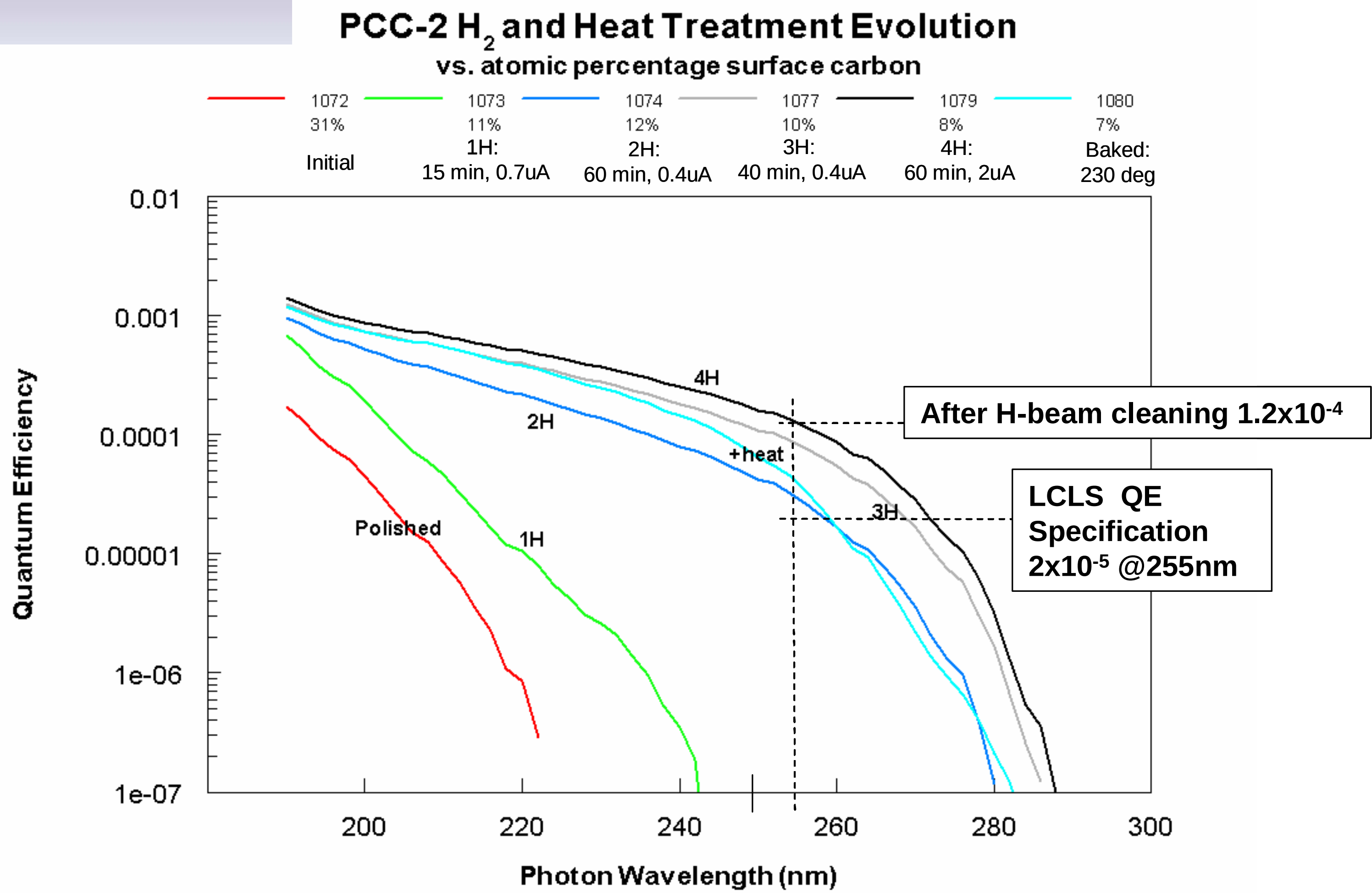
In-Situ Hydrogen Beam Cleaning of Cathode Surface



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The Drive Laser

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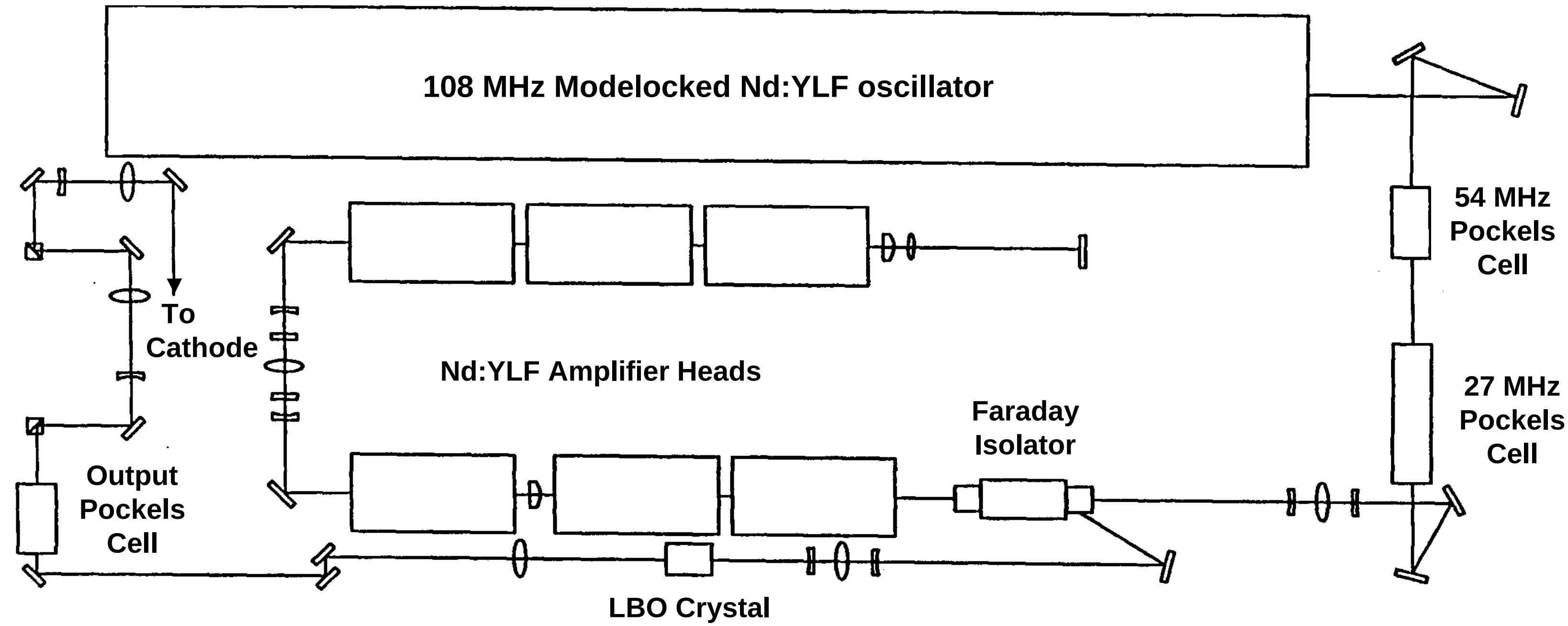
The 25% Duty Factor Drive Laser Used in Boeing/LANL Photocathode Injector Test*



*D.H. Dowell et al., NIM A356(1995)167-176.

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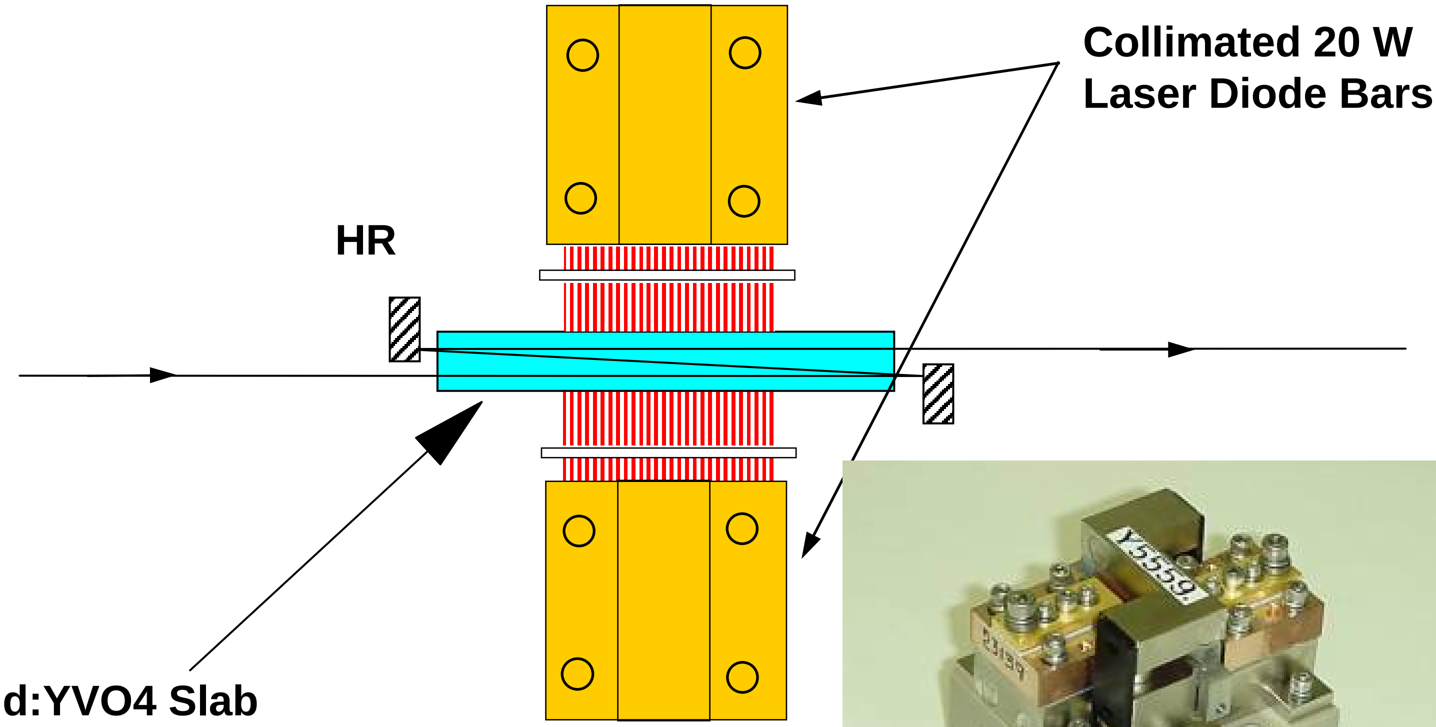
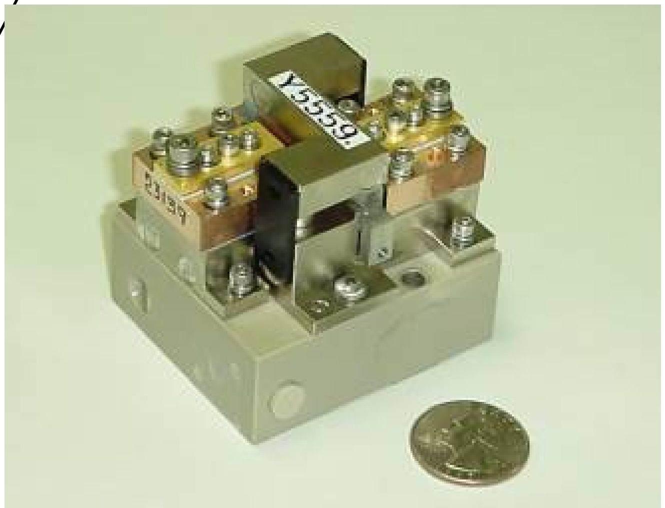
Drive laser should be diode pumped





slide compliments of M. Shinn

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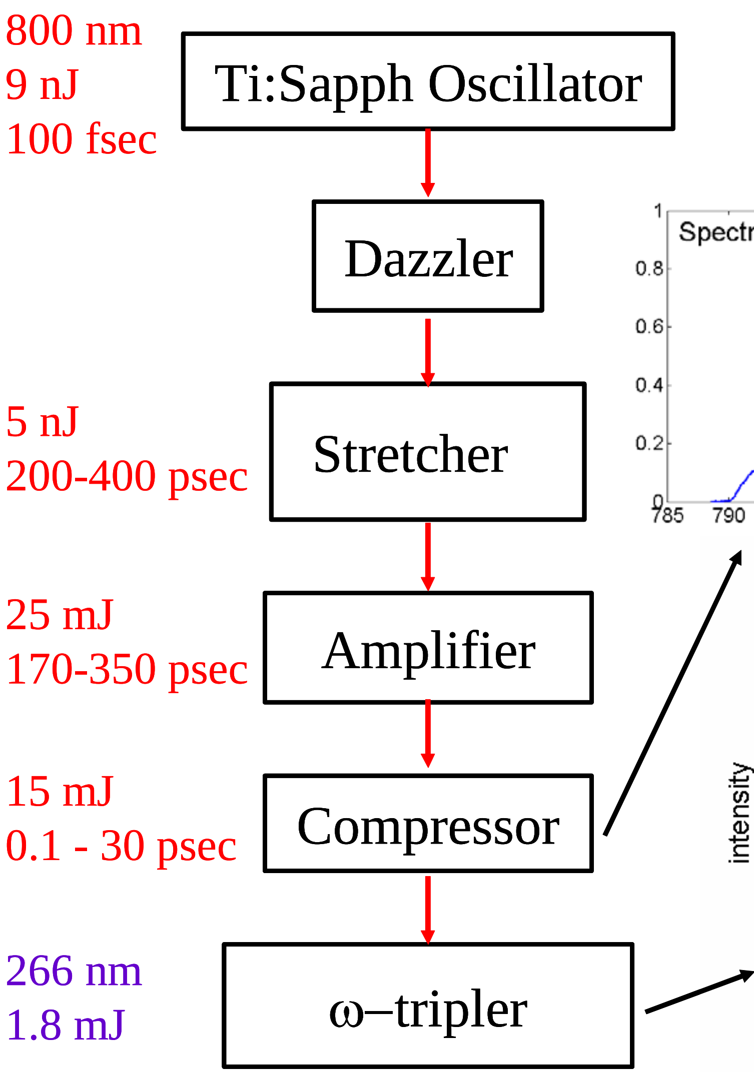
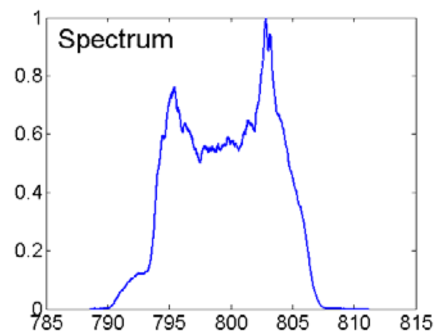
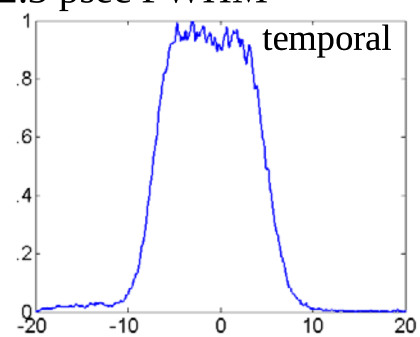
New Drive Lasers Should be Shaped Spatially and Temporally

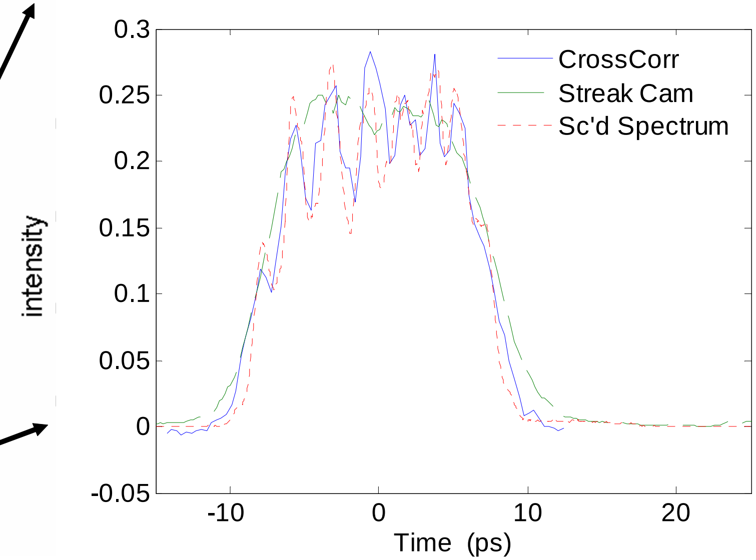
and Fully diode-pumped, fiber oscillator & amplifier



risetime: 20-80% 2.5 psec
10%-90% 4 psec
12.3 psec FWHM







Courtesy of Yuzhen Shen, Carlo Vicario, B. Sheehy, XJ Wang

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Beam Transport
(some comments)

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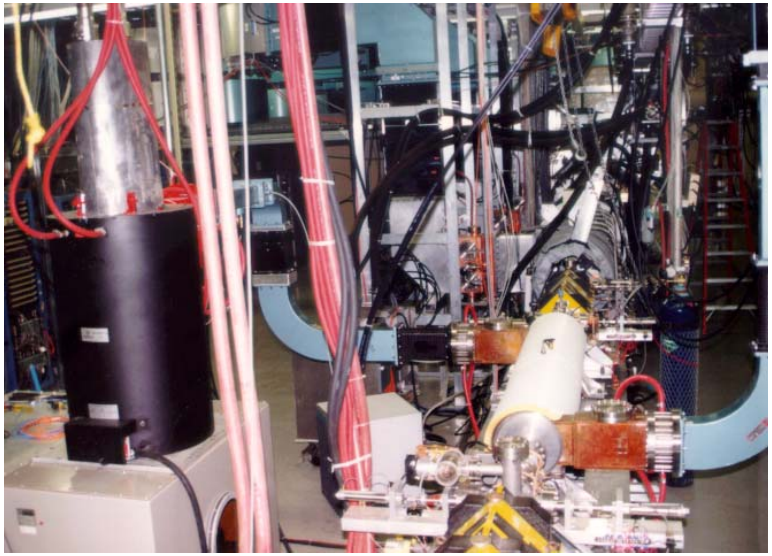
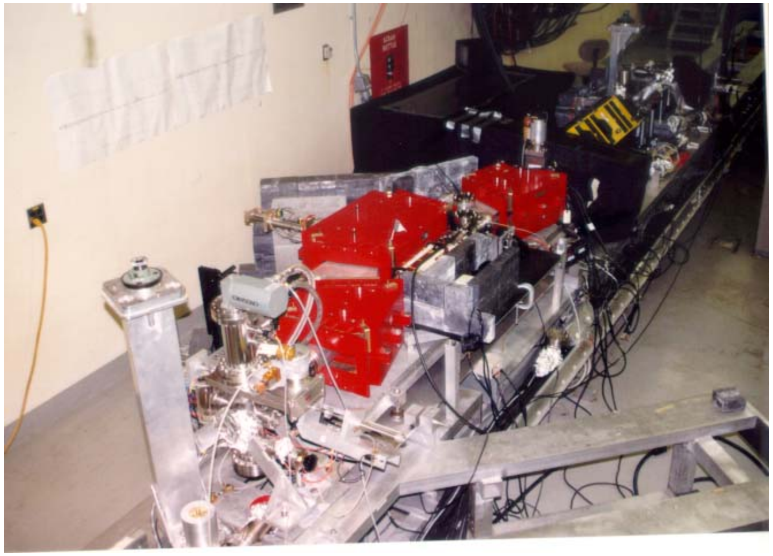
Linear Bunching for High Peak Current





1300 MHz (third harmonic) energy spectrum programming for bunch compression

Three dipole magnetic buncher and diagnostics

Proceedings of the 1995 Particle Accelerator Conference, Dallas, TX, USA, pp.992-994.

Nuclear Instruments and Methods, A393(1996)pp. 184-187.

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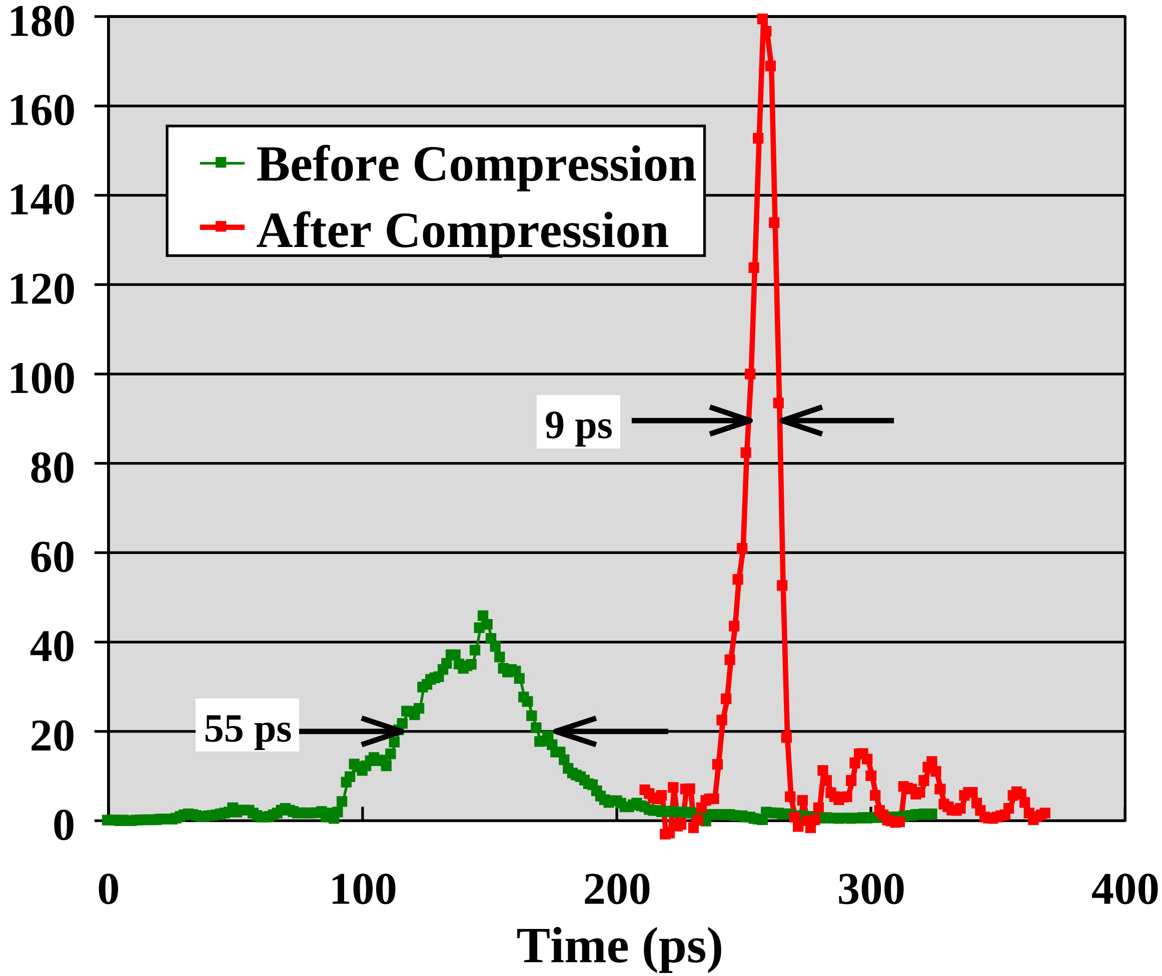
Pulse Compression Boosts Peak Current From 45 to 280 Amperes



Nuclear Instruments and Methods, A393(1996)pp. 184-187.

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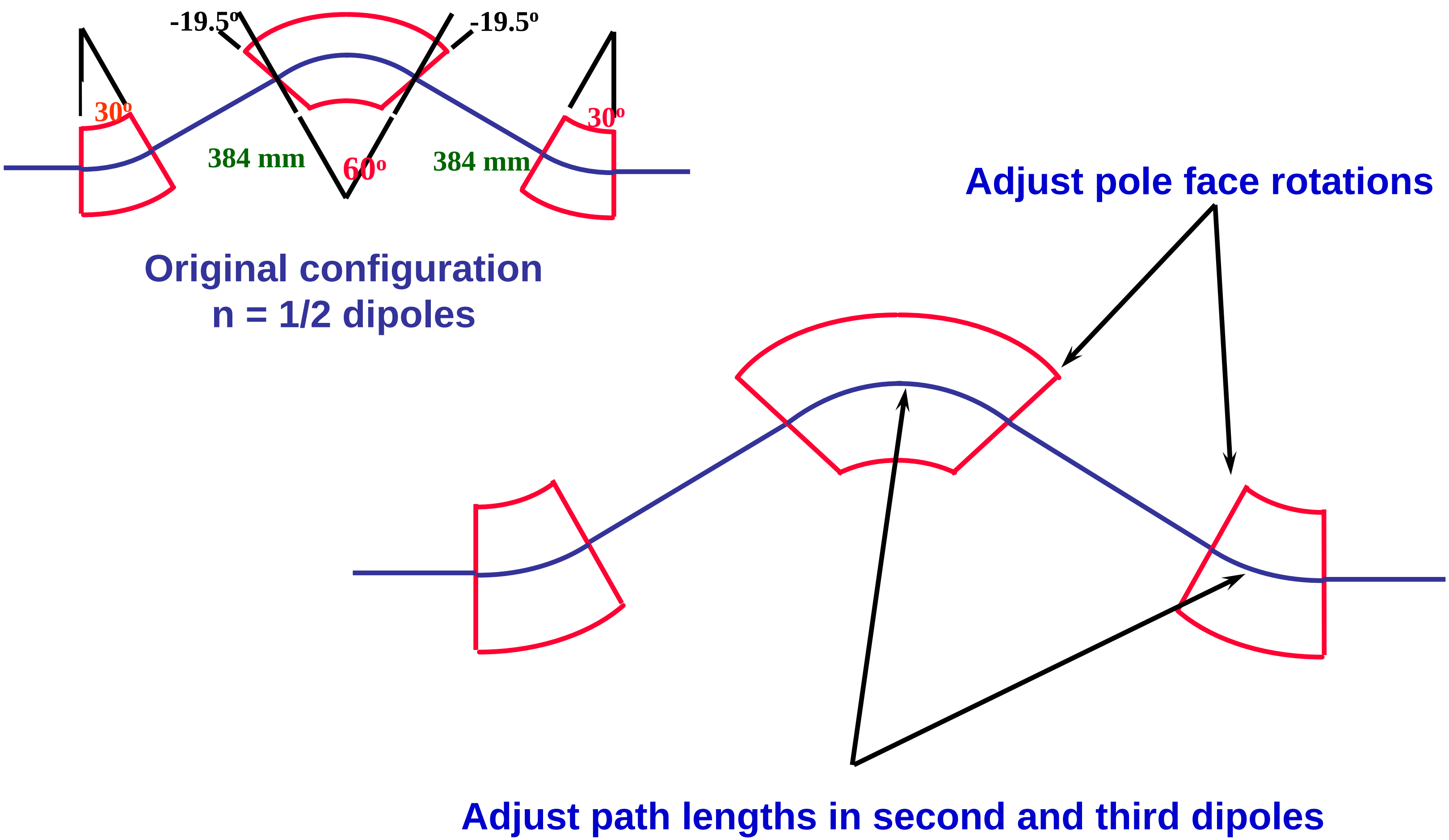
Emittance Compensation in the Three-Dipole Chicane



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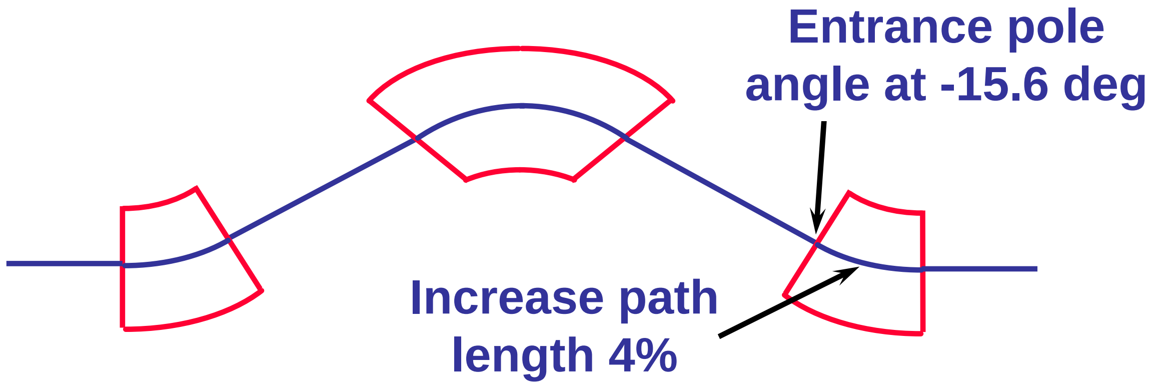
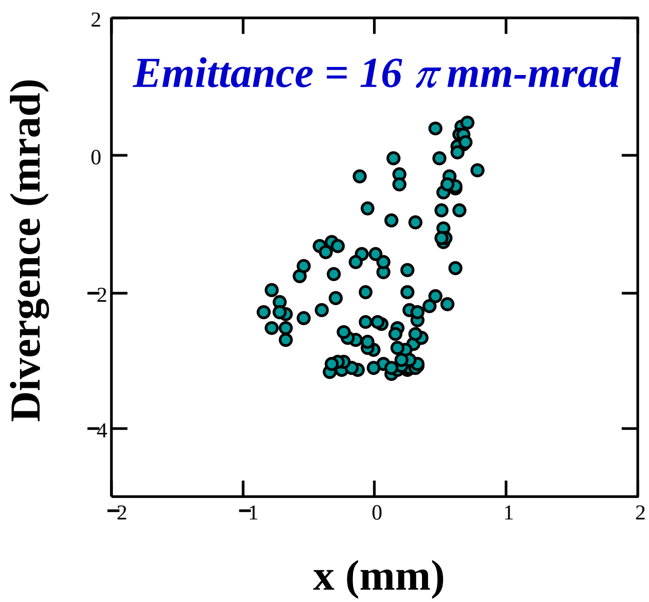
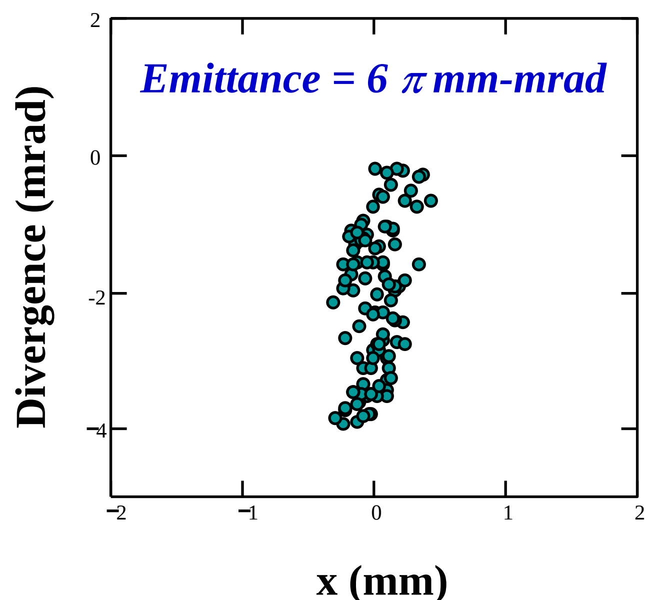


Compress a 3nC, 1 πmm-mrad microbunch from 7.5mm (50amps) to 0.39mm (1000amps). The emittance is reduced by increasing the third dipole path length 4% and rotating entrance pole face -15.6°. Net bend angle is 1.2°.

Uncompensated Phase Space



Compensated Phase Space



Proceedings of the 20th International
Free-Electron Conference, Williamsburg, VA, USA.

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Summary and Discussion

- **RF guns:**
  - **NCRF under construction by AES for LANL**
  - **SRF guns:**
    - **Rossendorf 0.5 cell, Version 1, 1.3 GHz**
    - **Rossendorf 3.5 cell, Version 2**
    - **BNL/AES 0.5 cell, 700 MHz**

- **Cathodes:**
  - **Requires visible sensitivity**
  - **High-QE, Diamond amplified?**
  - **Cathode survival at high current, vacuum, etc.**
  - **Thermal emittance**

- **Drive Laser:**
  - **3D Pulse shaping required**
  - **Direct-diode pumped**
  - **Fiber oscillator and amplifiers (future)**

- **Beam Transport, emittance presevation:**
  - **Wakefields, space charge, etc.**
  - **Asymmetric bends**

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