Challenges of High-Brightness Electron Beam R&D

X.J. Wang

National Synchrotron Light Source

Brookhaven National Laboratory

Upton, NY 11973, USA

Presented at the ANL Beam Physics Seminar

June 30, 2003

Outline

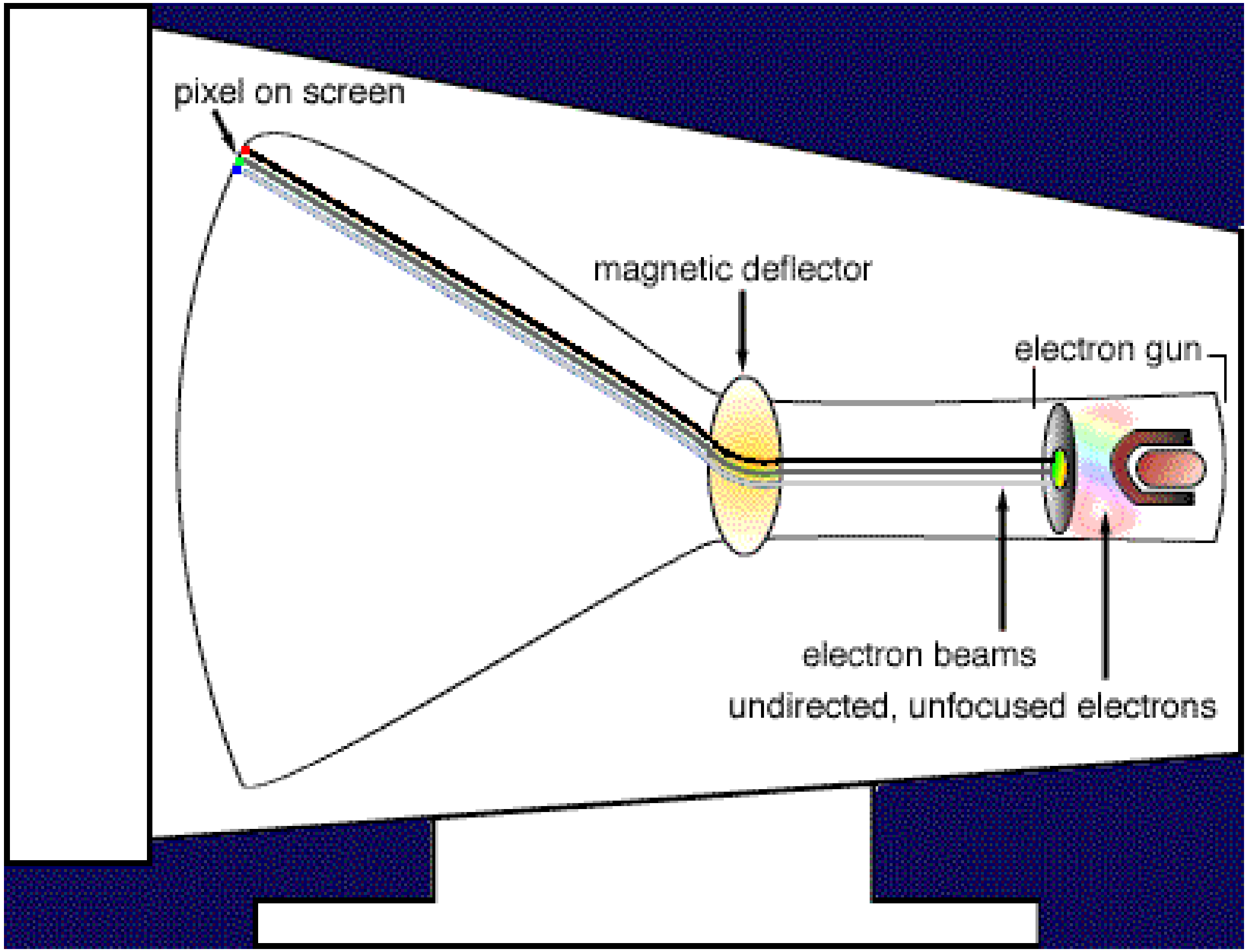
- Introduction: Bright beam ⇒ Bright Future
- The Applications

2. Photoinjector for Storage-Ring

3. Femto-second Electron Diffraction

- Challenges in High-brightness Beam R&D

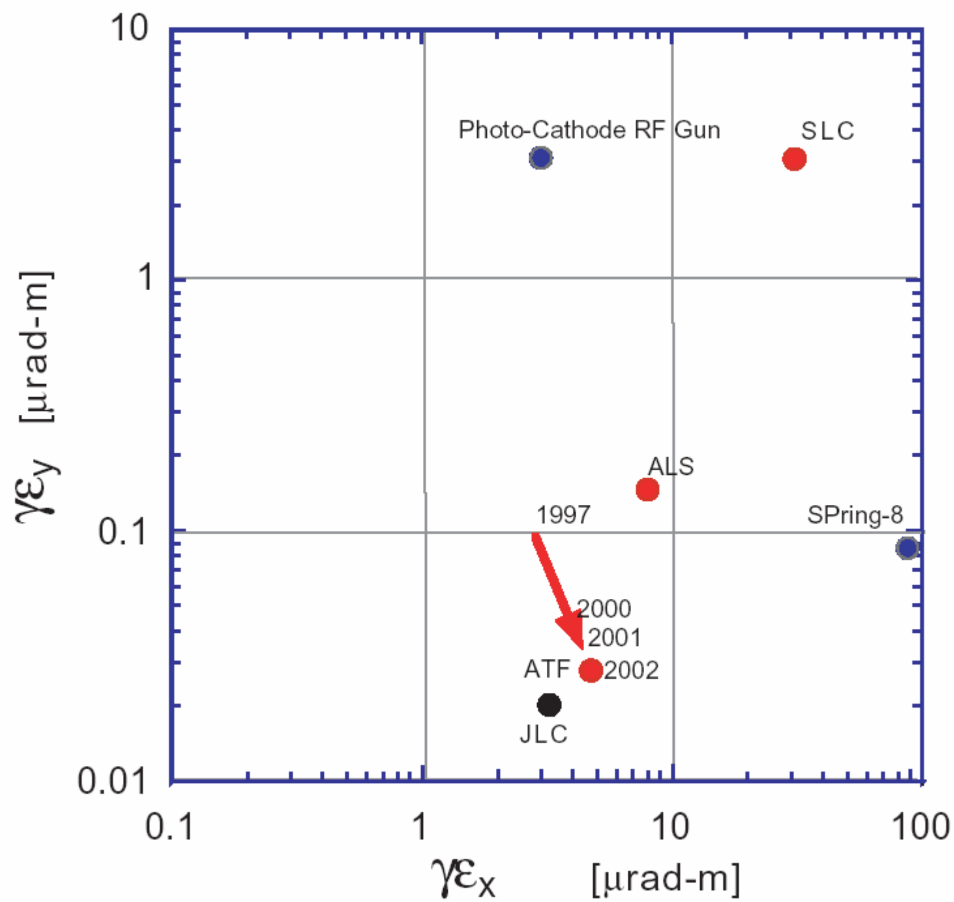
1. Issues in photoinjector R&D: stability and reliability; theoretical understanding; thermal emittance;beam based optimization.
2. New electron sources: CW source for ERL, High-frequency RF gun, DC pulse gun, laser plasma source, longitudinal emittance compensation.


pixel on screen
magnetic deflector
electron gun
electron beams
undirected, unfocused electrons

$$B \propto \frac{Ne}{\varepsilon_x \varepsilon_y \tau \delta_E}$$

We all agree that, brighter of the beam, and it is better off.
But …

Performance of Damping Ring – KEK ATF



ATF Emittance

World record of normalized emittance

$\gamma \epsilon_y \approx 4 \times 10^{-8} \mathrm{rad} \cdot \mathrm{m}$

XFEL vs Linear Collider

XFEL:

$$\lambda_r = \frac{\lambda_w}{2\gamma^2}(1+\frac{k^2}{2})$$

$$\lambda_{\min}[\mathrm{A}] = 4\frac{\pi\varepsilon_n[mm-mrad]}{\sqrt{I[kA]L_w[m]}}$$

$$\sigma_\delta < \rho \approx \frac{1}{4}\left(\frac{1}{2\pi^2}\frac{I_{pk}}{I_A}\frac{\lambda_u^2}{\beta\varepsilon_N}\left(\frac{K}{\gamma}\right)^2\right)^{1/3}$$

$$L_{G1D} = \frac{\lambda_u}{4\pi\sqrt{3}\rho}$$

Linear Collider:

$$L \propto \frac{fN^2}{\sigma_x\sigma_y}H$$

XFEL vs Linear Collider

Parameter	Unit	CLIC	LCLS
Wavelength, λ_r	Å	1.5	1.5
Energy	GeV	15	14.4
Undulator period, λ_u	mm	30	30
Undulator parameter, a_u	-	2.758	2.623
Magnetic field, B_u	T	0.985	0.937

Parameter	Unit	CLIC	LCLS
Energy	GeV	15	14.4
Energy spread, $\frac{\Delta\gamma}{\gamma}$	10^{-4}	150	0.6
Emittance, ϵ_x/ϵ_y	μm · rad	0.6/0.01	1.2/1.2
Bunch length, l_b	μm	35	23
Peak current, I	kA	2.7	3.4

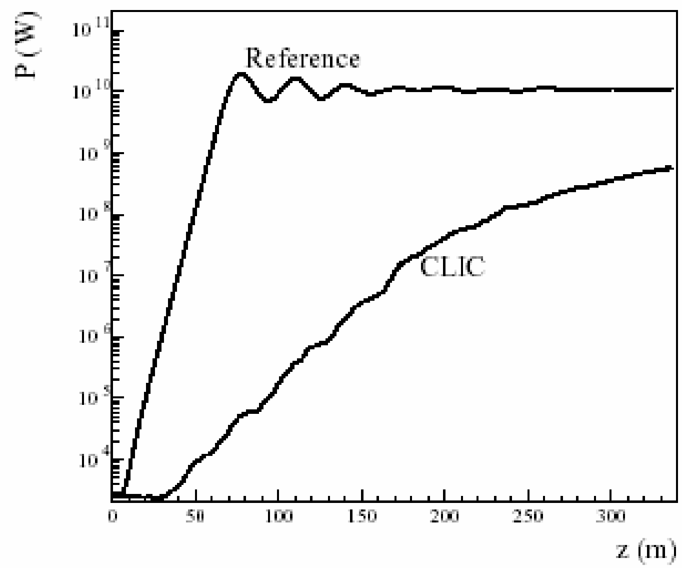


Figure 2: Evolution of the radiation power along the undulator for CLIC, compared to the reference case (LCLS).

M. Brandin et al, CLIC Note 543 (2002)

RF Photoinjctor For Storage Ring

There more than 70 storage rings operating around the world, and more than 10 in the various stages of development:

50 MeV – 2 GeV linac injector using either thermionic gun (including thermionic RF gun).

1. For existing ring: life time ~ 8 hours
2. New ring: top-off operation

Photo injector will improve the performance and new capabilities (FEL (SASE,HGHG), Coherent THz, Femto-second X-ray).

Why Photoinjector for Storage Ring?

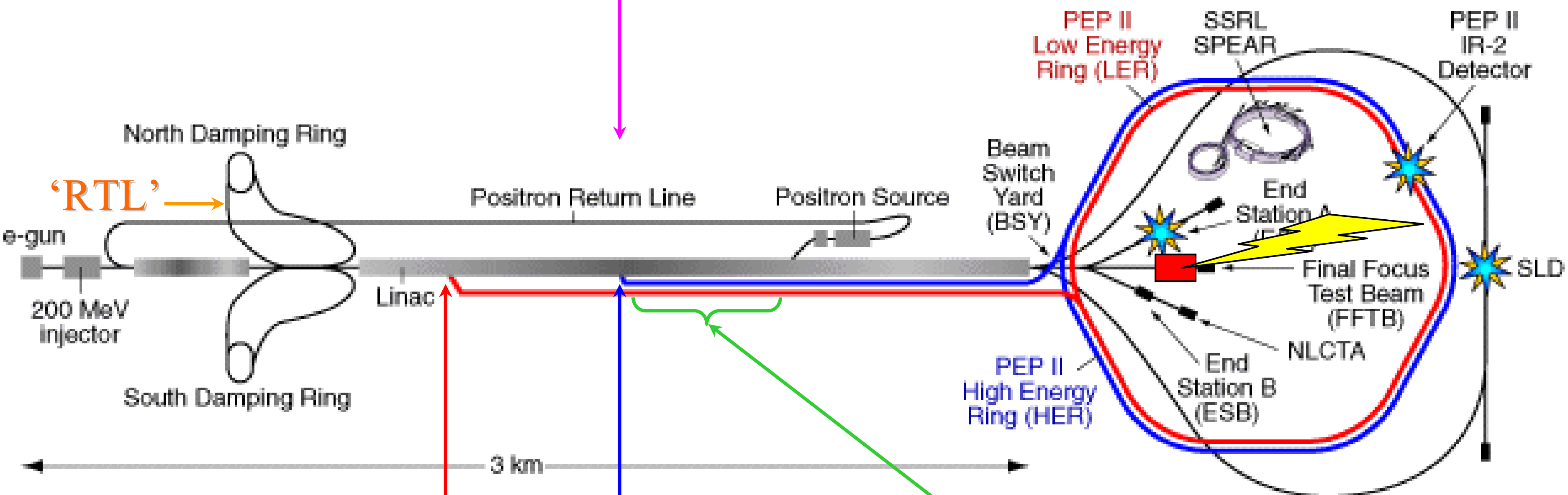
Benefit:

1. Reduce radiation hazard.
2. More efficient injection.
3. Better Control
4. New science , new user communities

Concern:

1. Stability and reliability?
2. Cost?

chicane located *after*
PEP-II extraction



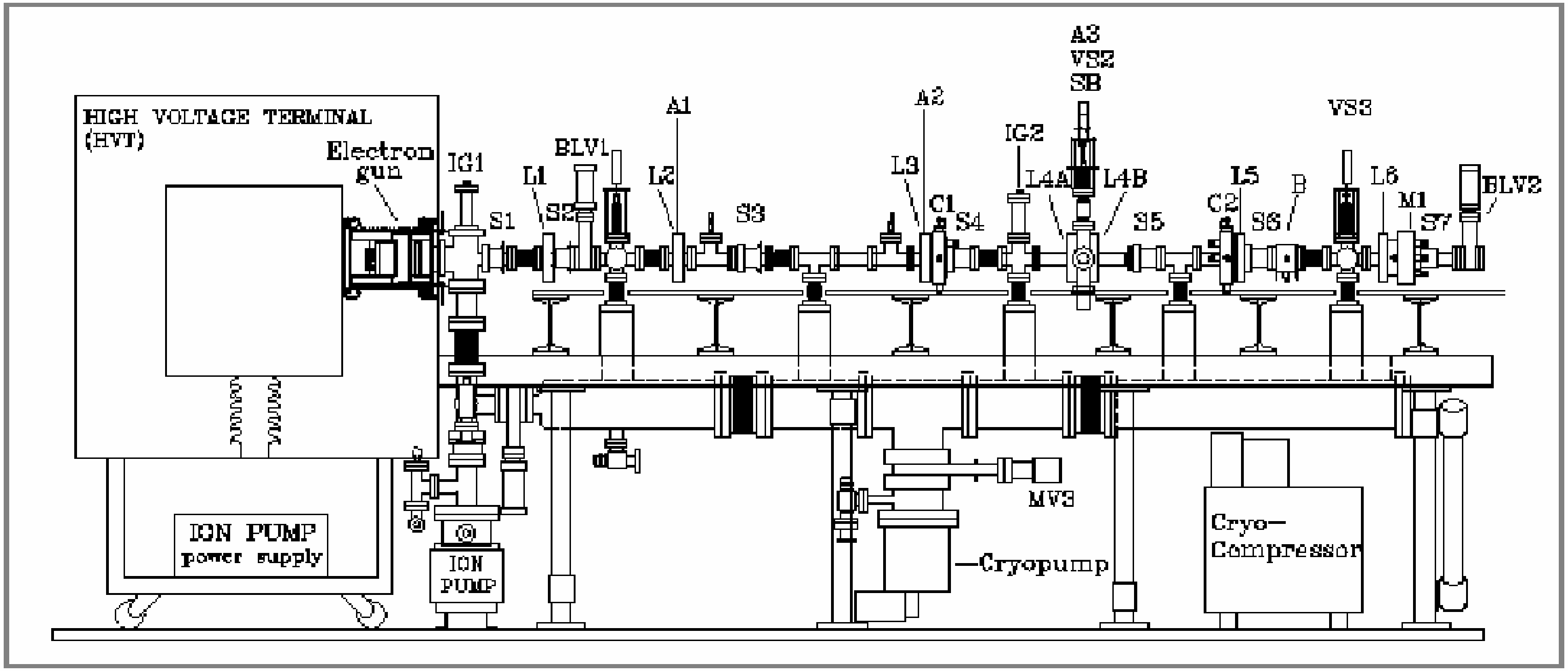
9 GeV e^- pulsed extraction

'scavenger' bunch (e+ production) passes through chicane

3 GeV e^+ pulsed extraction

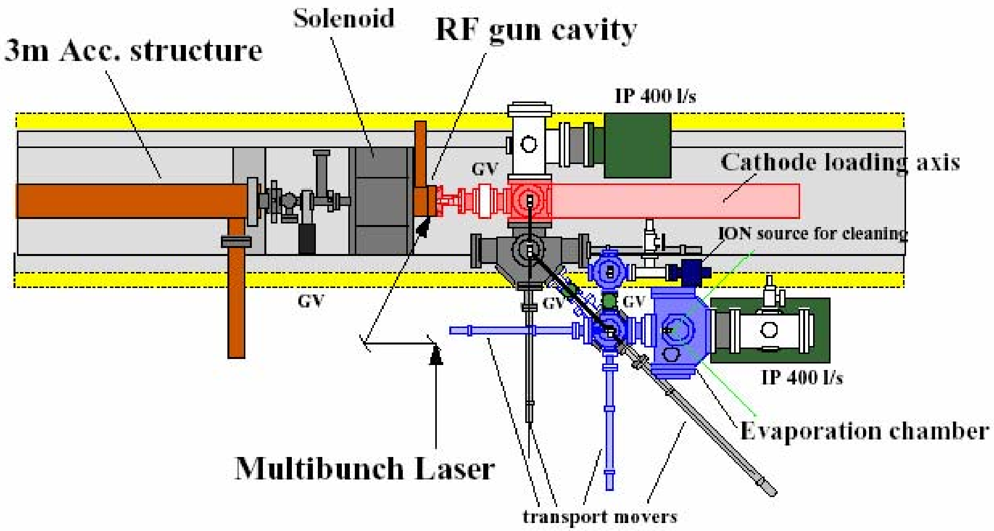
Routine interleaving of multiple energy beams on a pulse by pulse basis

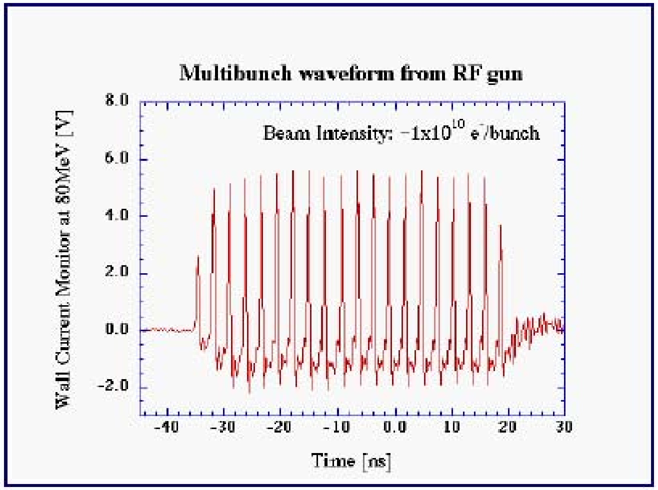
- Thermionic Electron Gun [100keV (β=v/c=0.56)]
- Chopper - Buncher System
- Capture Section (β-graded) [1.5 MeV (β=0.95)]
- Pre-Accelerator (few MeV, β~1)
- Booster (4 m long → 10.5 MeV)



Multibunch photo-cathode RF gun in ATF

for better Multibunch injection into DR





BNL type RF gun + CsTe cathode

Load-lock system for CsTe

357MHz , 266nm, 20 bunch Laser

at 80MeV
- *Intensity : ~1E10 /bunch*
- *bunch length : ~7ps*
- *Normalized emittance : 28E-6 m.rad*

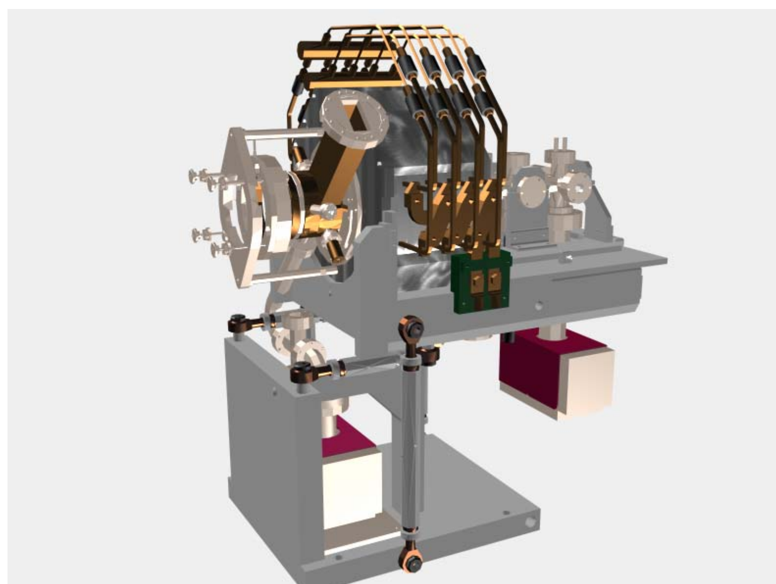
Oct. 2 2002

The timing of the meeting was very good: the ATF crew was then in the final stages of a wholesale replacement of their multibunch injector and we anticipated significantly improved intensity performance. After a short one year preparation time, and in the space of a few weeks, the group removed the old thermionic gun and buncher system and replaced it with a much better performing 1.5 cell S-band RF photocathode gun – with a multipulse laser and load-lock cathode processing system. Following installation in September, commissioning went very smoothly and operation in November was well beyond the best achieved with the old gun system. Typical beam intensity is now 1.2x 10^{10} particles per bunch in single bunch mode with up to 70 mA stored in the ring in three trains of twenty bunches each in multibunch mode. The new gun system provides a very flat intensity distribution along the train. The pulse-to-pulse stability is exceptional, so much so that the group has now automated single shot injection to effectively make the damping ring (nominally with a very short lifetime device) into an infinite lifetime storage ring. This enables careful 'stored beam' studies, such as emittance tuning and beam-based alignment (BBA).

MARC ROSS of SLAC for NLC Jan, 2003 News Letter

Phtoinjector
for T^2 (Table Top or 2 tables) system

- Beam Physics
- Soft X-ray Source
- Coherent THz source
- Pulse Radiolysis



Femto-second Electron Diffraction

Brookhaven Science Associates
U.S. Department of Energy

BROOKHAVEN NATIONAL LABORATORY

Ultrafast Temporal Resolution

- Picosecond Timescale:
  - Structures of Short-Lived Species
  - Kinetic Processes
  - Rotational Coherences
- Femtosecond Timescale:
  - Coherent Processes (Transition State)
  - Potential Energy Surfaces

$$\tau = \frac{\hbar}{kT} \approx \quad 100\, fs$$

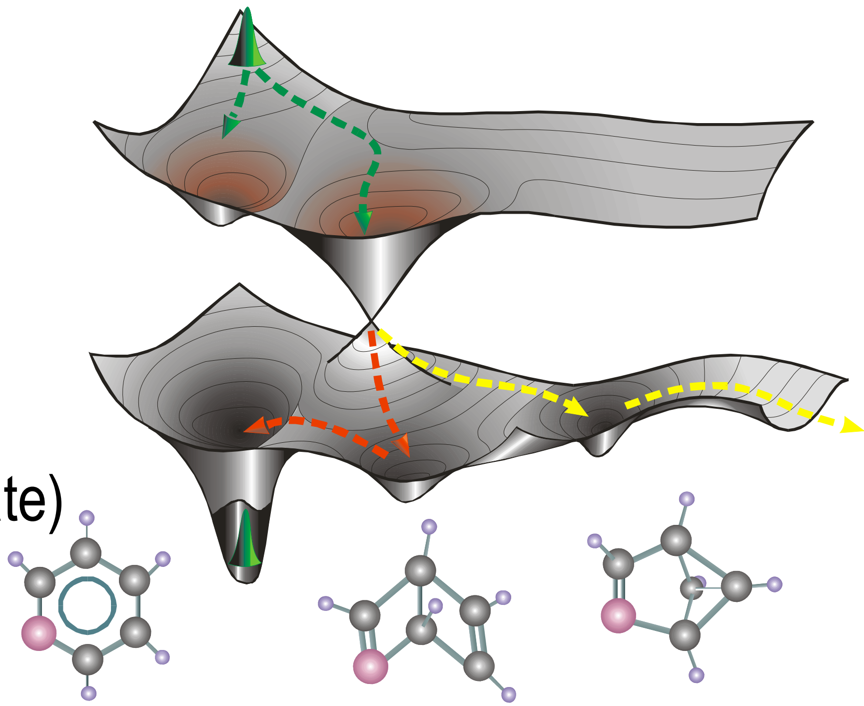
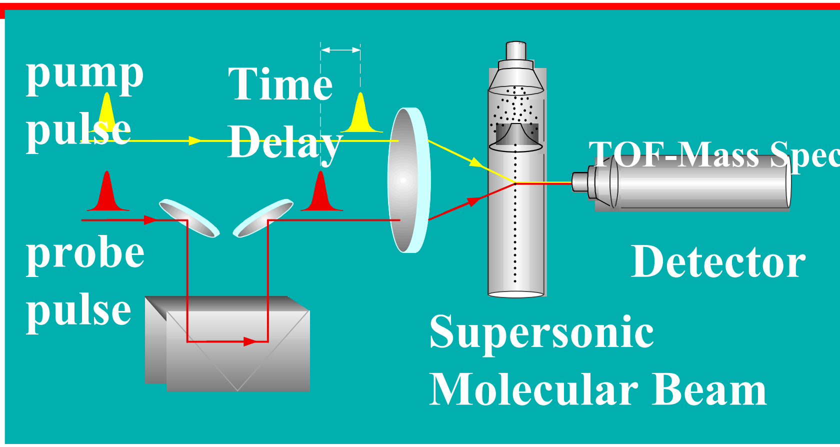
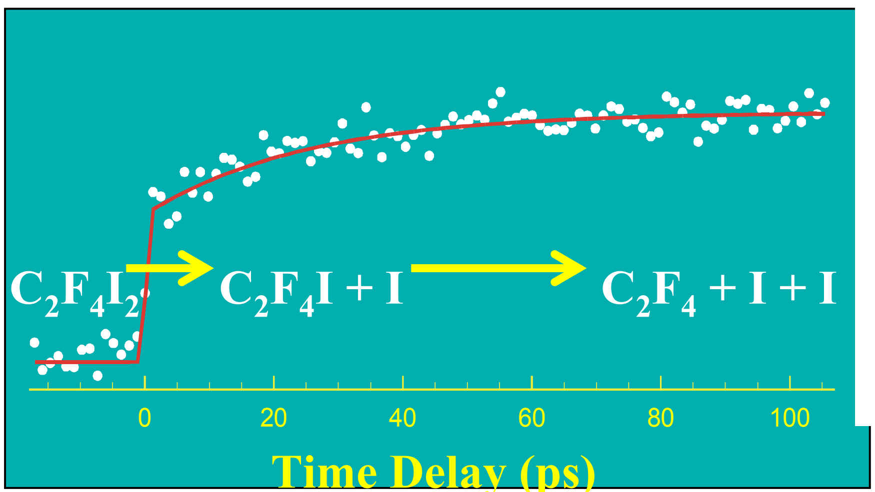


Figure from Zhong et al.
Chem. Phys. Lett. 298 (1998) 129-140

Femtosecond Spectroscopy





Electron Microscope

In biology... A Nobel prize has been suggested by many scientists for this work... . JCHS. NTEAM 7/18/0

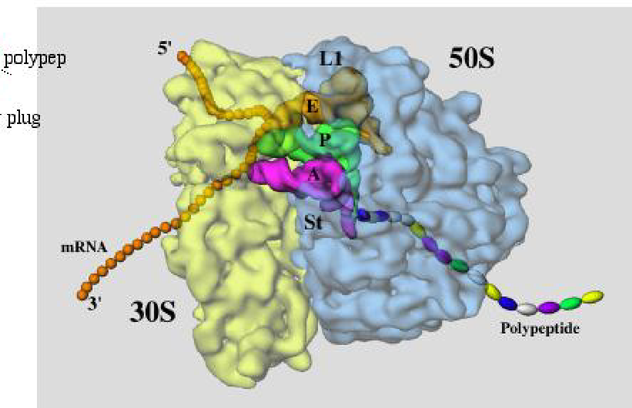
More contrast !

Protein synthesis ("Life itself") in the Ribosome: The ribosome structure determined to 1nm resolution by TEM (tomographic cryomicroscopy). J.Frank et al.

A - T
C - G word (codon) mRNA tRNA polypep
T - A
G - C Adaptor plug
T - A
A - T

DNA

4 nucleic acids
2 (4) base pairs
mRNA reads one side only
3 pairs per word (per amino)
$4^3 = 64$ possibilities per amino
20 amino acids.
n words per gene (protein)



Ribosome width 25nm (Cell,100, p.537 (2000))

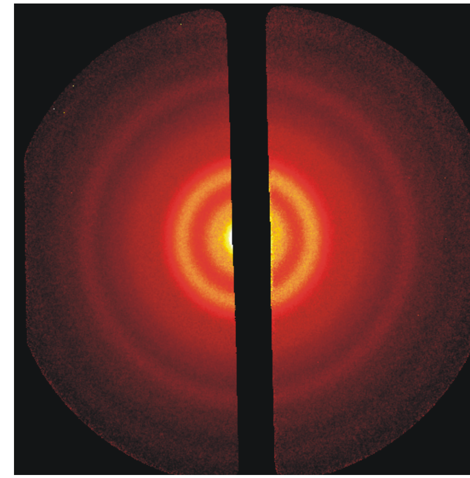
Experimental e-coli ribsome reconstuction from TEM images of non-crystallised mols in ice. mRNA bring 3-bit codons from DNA. tRNA "adaptors" (E,P,A) have plugs at one end to mRNA codon, at the other to an amino acid, which is added to the polypeptide chain as the ribo runs along the mRNA. Chain will fold to become a new protein. (Simplified).

fs+structure =femtosecond electron diffraction

Why Electron Diffraction?

Both electron and X-ray have been used for structure determination, electron diffraction has the following advantages:

- **Charge distribution**
- **Larger cross section ($\sim 10^6$).**
- **Surface structure**
- **Gas sample**
- **Compact.**



X-ray diffraction: $$L_x = \sum_i e^{i\mathbf{s}\mathbf{r}_i}$$

Electron diffraction: $$L_e = \sum_j Z_j e^{i\mathbf{s}\mathbf{R}_j} - \sum_i e^{i\mathbf{s}\mathbf{r}_i}$$

UED-3 Apparatus (CalTeC)

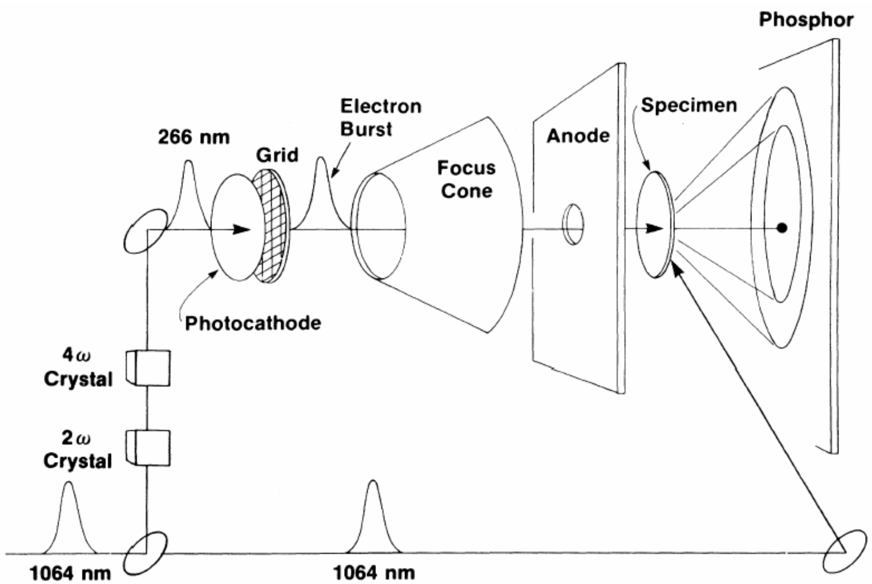
Picosecond electron diffraction

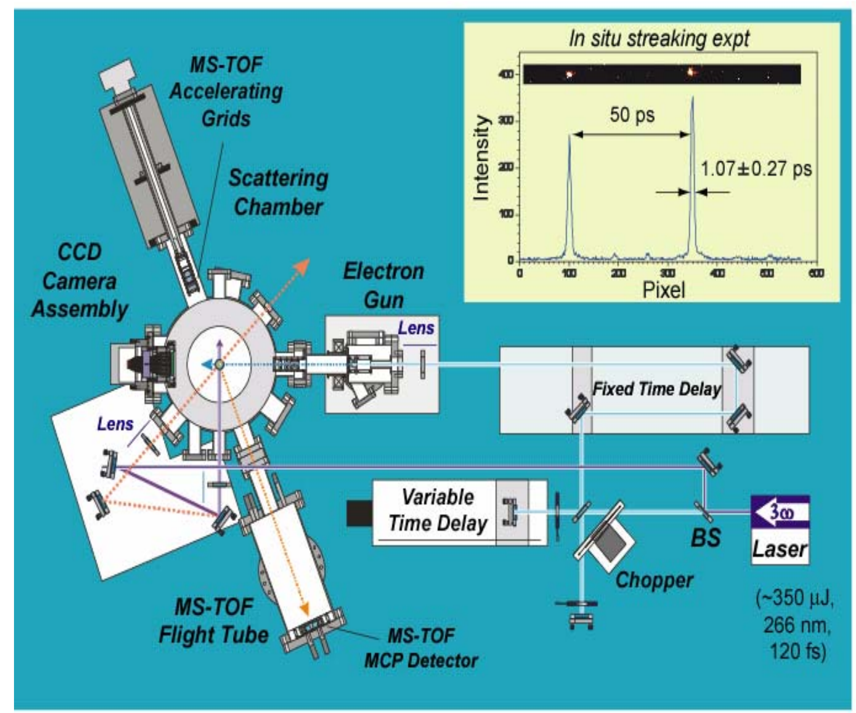
Gerard Mourou and Steve Williamson
Laboratory for Laser Energetics, University of Rochester, 250 East River Road, Rochester, New York 14623

(Received 8 March 1982; accepted for publication 22 April 1982)

A picosecond photoelectron pulse generated by a streak camera has been used to probe a thin film of aluminum producing a diffraction pattern representative of its lattice structure. Because this photoelectron pulse is in picosecond synchronism with the optical pulse, this technique will make possible the investigation of structural phase transitions in the picosecond time domain.

PACS numbers: 06.60.Jn, 35.80. + s, 41.80.Dd, 61.14.Fe





- Typically use ~3-5 ps e- pulses (25,000 e- per pulse)
- Overall time resolution: ~5 ps

Advance largely due to laser

Total Time Resolution

- the temporal pulsewidth of laser beam (Δt_{laser})
- the temporal pulsewidth of electron beam (Δt_e)
- the velocity-mismatch (Δt_{VM})
- Timing jitter between the laser and electron beam (Δt_{jitt})

$$(\Delta t)^2 = (\Delta t_{laser})^2 + (\Delta t_e)^2 + (\Delta t_{VM})^2 + (\Delta t_{jitt})^2 .$$

Δt_{laser} = 10 fs to 100 fs,

$\Delta t_e \approx$ 5 ps

$\Delta t_{VM} \approx$ *1.5 ps (40 KeV), < 100fs (>1.5 MeV).*

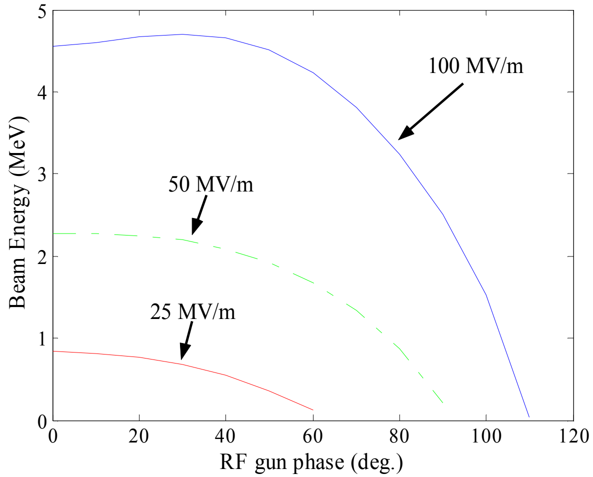
Δt *< 100 fs*

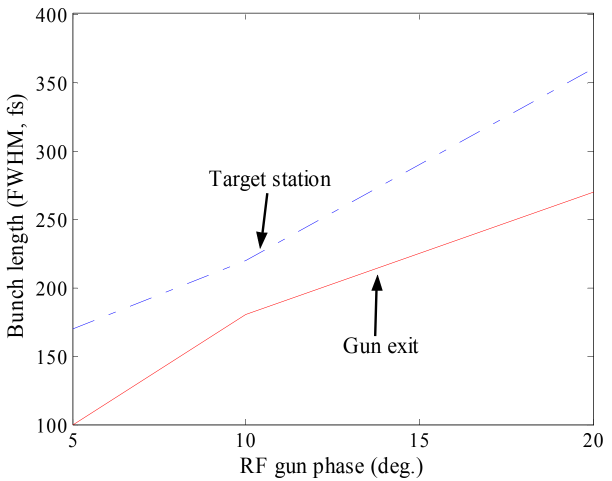
To realize fs electron diffraction, Δt_e <100fs

Why Photocathode RF gun for Femto-second Electron Diffraction

- Higher energy ⇒ Smaller space charge effect, shorter bunches.
- Bright Beam – at least one order magnitude brighter than thermionic source.
- Flexibility due by controlling the laser and RF gun phase
- Cheaper than MV electron microscope

Femto-second Electron beam



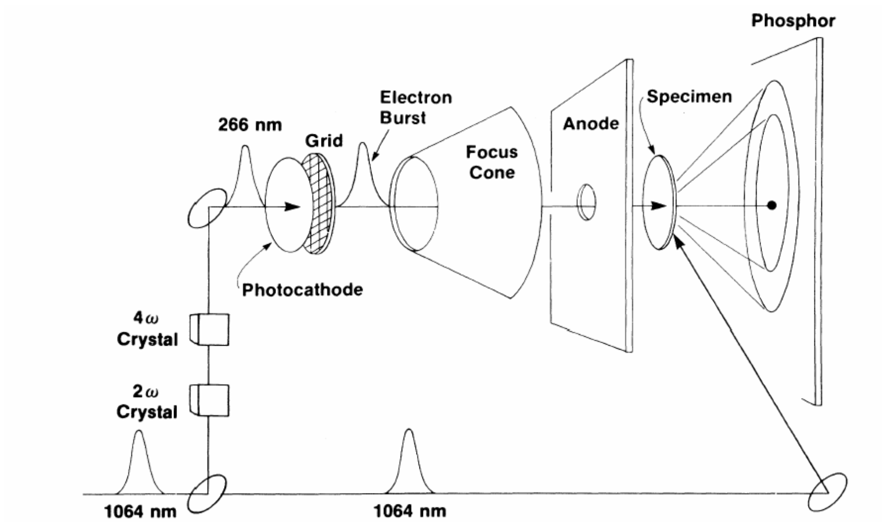


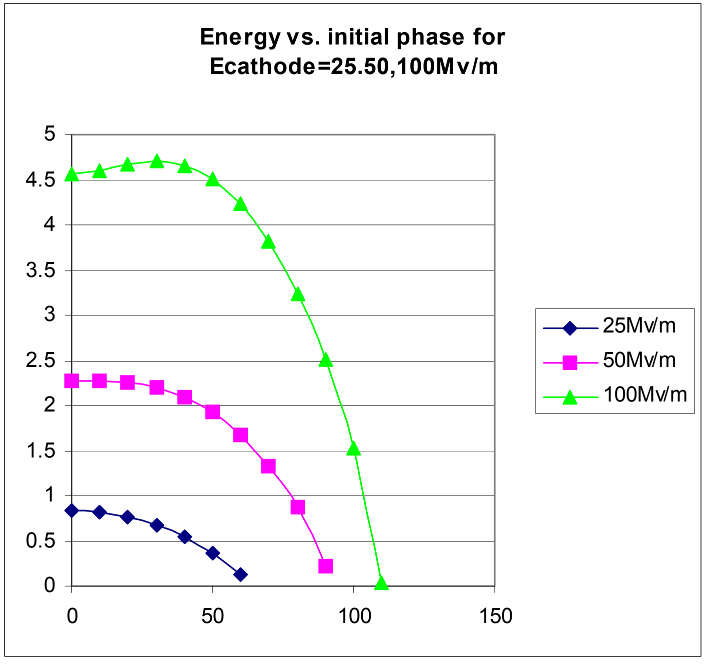
Emittance: 1 – 0.1 mm-mrad for electron 10^6 – 10^5 (at least factor of ten or more than DC)

Pulse length – 200 – 100 fs (factor 20 to 50 shorter)

Energy spread: 0.01 to 0.1%

Possible Issues - Timing Jitter

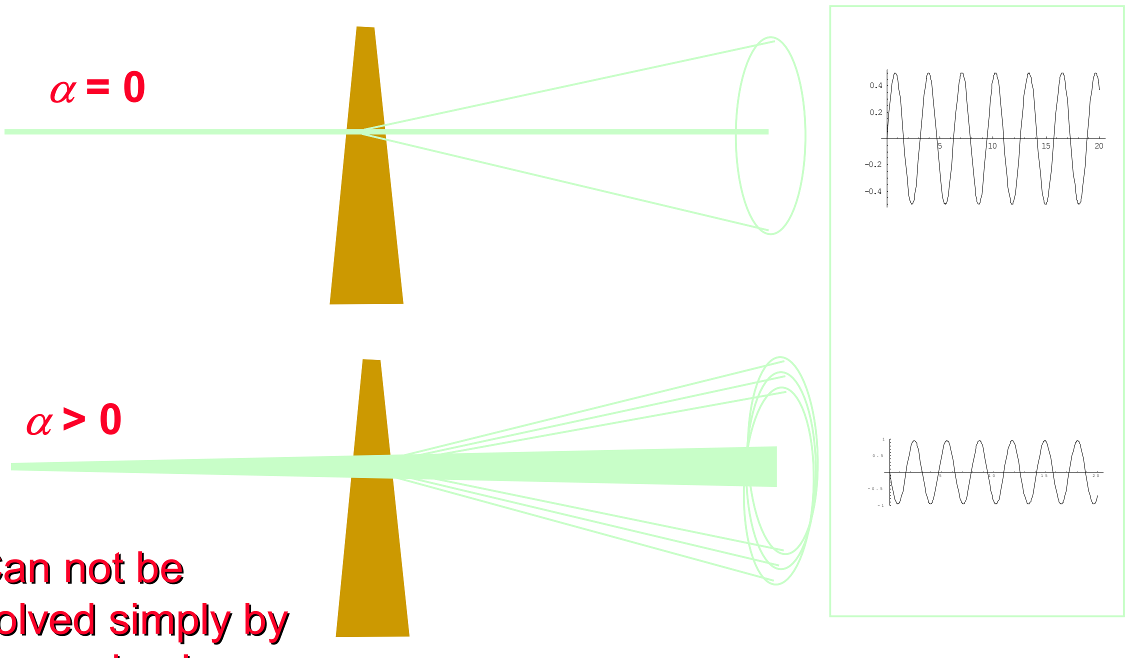




$$\delta t = \frac{L}{c\gamma^2}\frac{\Delta p}{P} \prec 100\,fs$$

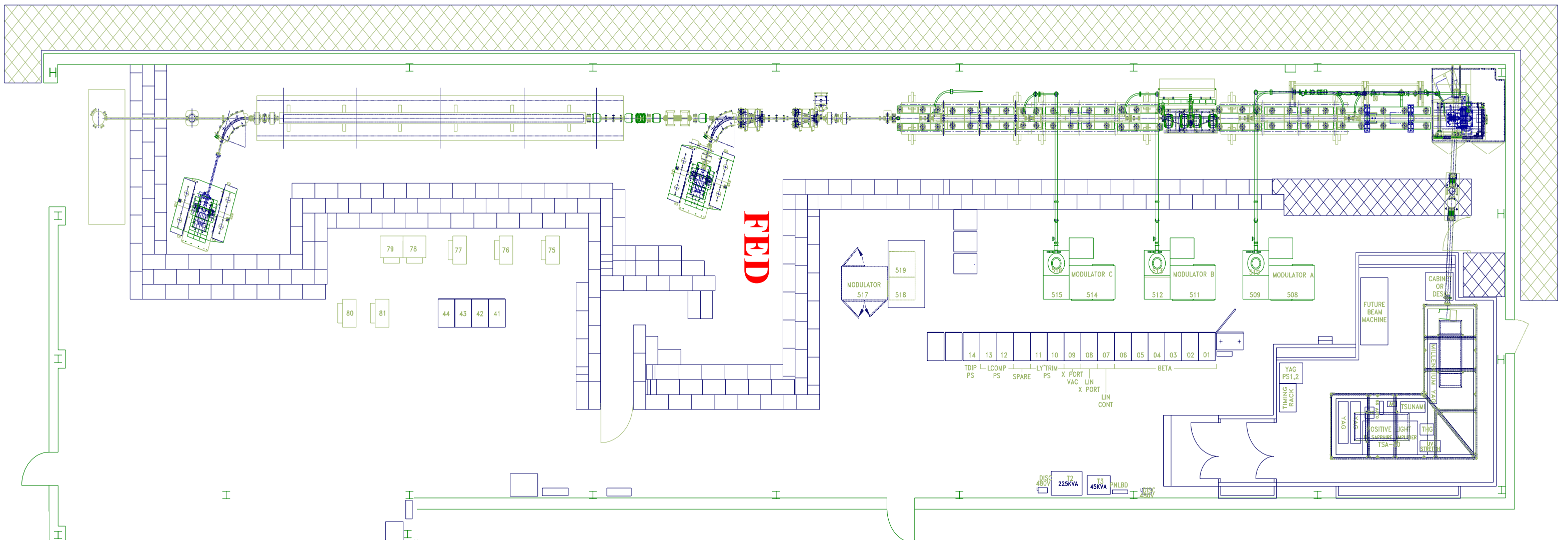
Possible Issues – spot size, energy and beam divergence

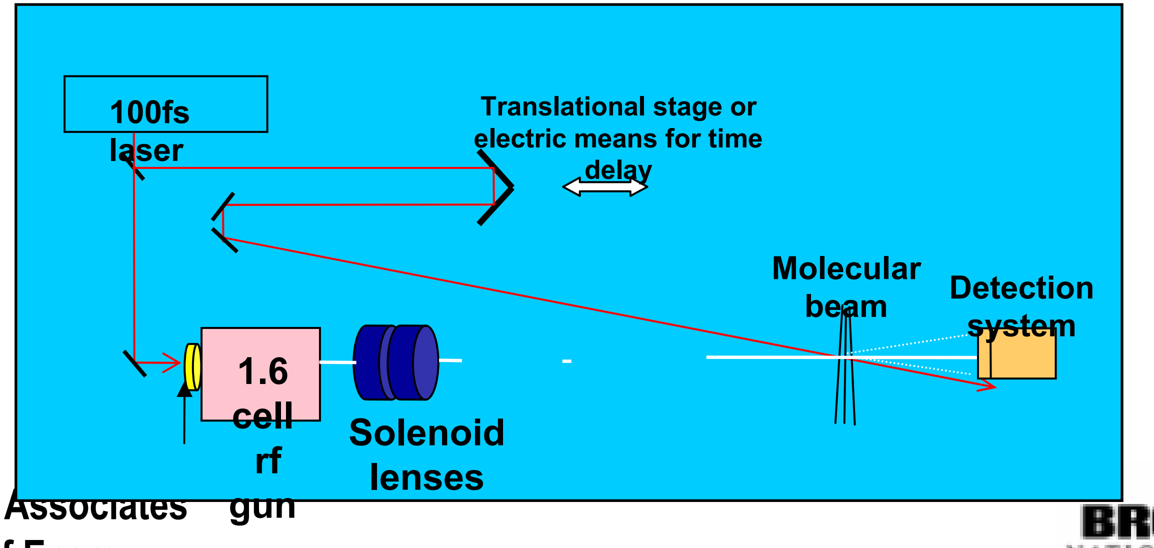
Lateral Incoherence
Due to finite e-beam divergence



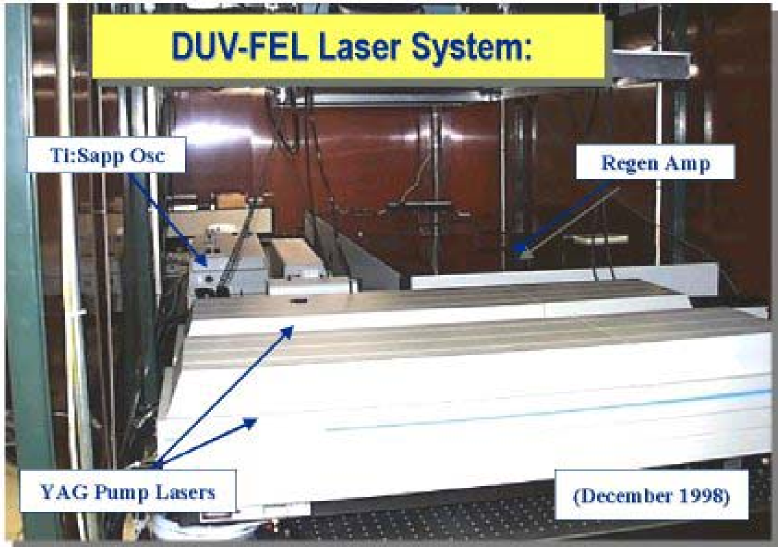
Can not be solved simply by increasing L.

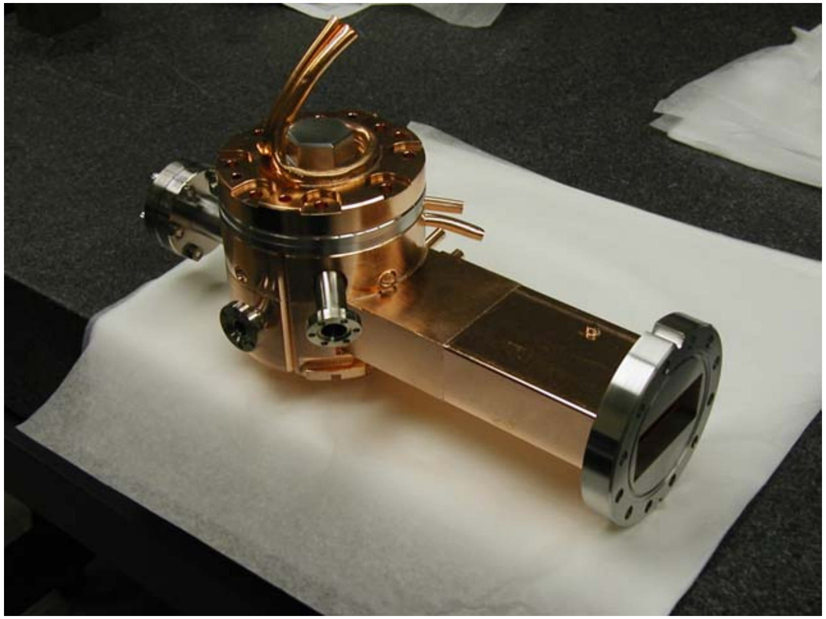
Femtosecond electron diffraction at the BNL DUV-FEL facility





DUV-FEL Equipments





Proof of Principle Experiments

To demonstrate the feasibility femtosecond electron diffraction using photocathode RF gun, we propose

- Thin metal film (e.g. Al)
- Gas sample (e.g CCl_4 or CF_3I)
- Single crystal

First observe diffraction pattern, then develop time-resolved diffraction.

Challenges in High-Brightness R&D

Improvement of Present electron sources:

- Stability and Reliability
- Timing jitter and its control
- Better theoretical Understading
- Thermal Emittance – fundamental limit and importance of beam instrumentation
- Beam based laser optimization.

Next Generation Electron source:

1. CW injector –DC, RF, SRF, what should be? 3H - Heat, Heat and Heat;
2. High-Brightness Beam pulse source – 6-D optimization;

Higher frequency gun, pulse DC gun, laser plasma source, longitudinal emittance compensation

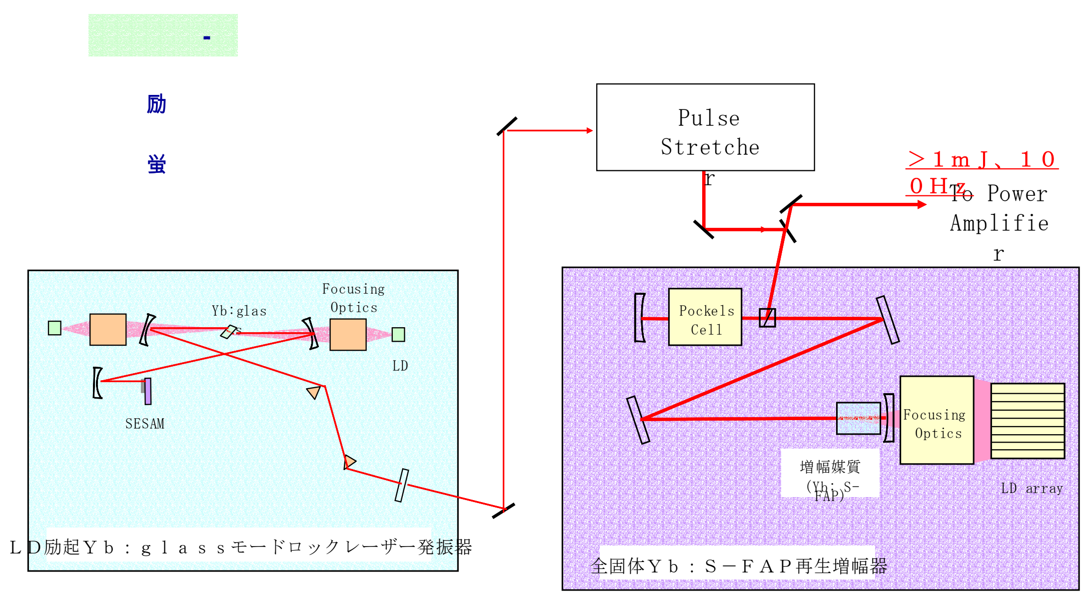
Stability and Reliability

Laser system – technology and environment

Photocathode – Life time and uniformity

RF gun – breakdown and field stability

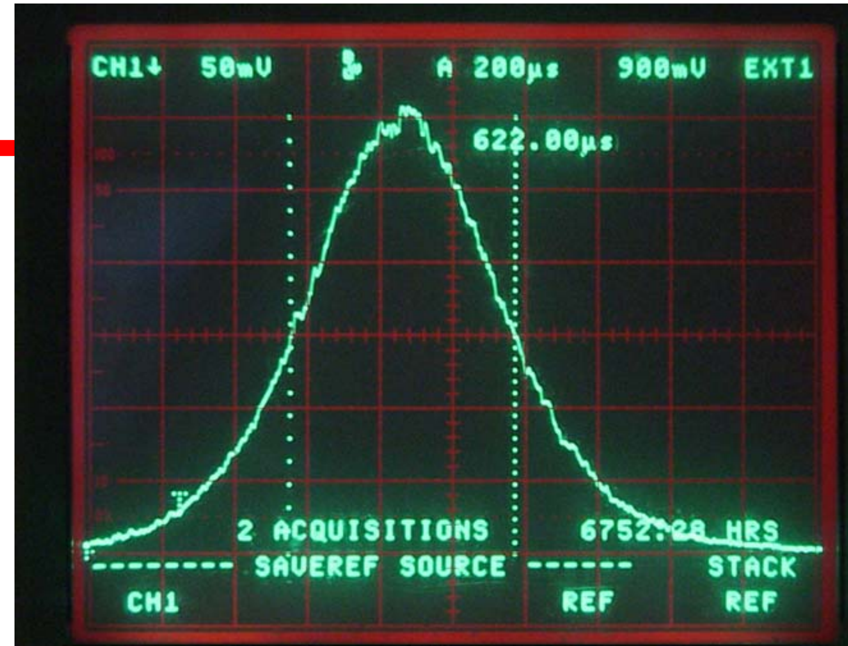
ＬＤ直接励起Ｙｂ：Ｓ－ＦＡＰ高出力再生増幅器

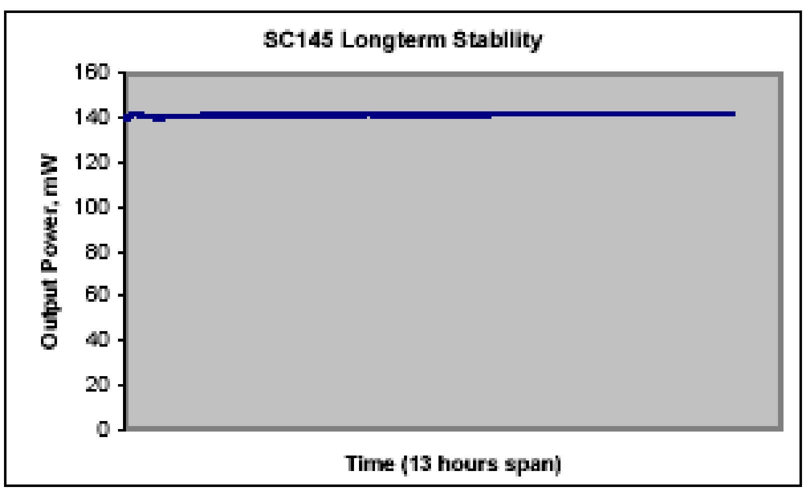


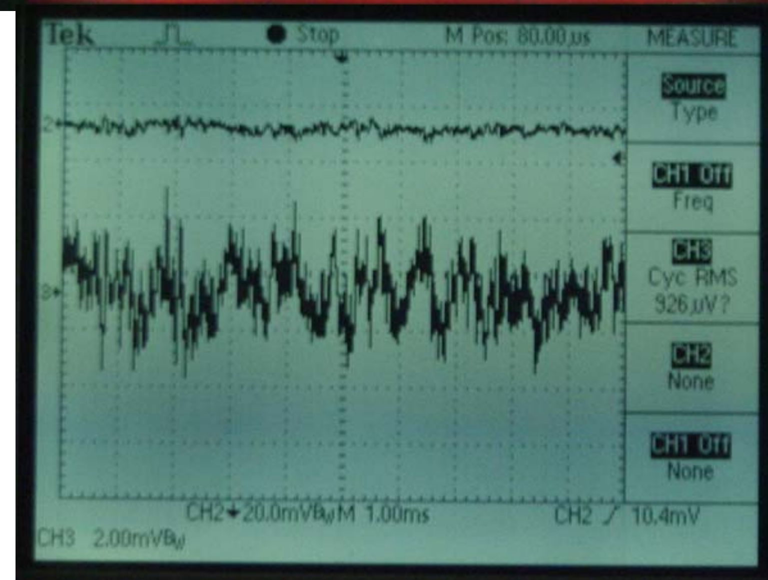
200 fs Yb:glass oscillator

λ(um)	P (mW)	τ(FWHM, fs)
1.051	136	150
1.047	117	177

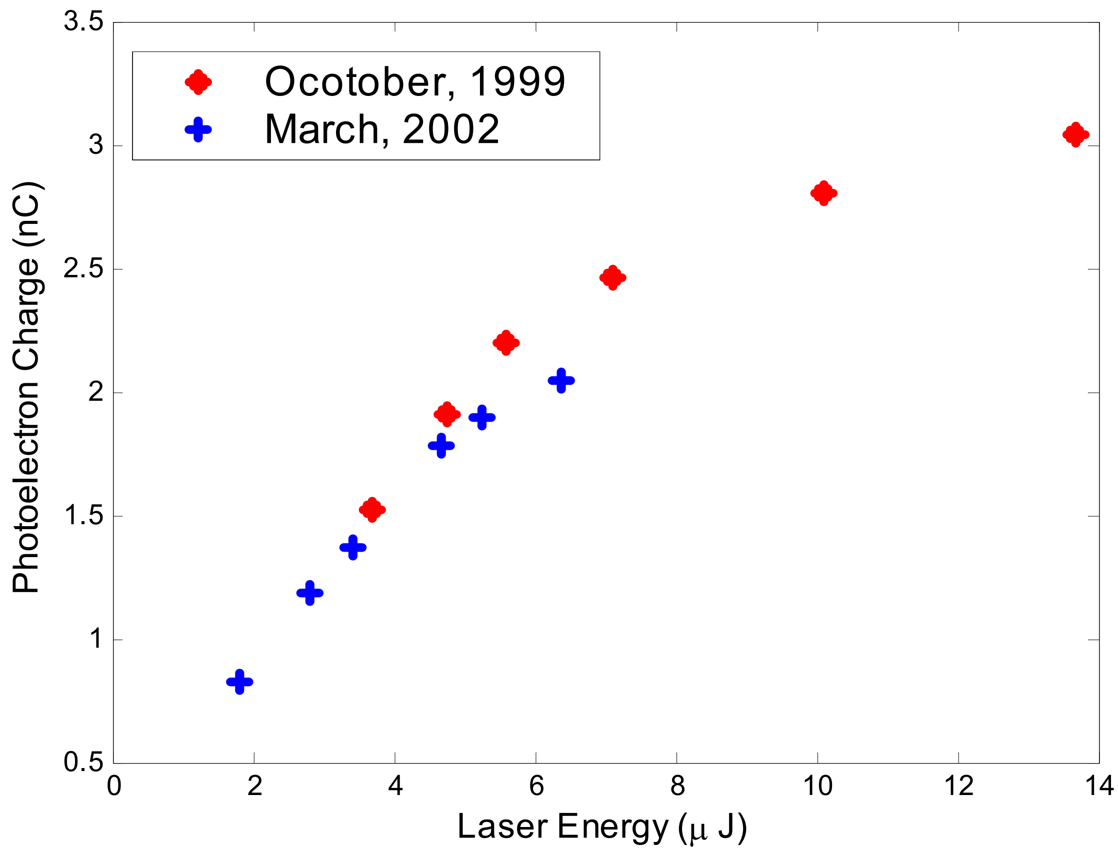
Timing jitter: < 200fs (detector limited)



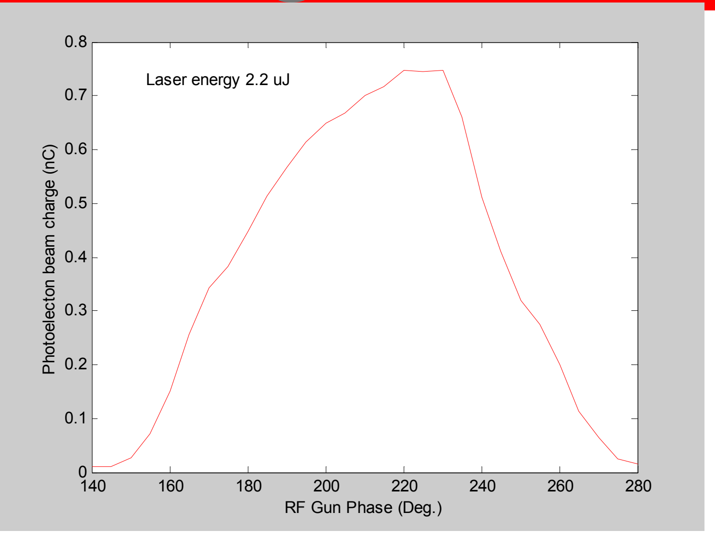




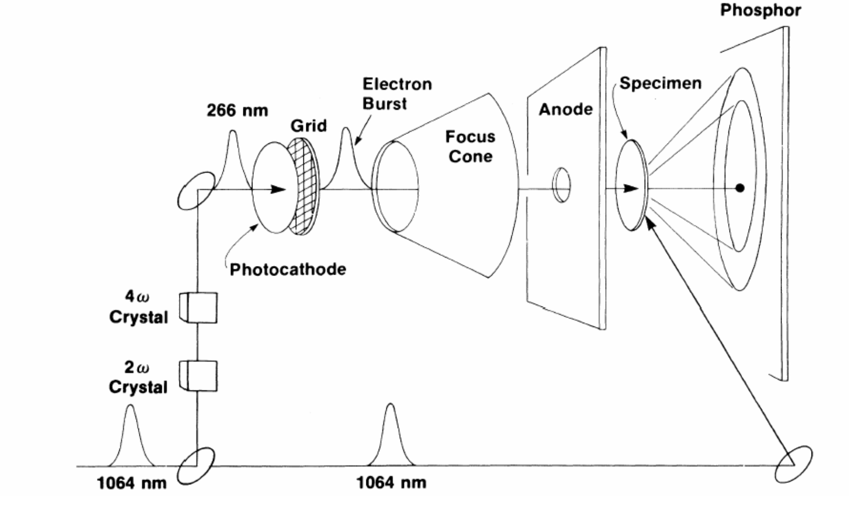
Quantum Efficiency Measurements

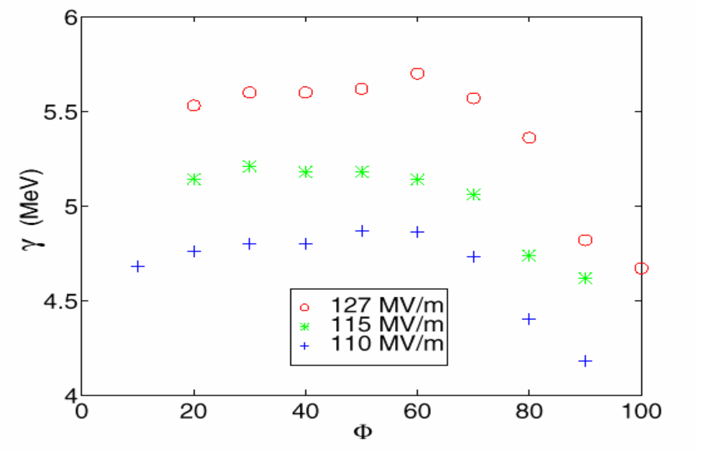


Timing Jitter



$$\delta t = \frac{L}{c\gamma^2}\frac{\Delta p}{P}$$





Brookhaven Science Associates
U.S. Department of Energy

BROOKHAVEN NATIONAL LABORATORY

RF Photoinjector Theory

- Are all emittance uncorrelated?

$$\varepsilon = \sqrt{\varepsilon^2{}_{ther} + \varepsilon^2{}_{rf} + \varepsilon^2{}_{sc}}$$

K-J.'s theory:

$$\varepsilon_{nx}^{sc} = \frac{\pi}{4}\frac{1}{\alpha k}\frac{1}{\sin\phi_0}\frac{I}{I_A}\mu_x(A)$$

Emittnace growth (Rieser):

$$\frac{\varepsilon_{nf}}{\varepsilon_{ni}} = \left[1 + \frac{N r_c \widetilde{x}}{15\sqrt{5}\gamma_0 \varepsilon_{ni}^2}\frac{U}{w_0}\right]^{1/2}$$

Typical operating parameters

** determined in the RF gun with a picosecond Nd:YAG laser **

(1) Laser injection phase in RF gun : 30°

⇒ *for a maximum energy with low emittance*

(2) Linac RF phase : 47°

⇒ *for a minimum energy spread*

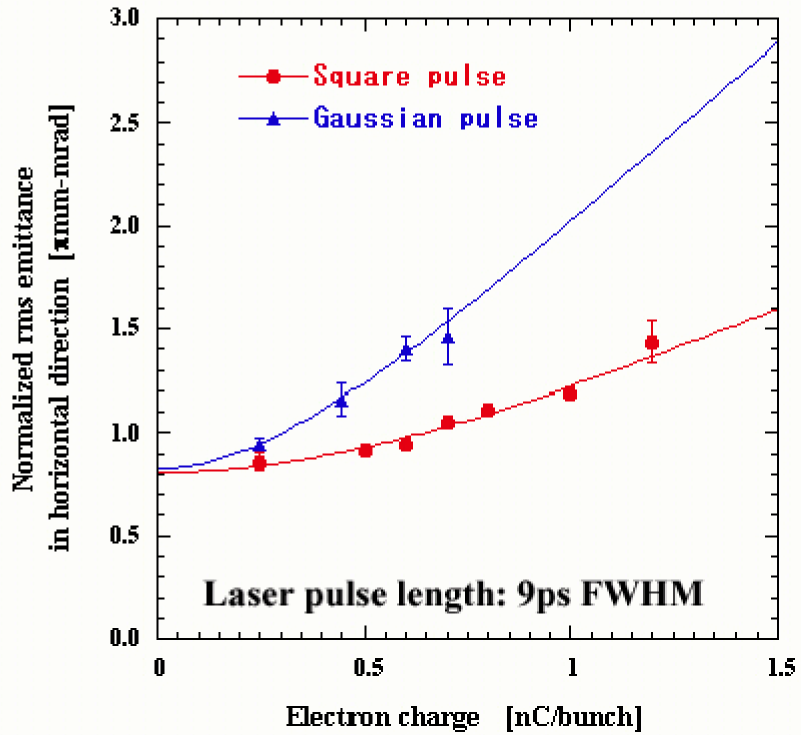
(3) Solenoid magnetic field : 1.57kG

⇒ *For an optimal emittance compensation at 0.6nC, 14MeV*

FESTA

Sumitomo Heavy Industries, Ltd.

Emittance measurements for gaussian and square laser pulse shapes



$$\varepsilon_n = \sqrt{(a' \cdot Q)^2 + b'^2}$$

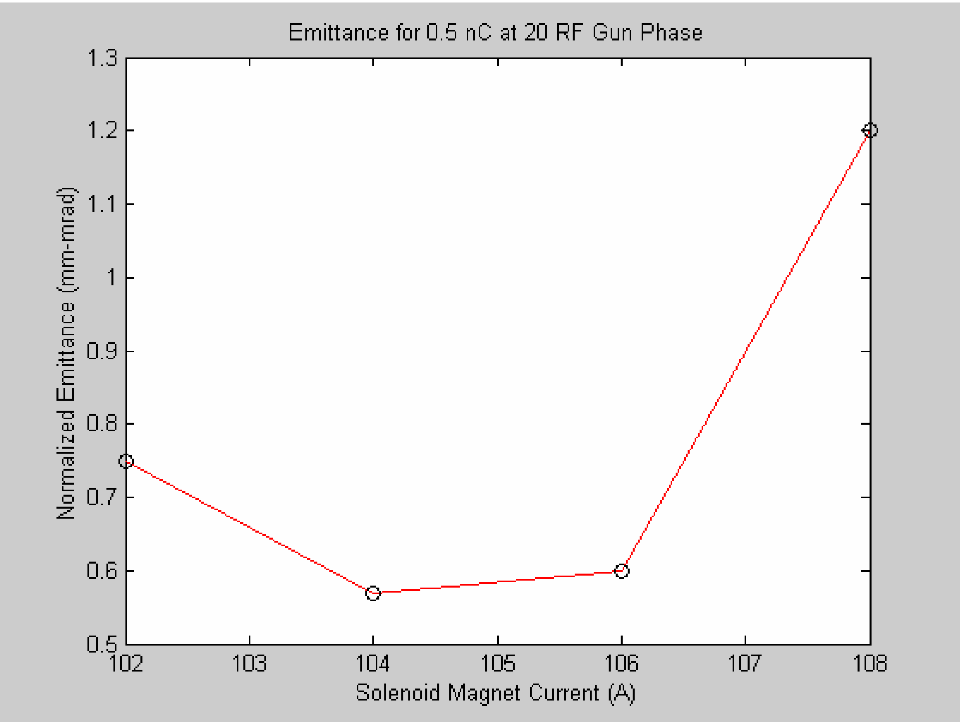
	a'	$b' = \sqrt{\varepsilon_{rf}^2 + \varepsilon_{th}^2}$
	πmm-mrad/nC	πmm-mrad
Gaussian(9ps)	1.85±0.13	0.83±0.05
Square (9ps)	0.92±0.05	0.81±0.03

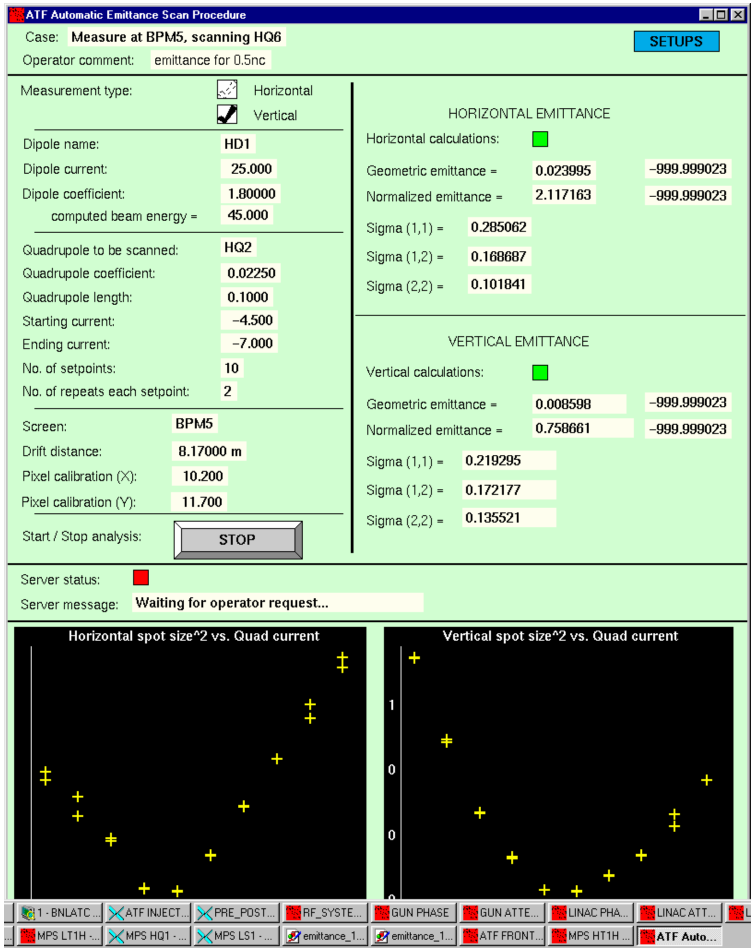
The reduction of the linear space-charge emittance for the square pulse shape: ~50%.

FESTA

Sumitomo Heavy Industries, Ltd.

Emittance Optimization





Thermal Emittance

Electrons are emitted with a kinetic energy E_k

$$\varepsilon_{th} = \frac{r}{2}\sqrt{\frac{E_k}{m_e c^2}}$$

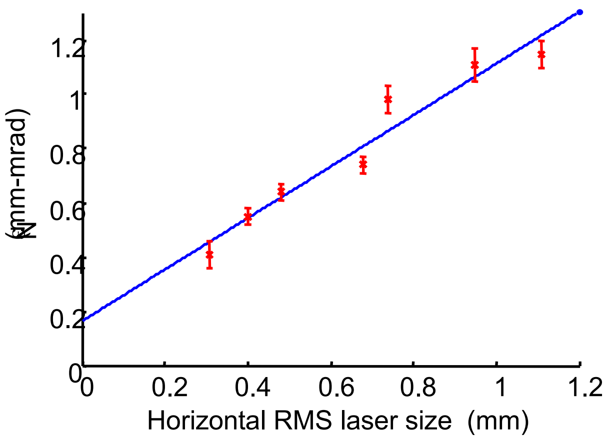
laser spot assumed uniform with radius r

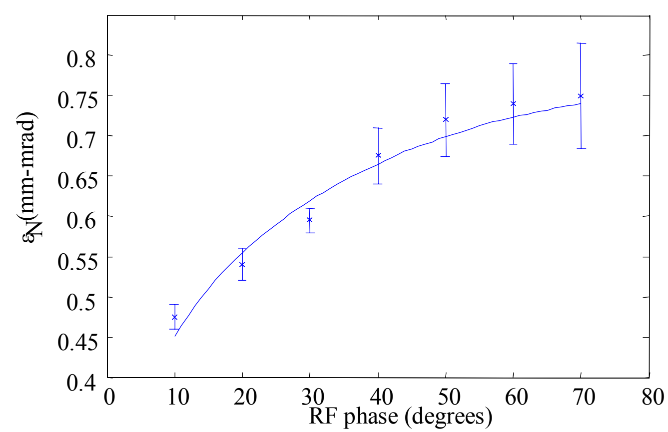
$$E_k = h\nu - \Delta + \alpha\sqrt{\beta_{RF} E_{RF} \sin\theta_{RF}}$$

$$\Delta = \Phi \text{, or } E_G + E_A$$

Example of measurement for Cu-cathode

(Courtesy of W. Graves)

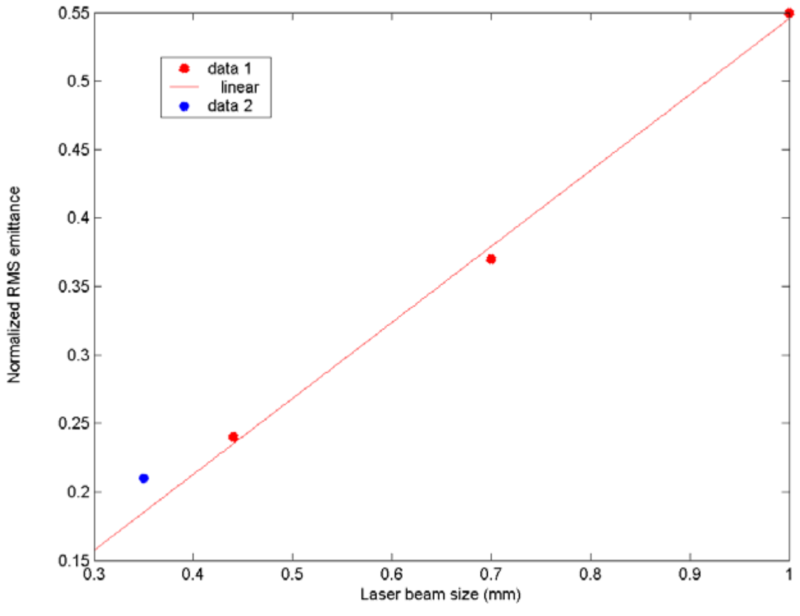




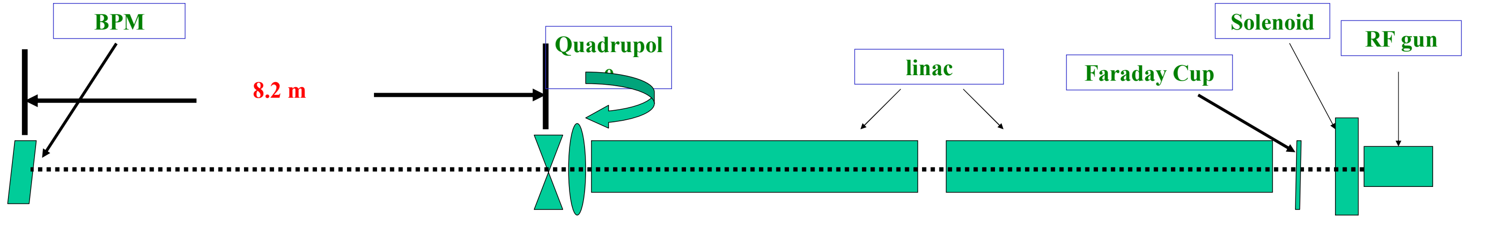
Linear fit gives E_k=0.43 eV

Nonlinear fit gives β_{rf}=3.1+/-0.5, Φ_{cu}=4.73+/-0.04 eV, and E_k=0.40 eV

Mg thermal Emittance



$$\Delta\varepsilon_{res} = \frac{\sigma_{res}\sigma_{quad}}{L}, \qquad where\ \sigma_{res}\ is\ a\ const.$$



Why 1 nC ?
World wide FEL Saturation Performance

RESEARCH ARTICLES

Exponential Gain and Saturation of a Self-Amplified Spontaneous Emission Free-Electron Laser

S. V. Milton,[1*] E. Gluskin,[1] N. D. Arnold,[1] C. Benson,[1] W. Berg,[1] S. G. Biedron,[1,2] M. Borland,[1] Y.-C. Chae,[1] R. J. Dejus,[1] P. K. Den Hartog,[1] B. Deriy,[1] M. Erdmann,[1] Y. I. Eidelman,[1] M. W. Hahne,[1] Z. Huang,[1] K.-J. Kim,[1] J. W. Lewellen,[1] Y. Li,[1] A. H. Lumpkin,[1] O. Makarov,[1] E. R. Moog,[1] A. Nassiri,[1] V. Sajaev,[1] R. Soliday,[1] B. J. Tieman,[1] E. M. Trakhtenberg,[1] G. Travish,[1] I. B. Vasserman,[1] N. A. Vinokurov,[3] X. J. Wang, G. Wiemerslage,[1] B. X. Yang[1]

VOLUME 88, NUMBER 20 PHYSICAL REVIEW LETTERS 20 MAY 2002

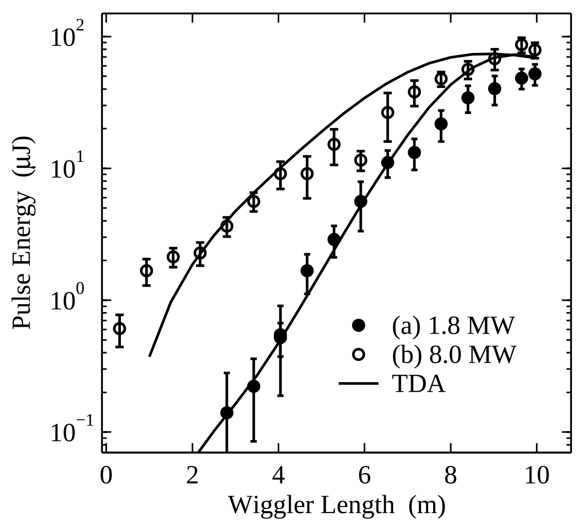
Experimental Characterization of Nonlinear Harmonic Radiation from a Visible Self-Amplified Spontaneous Emission Free-Electron Laser at Saturation

A. Tremaine,[1] X. J. Wang,[2] M. Babzien,[2] I. Ben-Zvi,[2] M. Cornacchia,[3] H.-D. Nuhn,[3] R. Malone,[2] A. Murokh,[1] C. Pellegrini,[1] S. Reiche,[1] J. Rosenzweig,[1] and V. Yakimenko[2]
[1]*Department of Physics & Astronomy, UCLA, Los Angeles, California 90095*
[2]*Accelerator Test Facility, NSLS, BNL, Upton, New York 11973*
[3]*SSRL, SLAC, Stanford, California 94309*
(Received 20 September 2001; published 3 May 2002)

VOLUME 88, NUMBER 10 PHYSICAL REVIEW LETTERS 11 MARCH 2002

Generation of GW Radiation Pulses from a VUV Free-Electron Laser Operating in the Femtosecond Regime

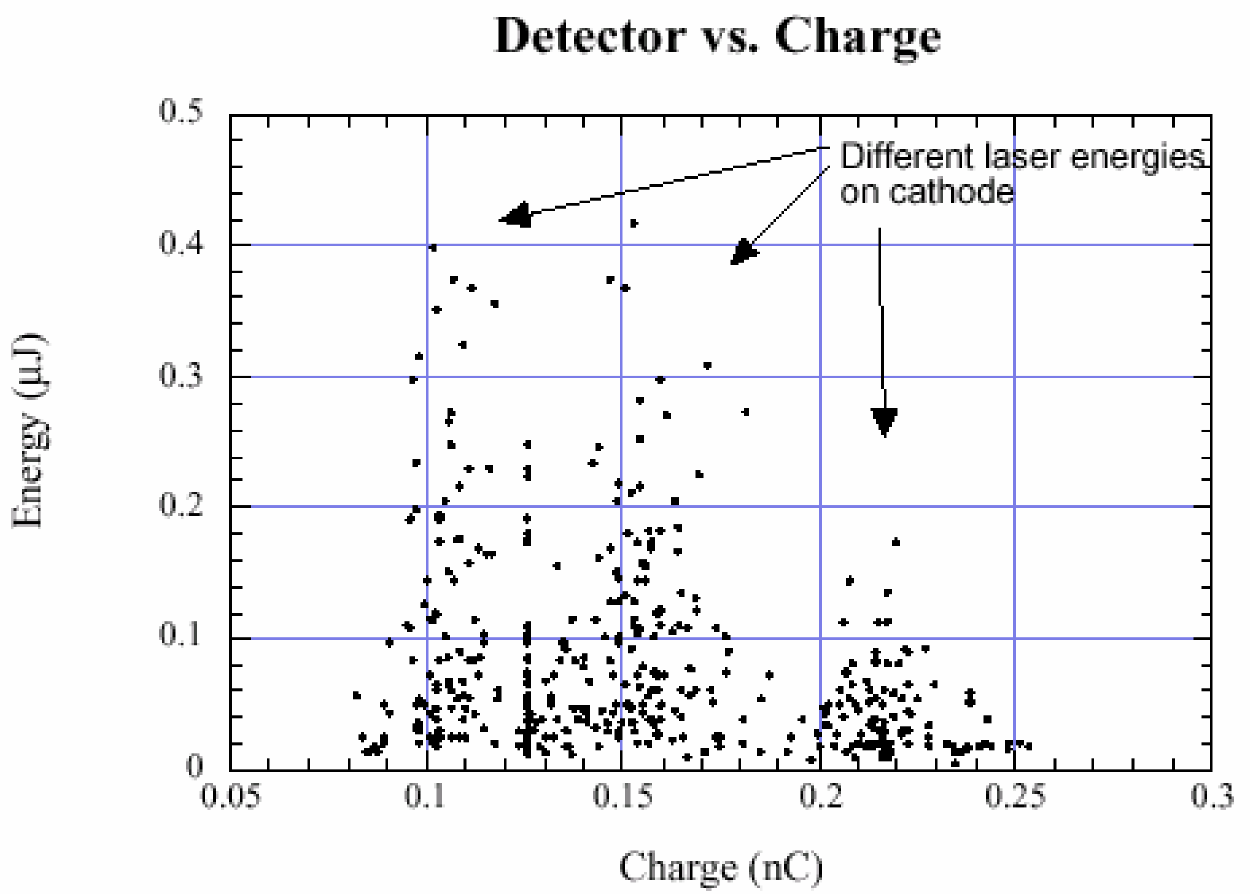
V. Ayvazyan,[4] N. Baboi,[7,16] I. Bohnet,[5] R. Brinkmann,[4] M. Castellano,[8] P. Castro,[4] L. Catani,[10] S. Choroba,[4] A. Cianchi,[10] M. Dohlus,[4] H. T. Edwards,[6] B. Faatz,[4] A. A. Fateev,[13] J. Feldhaus,[4] K. Flöttmann,[4] A. Gamp,[4] T. Garvey,[14] H. Genz,[3] Ch. Gerth,[4] V. Gretchko,[11] B. Grigoryan,[19] U. Hahn,[4] C. Hessler,[3] K. Honkavaara,[4] M. Hüning,[17] R. Ischebeck,[17] M. Jablonka,[1] T. Kamps,[5] M. Körfer,[4] M. Krassilnikov,[2] J. Krzywinski,[12] M. Liepe,[7] A. Liero,[17] T. Limberg,[4] H. Loos,[3] M. Luong,[1] C. Magne,[1] J. Menzel,[17] P. Michelato,[9] M. Minty,[4] U.-C. Müller,[4] D. Nölle,[4] A. Novokhatski,[2] C. Pagani,[9] F. Peters,[4] J. Pflüger,[4] P. Piot,[4] L. Plucinski,[7] K. Rehlich,[4] I. Reyzl,[4] A. Richter,[3] J. Rossbach,[4] E. L. Saldin,[4] W. Sandner,[15] H. Schlarb,[7] G. Schmidt,[4] P. Schmüser,[7] J. R. Schneider,[4] E. A. Schneidmiller,[4] H.-J. Schreiber,[5] S. Schreiber,[4] D. Sertore,[9] S. Setzer,[2] S. Simrock,[4] R. Sobierajski,[4,18] B. Sonntag,[7] B. Steeg,[4] F. Stephan,[5] K. P. Sytchev,[13] K. Tiedtke,[4] M. Tonutti,[17] R. Treusch,[4] D. Trines,[4] D. Türke,[17] V. Verzilov,[8] R. Wanzenberg,[4] T. Weiland,[2] H. Weise,[4] M. Wendt,[4] I. Will,[15] S. Wolff,[4] K. Wittenburg,[4] M. V. Yurkov,[13,*] and K. Zapfe[4]



L.H. Yu et al, to be submit to PRL

BROOKHAVEN NATIONAL LABORATORY

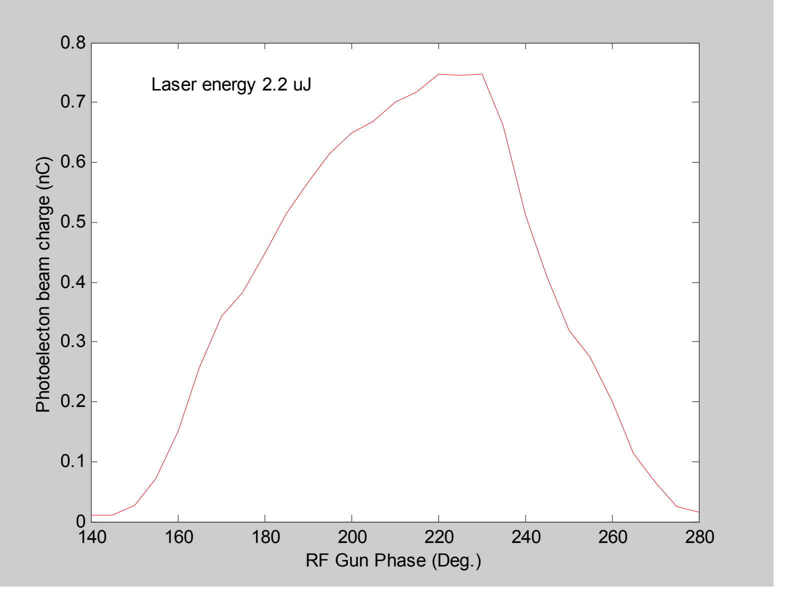
Experimental data

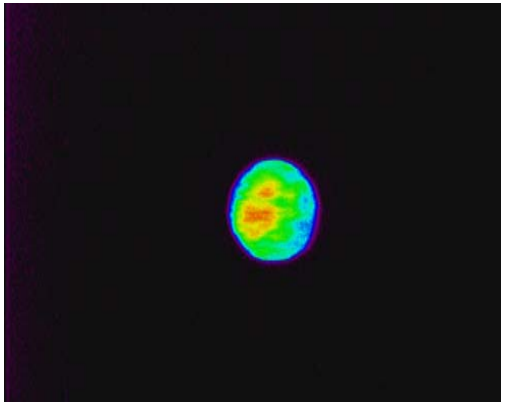


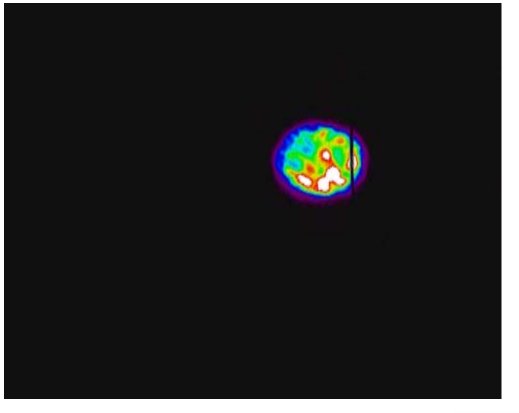
Electron beam Based Laser Optimization

1. The Schottky effect leads slope in longitudinal distribution.

2. Non-uniformity in QE laser distributions.







BNL NSLS Gun Workshop (1/2001)

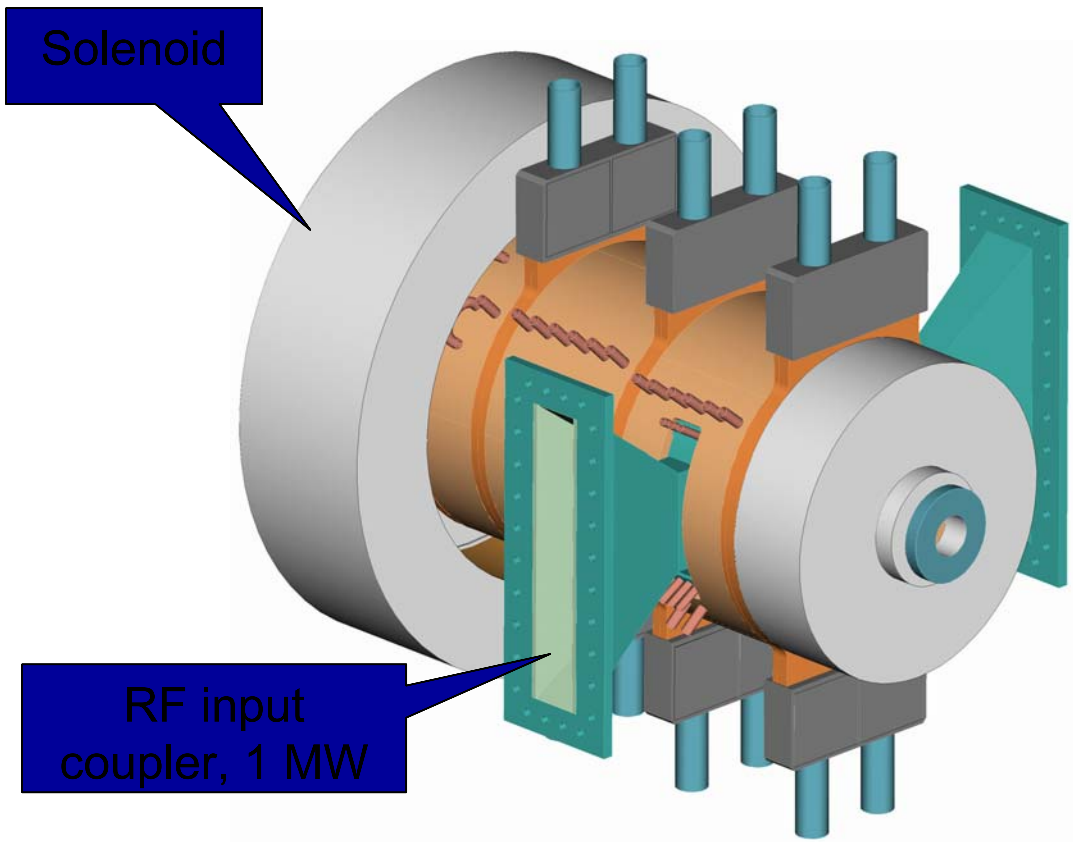
- **High QE Green or Red Cathode.**
- **2 ½ Cell low temperature RF gun**
- DC and RF gun both capable of CW operation.

Dc: 10 mm-mrad

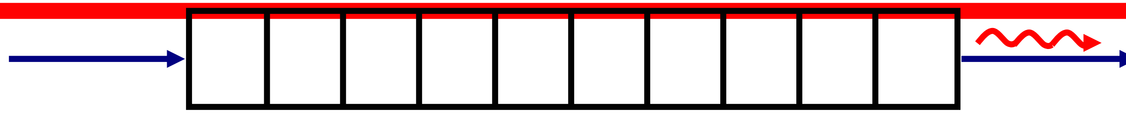
RF: 1.0 mm-mrad

LANL & AES CW Photoinjector

New 703 MHz
CW Photoinjector
Under design



SASE FEL for 30 keV (From BES GFEL presentation, Kim, JBM,JG)



- LCLS reference parameters:
  λ = 8 keV, λ_u = 3 cm, K = 3.7, I_p = 3.5 kA, E_e = 15 GeV,
  $\Delta E/E$ = 0.01%, ε_n = 1.2 mm mrad, L_{sat} = 100 m
- Vary K, ε_n, and E_e

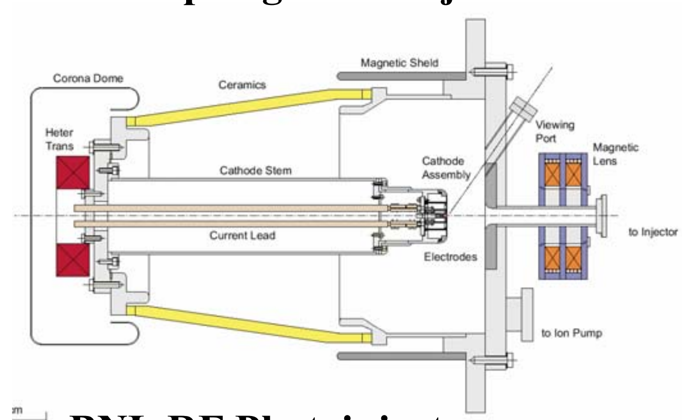
K	E_e (GeV)	ε_n (mm-mrad)	L sat (m)	
3.7	30	1.2	300	
3.7	30	0.5	130	
3.7	30	0.1	40	← **shorter undulator**
1	12	0.1	60	← **shorter undulator and shorter linac**

- *It pays to strive for an ultra-low emittance e-beam.*

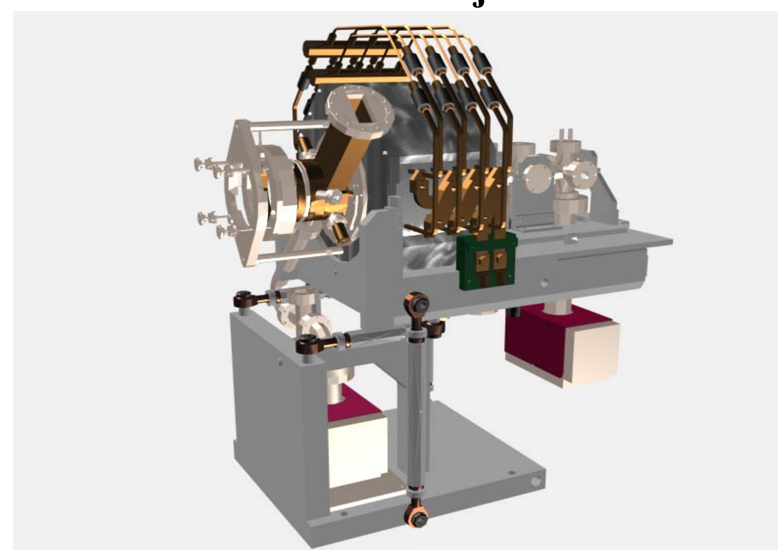
High Brightness Electron Injectors

Type	DC Gun	RF Gun	GreenField
E [MeV]	0.5	5	**50**
G[MV/m]	10	100	**500**
τ [ps]	500	10	<1
I_p [A]	10	100	500
Q [nC]	0.5	1	<0.5
ε_n [μm]	1	1	0.1

500 kV Spring-8 DC Injector



BNL RF Photoinjector



How to create the Greenfield FEL injector?

- ***Optimize 6-D phase space, not just ε_n or I_p***
- ***To realize this the GFEL injector should achieve:***

  G > 500 MV/m , E > 50 MeV

  in order to produce and preserve the beam.

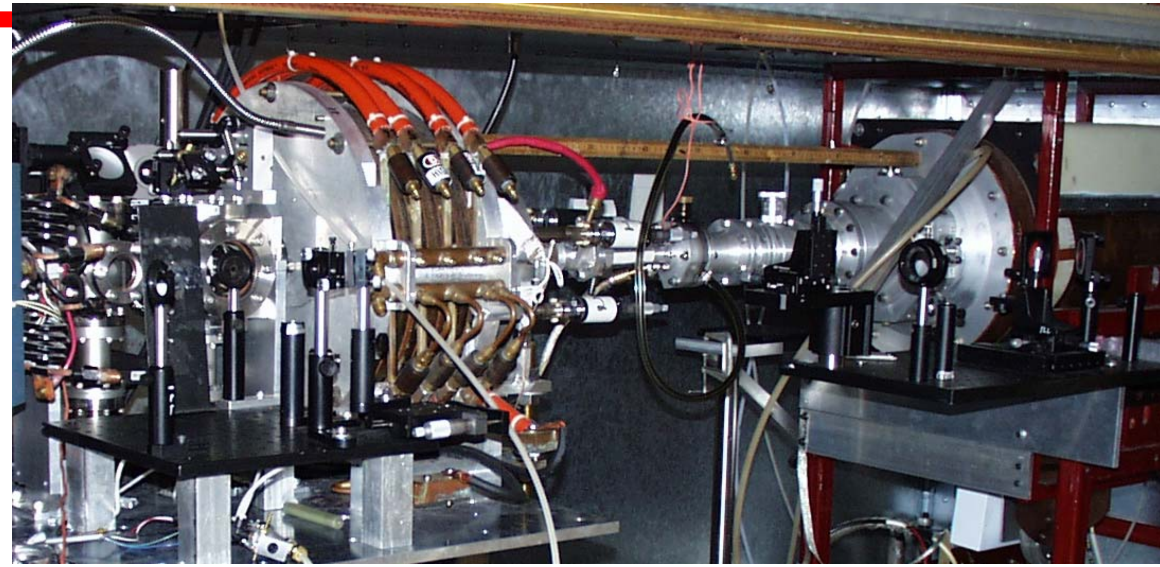
Higher frequency $\rightarrow$ Brighter beam?

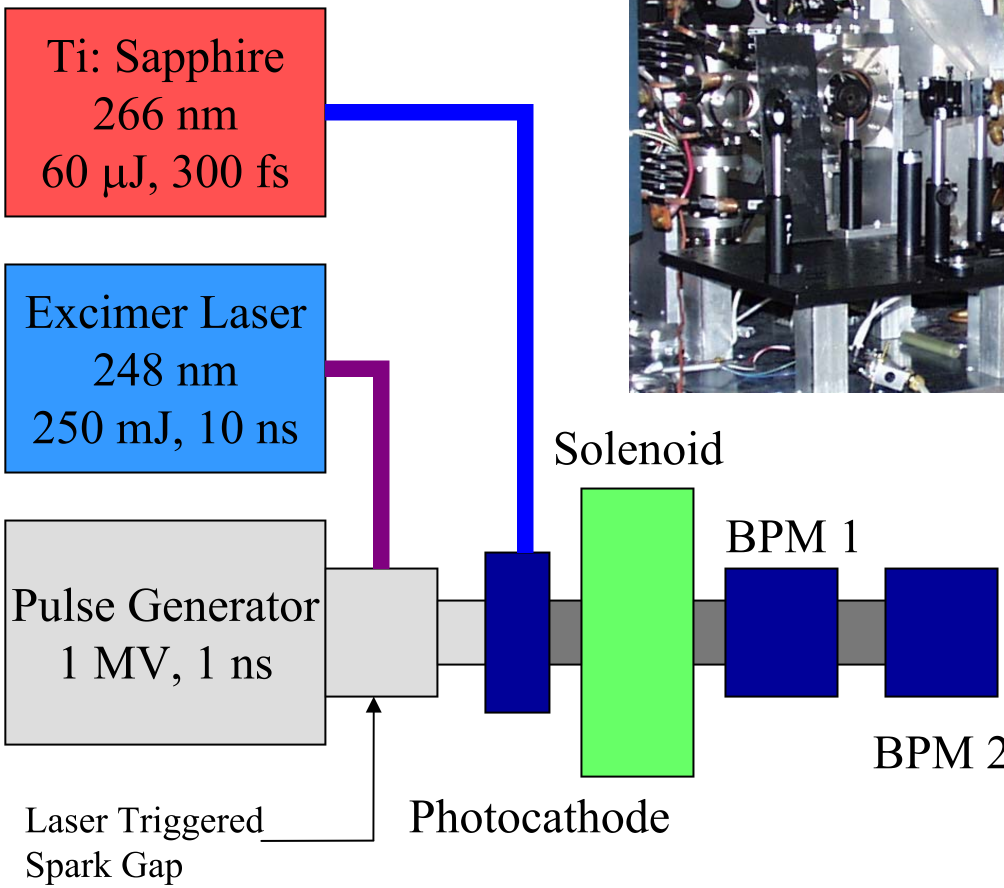
Field gradient $\propto f^{1/2}$

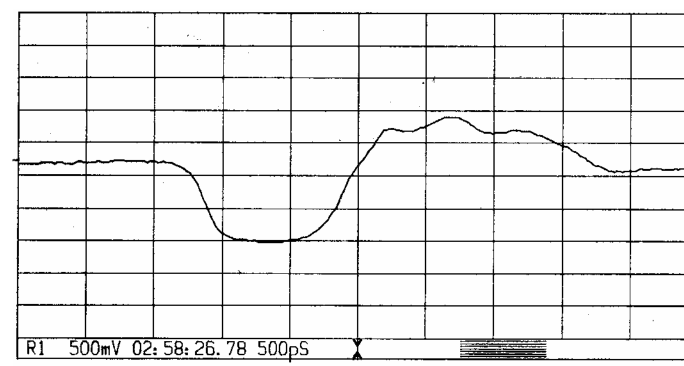
$B \propto f^{1/2}$?

Terminal E $\propto 1/f^{1/2}$ *for the same cell No.*

Pulser System Schematic w/ Diagnostics







900 kV, 1 ns Voltage Pulse

Courtesy of J. Smedley of Instrumentation

Pulsed Power Photoinjector

System Capabilities

Voltage Range:

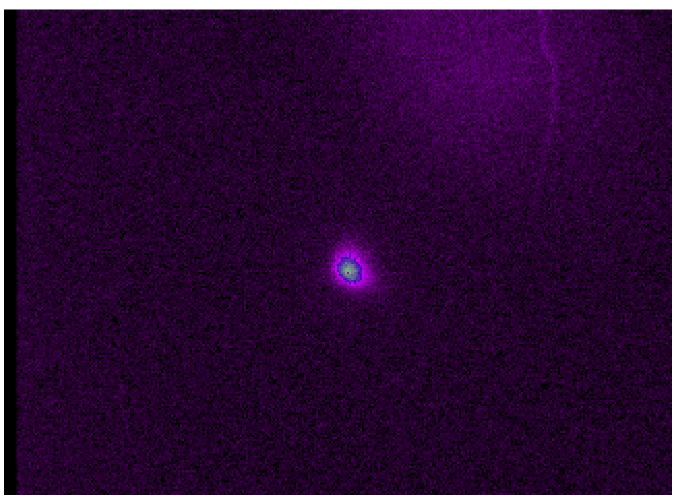
350 - 900 kV, 1 ns FWHM

Cathode Laser:

60 μJ, 300 fs FWHM, 266nm

System Jitter: <1 ns

Accelerating Gradient: >1 GV/m



Typical Focal Spot
(σ=130μm)

Results

Photoemission: > 60 pC from 300 fs laser

Current Density: >100 kA/cm^2

Focal Spots: σ ~ 100μm

Best Norm. Emittance [measured]:

0.7 mm-mrad

(400 keV beam, 400 MV/m, 5 pC, 300 fs)

Simulated Emittance (similar parameters):

0.35 mm-mrad

At a 1 GV/m gradient, simulations predict:

Emittance is thermally dominated for current densities up to 25kA/cm^2 (50A from .25mm radius cathode spot)

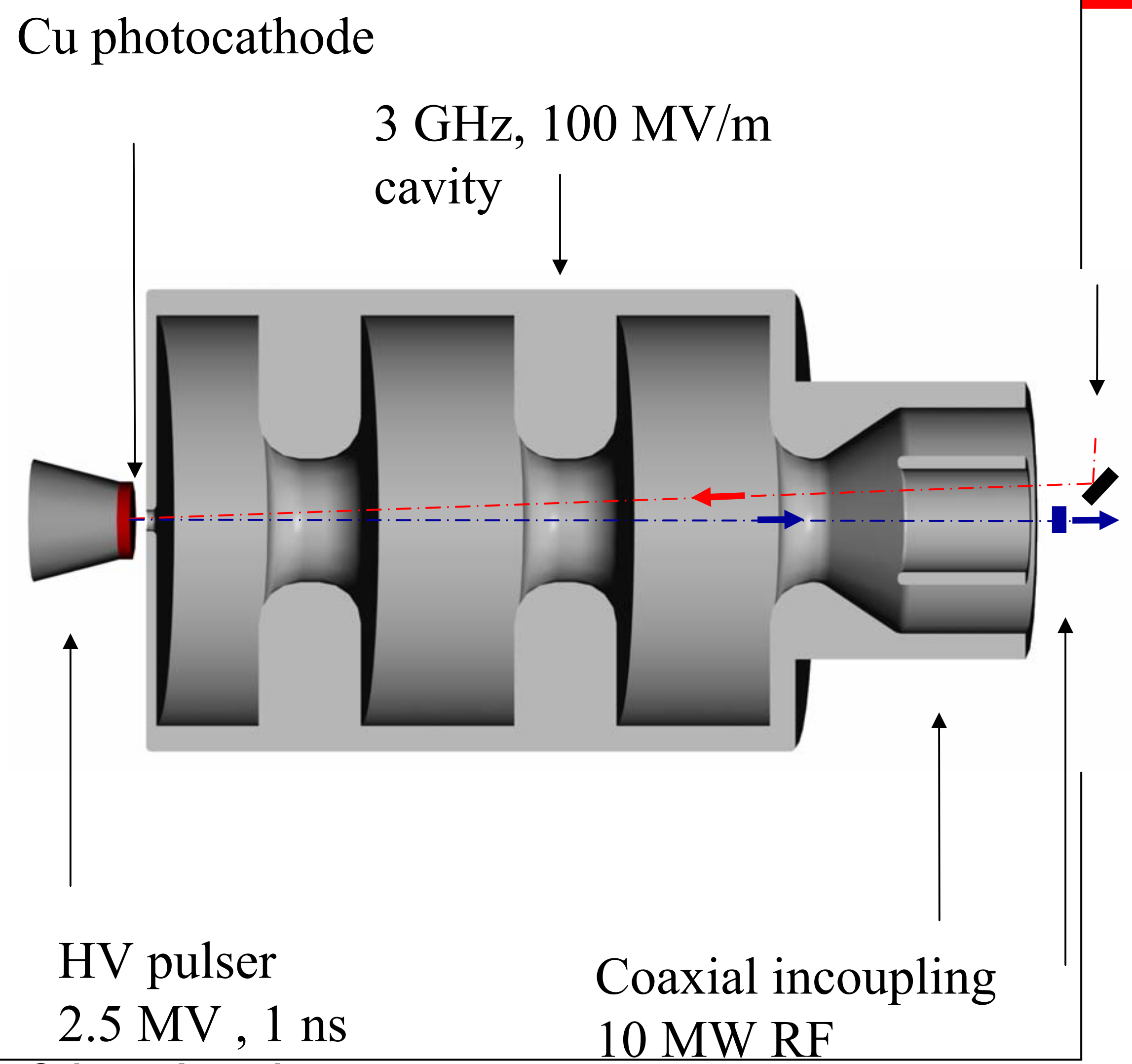
Maximum current density (Child's Law]:

380kA/cm^2

Emittance Measurement Ongoing

Courtesy of J. Smedley of Instrumentation

TUE-Pulser


Cu photocathode
3 GHz, 100 MV/m
cavity
Laser pulse
50 fs, 100 μJ,
260 nm
Microbunch
Goal:100 pC, 100 fs,
10 MeV
HV pulser
2.5 MV , 1 ns
Coaxial incoupling
10 MW RF

Longitudinal Emittance Compensation

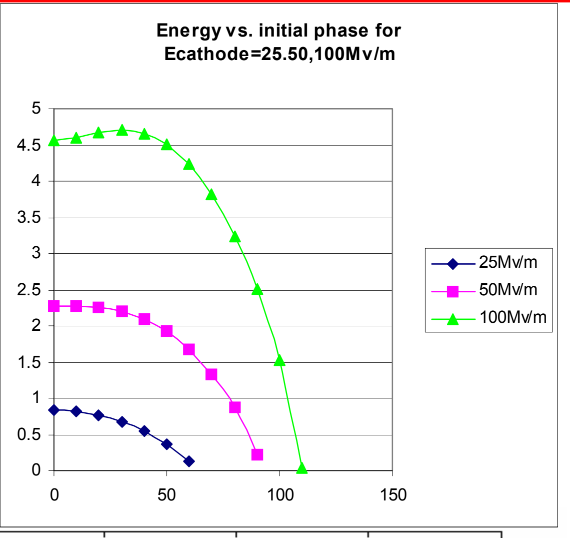
A technique of optimize 6-D emittance of electron beam produced by photocathode RF gun, by proper choosing the laser and electron beam parameters, this technique is capable of produce kilo-Ampere, mm-mrad electron beam.

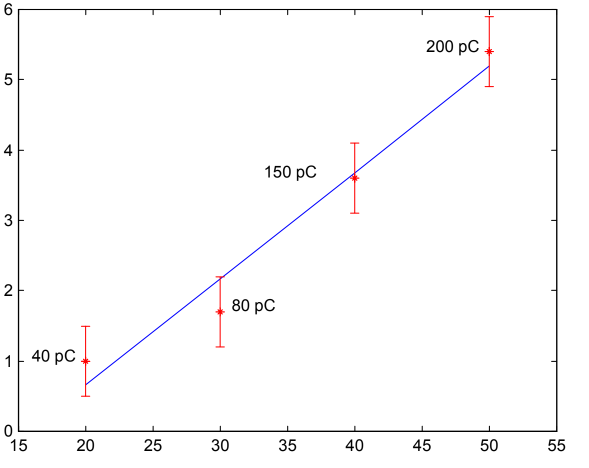
It involves three steps:

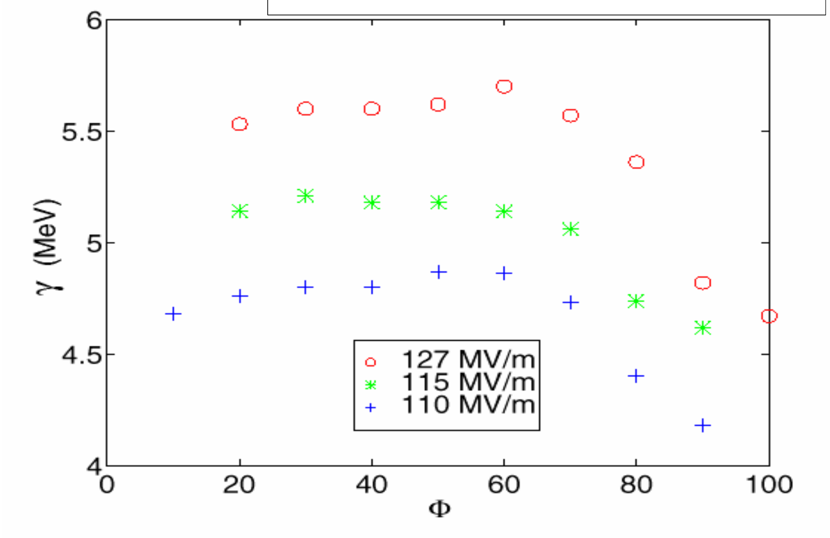
1. Electron beam launched at lower RF gun phase, compress beam and set up right energy chirp.
2. Ballistic compression in the drift space
3. RF focusing in the linac by off-crest acceleration.

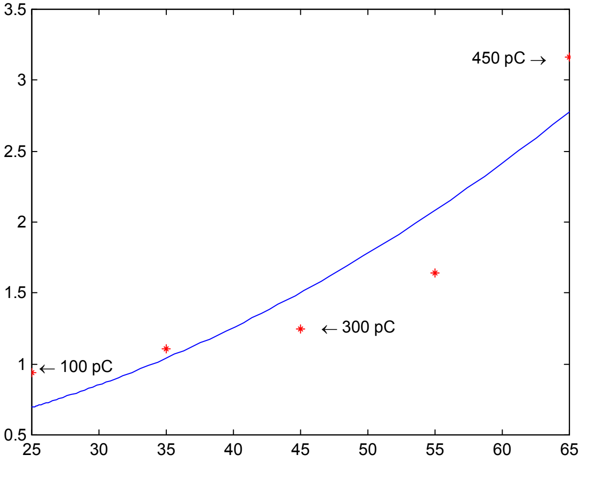
Why Photocathode RF Gun

- Space charge.
- Emittance.



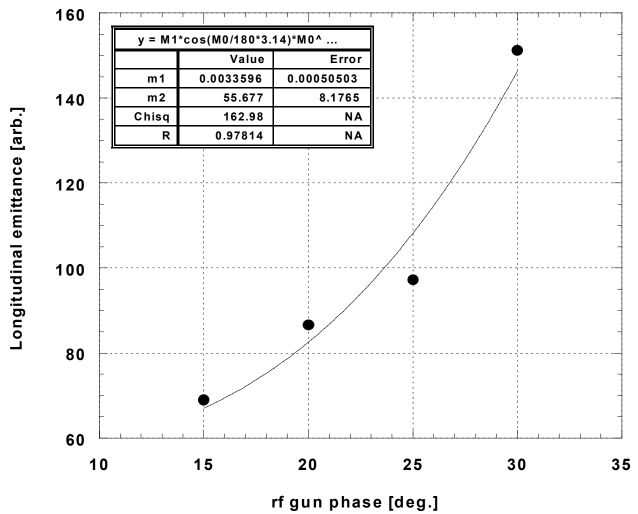


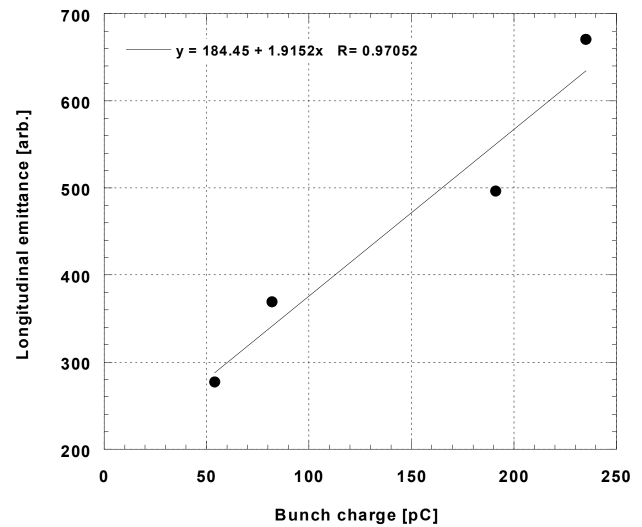




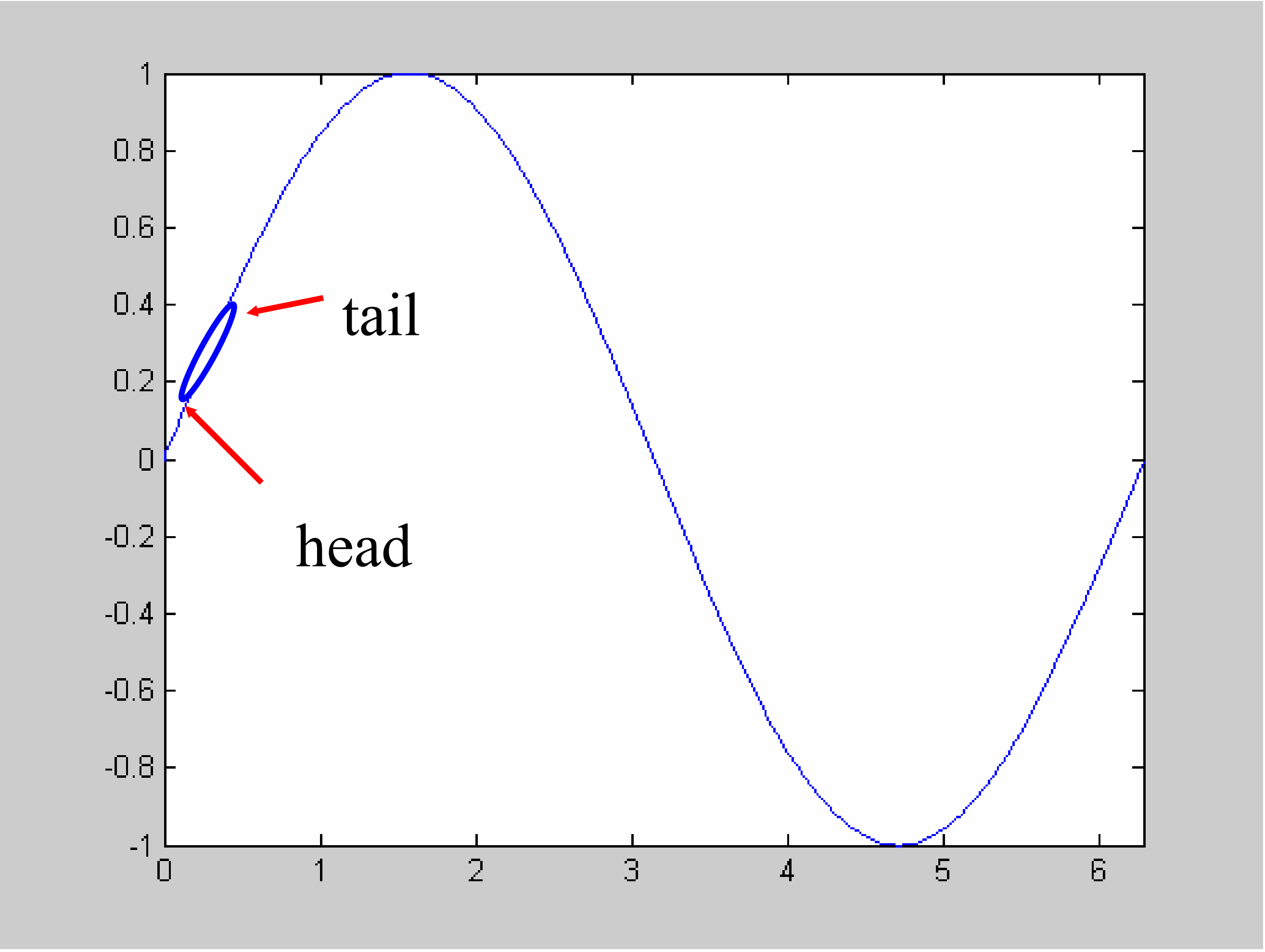
Longitudinal Emittance

$$\varepsilon_{\phi} \approx \frac{1}{2}\sigma_{\phi}^{\;3}\cos(\phi_0)$$

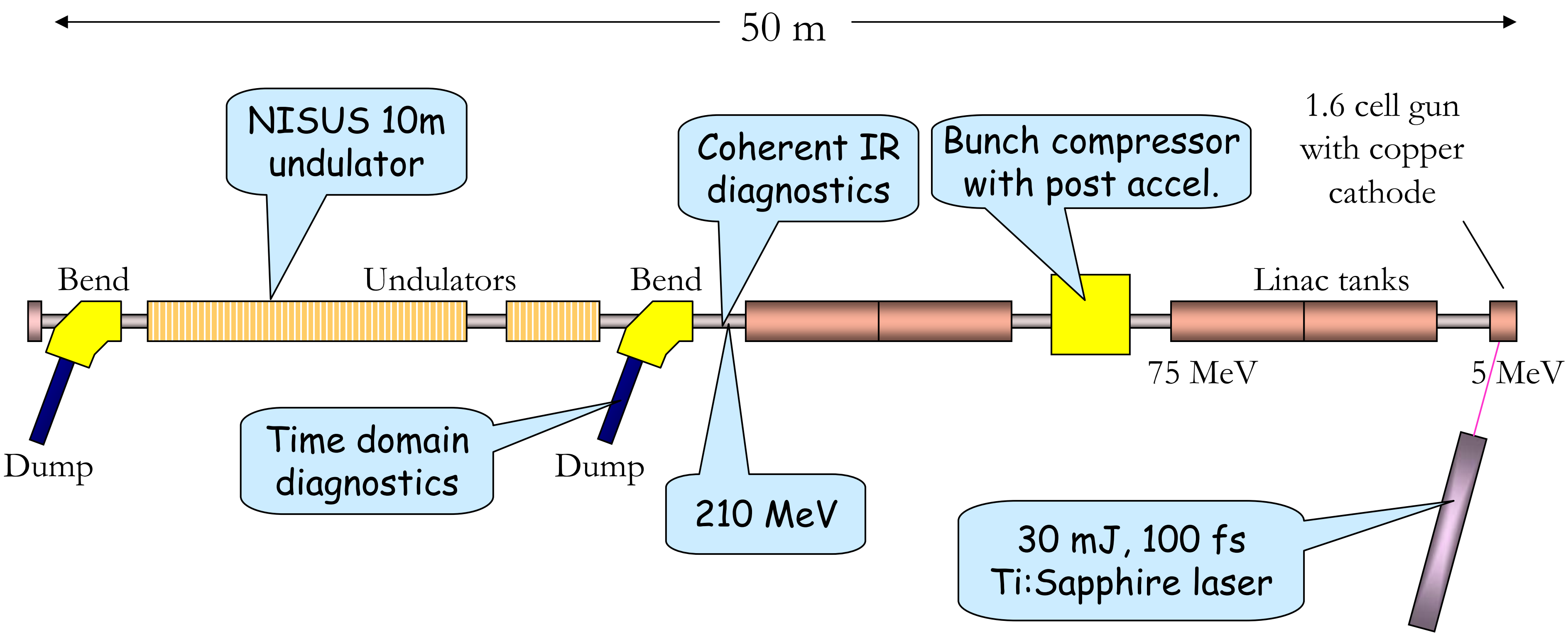




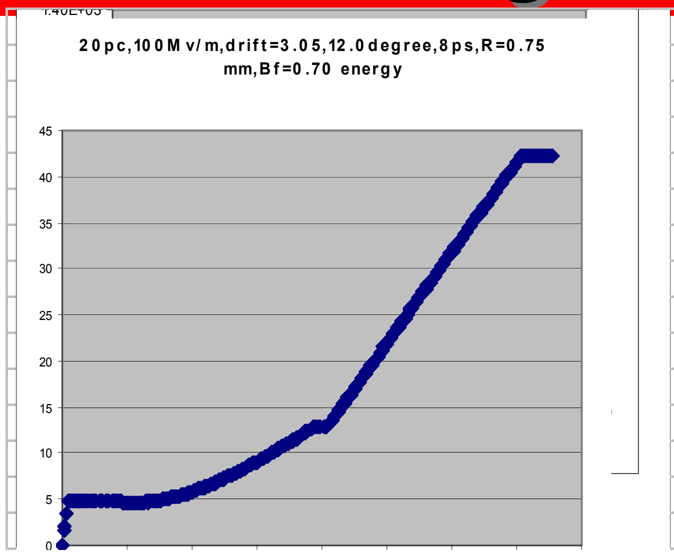
Buncher

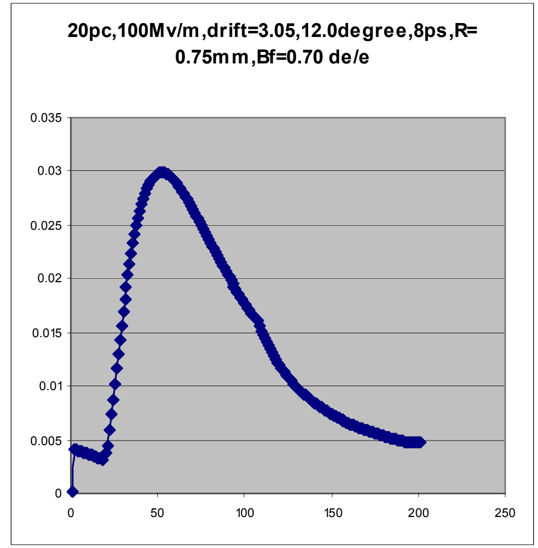


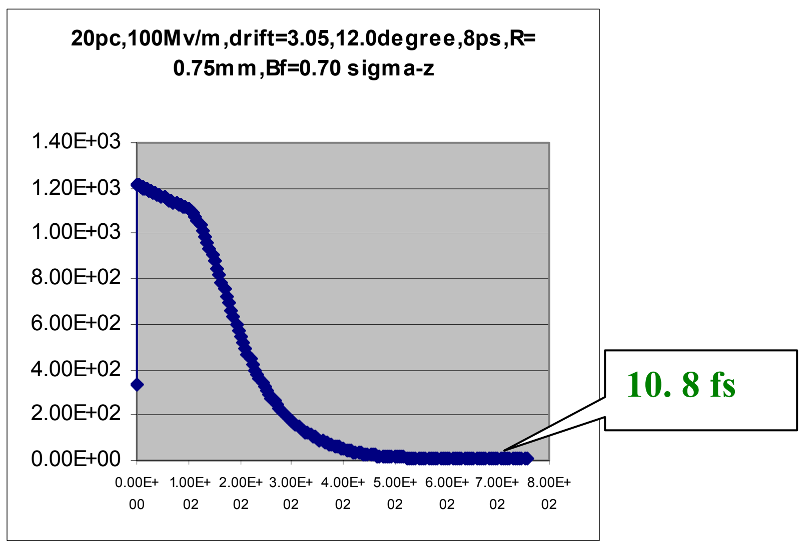
DUV-FEL Facility



10 fs kilo-Ampere Electron beam generation

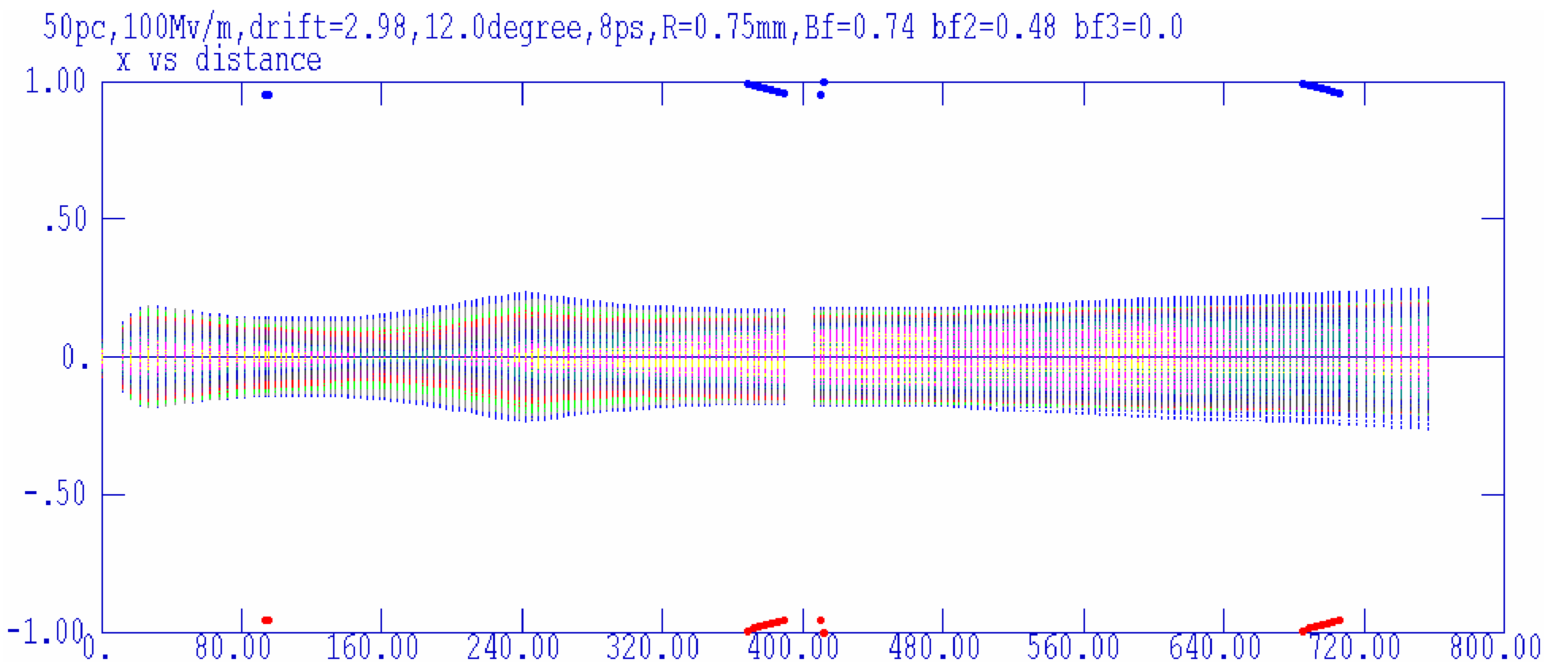


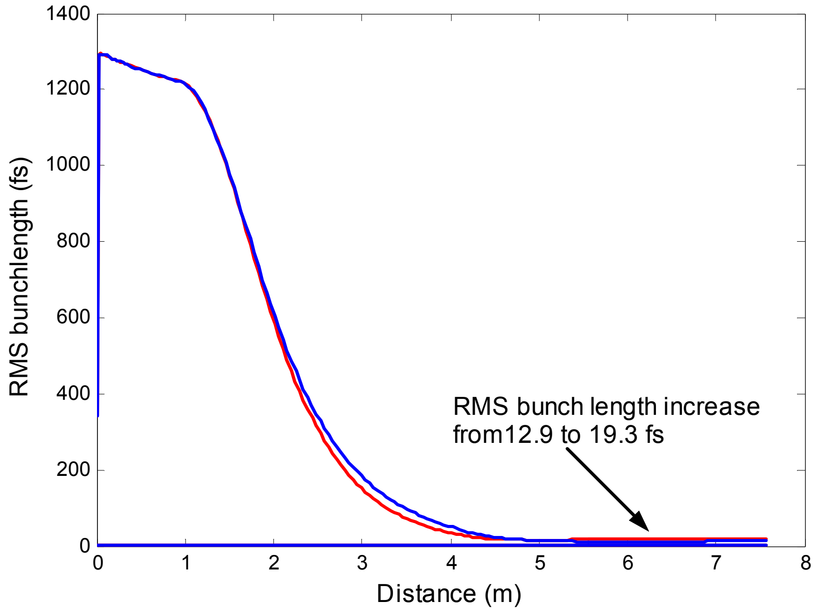




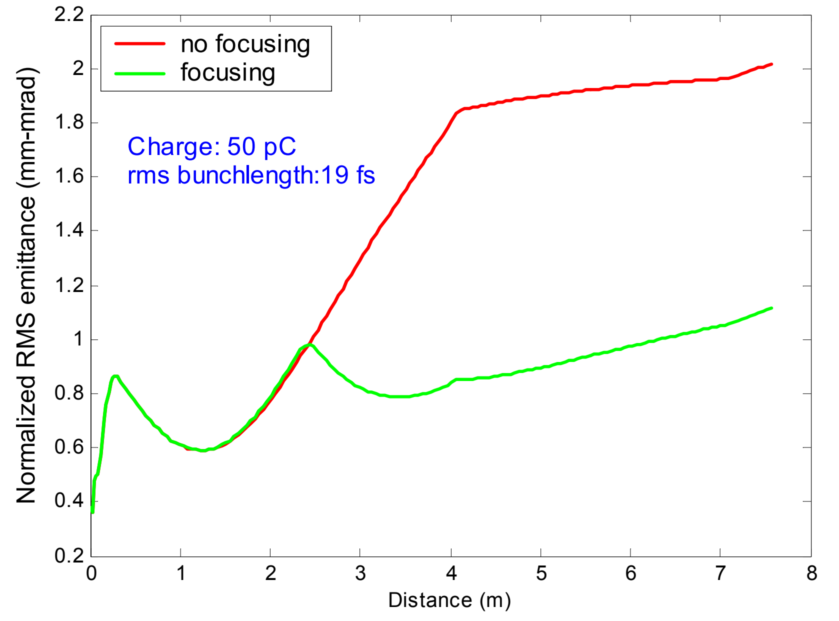
Brookhaven Science Associates
U.S. Department of Energy

BROOKHAVEN NATIONAL LABORATORY


50pc,100Mv/m,drift=2.98,12.0degree,8ps,R=0.75mm,Bf=0.74 bf2=0.48 bf3=0.0
x vs distance
1.00
.50
0.
-.50
-1.00
0.
80.00
160.00
240.00
320.00
400.00
480.00
560.00
640.00
720.00
800.00

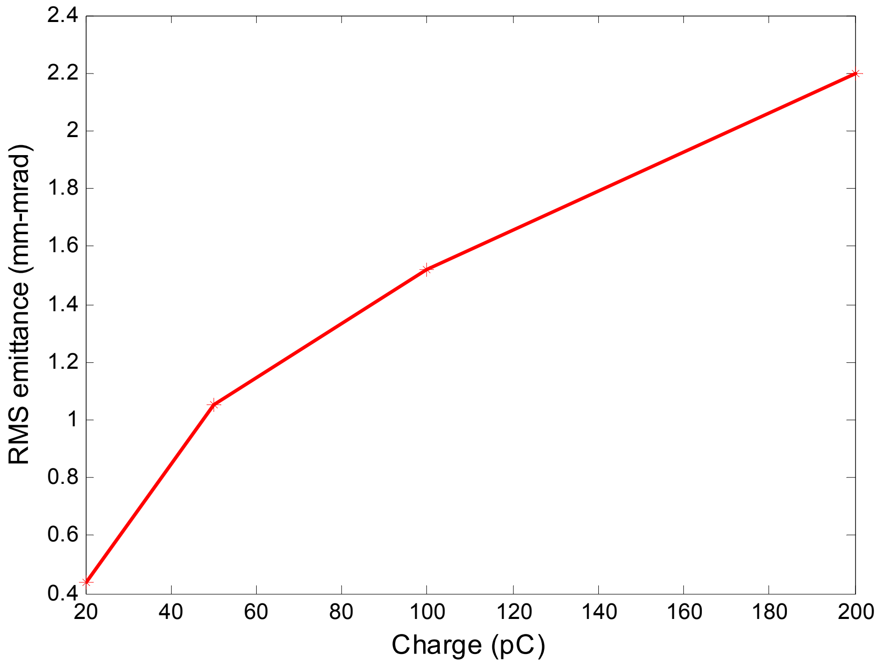


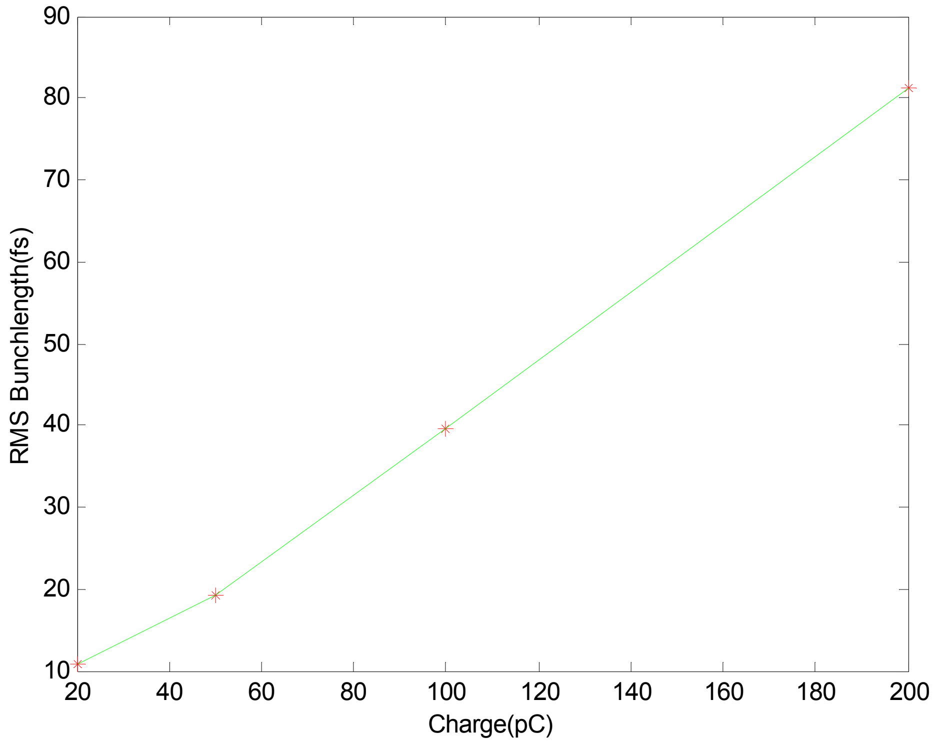
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
8
RMS bunchlength (fs)
Distance (m)
RMS bunch length increase
from12.9 to 19.3 fs



2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
no focusing
focusing
Charge: 50 pC
rms bunchlength:19 fs
Normalized RMS emittance (mm-mrad)
Distance (m)

Electron Beam Properties as function of the Charge





Summary

The DOE BESAC subcommittee On 20-Year Basic Energy Sciences Facilities Roadmap:

"The evolution of light sources toward diffraction limited radiation at high energy, to sub-picosecond photon pulse lengths, and with FEL operation places increasingly stringent demands on the three dimensional phase space density of the electron beam. For linear accelerators, these performance requirements translate directly into the necessity of smaller emittance, higher charge bunches generated at the electron gun. In addition, increased repetition rates at the gun allow higher average flux, multiple undulator end stations, and ultimately the generation of storage-ring-class currents in energy recovery linacs. Also, with lowered emittance, the resulting higher gain will enable important cost savings. For example, undulator lengths and electron beam energy could be reduced".

"The critical enabling technology to advance linac-based light sources is the electron gun. At low repetition rates, the present RF photocathode technology generates 1 mm-mrad normalized emittance bunches with a charge of a nanocoulomb at 100 Hz repetition rates."