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PROPOSED UV-FEL USER FACILITY AT BNL*

I. Ben-Zvi, L. F. Di Mauro, S. Krinsky, M. G. White, L. H. Yu, K. Batchelor, A. Friedman, A.S. Fisher, H. Halama, G. Ingold, E. D. Johnson, S. Kramer, J.T. Rogers, L. Solomon, J. Wachtel and X. Zhang

Brookhaven National Laboratory, Upton NY 11973 USA

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ABSTRACT

The NSLS at Brookhaven National Laboratory is proposing the construction of a UV-FEL operating in the wavelength range from visible to 750Å. Nano-Coulomb electron pulses will be generated at a laser photo-cathode RF gun at a repetition rate of 10 KHz. The 6 ps pulses will be accelerated to 250 MeV in a superconducting linac. The FEL output will serve four stations with independent wavelength tuning, using two wigglers and two rotating mirror beam switches. Seed radiation for the FEL amplifiers will be provided by conventional tunable lasers, and the final frequency multiplication from the visible or near UV to the VUV will be carried out in the FEL itself. Each FEL will comprise of an initial wiggler resonant to the seed wavelength, a dispersion section, and a second wiggler resonant to the output wavelength. The facility will provide pump probe capability, FEL on FEL, and FEL on synchrotron light from an insersion device on the NSLS X-Ray ring.

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INTRODUCTION

In this paper, we describe the progress made on the design of an accelerator-based UV/VUV radiation source capable of providing tunable, coherent radiation from 3000Å to 750Å at near gigawatt peak powers [1]. Unlike FEL's utilizing UV/VUV oscillator cavities, the laser amplifier scheme proposed here will provide high peak power VUV radiation with the mode structure, bandwidth and frequency stability of an input seed laser. Such a VUV source with peak energies near 1 mJ/pulse is well beyond conventional laser technology and could have an immediate impact on experimental studies of photo-induced processes in chemistry and physics and biology. The choice of the FEL wavelength (3000Å-750Å) is largely driven by the fact that such radiation is sufficiently energetic to induce fragmentation and ionization of any atom or molecule leading to exciting new scientific possibilities in photo-induced chemistry and physics.

A novel feature of the FEL will be the method of generating the short wavelengths [1,2]. We propose to do the last stage of frequency multiplication in the FEL. The FEL is a high quality nonlinear medium, offering a high conversion efficiency, high power handling capability, high stability of the nonlinear operation parameters and wide band tunability in a single device. We propose to carry out an experiment designed to test this harmonic generation technique [3] at the BNL Accelerator Test Facility (ATF) [4].

By using a short pulse seed laser (shorter than the electron pulse length), a wide range of pulse length, from 200 fs to a few ps is made possible, offering exciting new science possibilities. Furthermore, the 'Fresh Bunch' technique [5] can be used to increase the output power or significantly reduce the wiggler length.

The electron source will be based on BNL's laser photocathode rf gun. The present gun performance is quite good [6,7] and it is well matched to the needs of the UV-FEL facility. A new version of this gun is being developed [8] which will have the large duty factor capability to provide the necessary pulse repetition rate.

The accelerator which we propose to use is a superconducting recirculating linac. Such a machine offers the advantages of a low energy spread, and good temporal structure of the produced radiation. The cost effectiveness of the facility is enhanced by two features. One is the high pulse repetition rate made possible by the superconducting linac, and the other is beam sharing in real-time by multiple users. The accelerator will provide photon pulses to two wigglers with about 10 ns separation. In each wiggler the rate will be up to 5 kHz. Further spliting between two experimental stations will be done by rotating mirrors. Thus the machine will serve simultaneously four users.

Wave... tuning will be done by energy modulation of the electron beam rather than by wiggler gap change. (Naturally, the seed lasers will tune in synchronism.) This final energy modulation will be done by special purpose accelerating cavities placed just before each of the two wigglers, thus necessitating virtually no transport element adjustments. This method offers the following advantages: 1) simpler wiggler design; 2) wiggler operation at its highest K; and

3) much faster wavelength tuning, limited in principle only by the seed laser tuning speed. Furthermore, with four seed lasers, each of the independent users will be able to tune the wavelength completely independently of the others.

This UV-FEL facility will have numerous options for performing pump probe experiments. The most common mode of pump-probe experiment would involve IR or UV end station lasers in conjunction with the FEL. Another one is the FEL in conjunction with the NSLS X-Ray Ring and another is a unique FEL/FEL pump probe at two independent colors. The first will be provided by bringing one of the FEL photon lines to the X13 beamline of the NSLS X-Ray Ring, a multiple insertion device line. The second will be provided by simply bringing together the output from the two wigglers at one station. The 10 ns delay between these pulses may be varied by optical means to a larger, or smaller (down to zero) delay time. This option, in conjunction with the sub-picosecond pulse length and high power of the FEL beams should open up new science possibilities.

In this paper we describe the main features and parameters of the facility, including the rf gun, recirculating linac and its beam dynamics, the FEL, the seed and photocathode lasers and the beam switching system. References will be made to publications which contain detailed material.

THE ELECTRON GUN

The electron gun is required to produce short ($\approx$6 psec) bunches of electrons at high repetition rates ($\approx$10 kHz), with small energy spread (<100 keV), high current ($\approx$300 A) and a total electronic charge of about 1 to 2 nC. At the highest charge, the normalized rms transverse emittance should be as small as possible ($\epsilon_n < 8\pi$ mm.mrad). A number of options are available for the design but we will consider here a normal conducting, copper rf gun operating in a pulsed mode at a frequency of 2856 MHz, based on the BNL gun [6,7,8].

At 10 KHz the average power presents a high heat load on the gun. Also, the availability of power sources for high peak and high average power is a consideration. The output energy and beam divergence from the electron gun are also important since this strongly influences the design of the transport system from the gun to the linac. At low energy, it is difficult to preserve the beam quality, particularly for high brightness beams where space charge forces are significant. It is also desirable to utilize magnetic pulse compression to allow for flexibility in the output beam bunch length and peak current. Finally, the choice of laser plus photocathode material is important in terms of lifetime and operational reliability.

Reference [8] gives detailed simulations of a 2856 MHz radiofrequency electron gun and the results of these simulations are given in Table I below. This gun will provide 10 MeV from 3½ cells. The results in Table I are past the first 1½ cells. Tests of a similar gun design [7] indicate that these beam parameters are realistic. The remaining question is one of repetition frequency, or average power capability. Grumman Aerospace Corporation staff in collaboration with BNL have carried out thermal studies on the BNL gun design and these indicate that a 1% duty factor is feasible for this option [8]. This duty factor allows a 2 μS average gun 'on' time at 5 kHz. By using two micropulses per gun macropulse we obtain a pulse repetition rate of 10 kHz, so this design objective is within the range of a conventional water-cooled copper system. Klystrons delivering average powers of 50 kW at 2856 MHz are available commercially and the 5046 klystron developed at SLAC operates at 65 kW average and 65 MW peak power levels so the power source should not be a problem.

Table I. RF Gun Parameters

Frequency	2856 MHz
Cathode peak electric field	100 MV/m
Beam energy at exit	4.6 MeV
Laser spot radius (1σ cutoff)	4 mm
Laser pulse width (2σ cutoff)	2 ps
Charge in bunch	1.5 nC
Peak current	300 A
Normalized rms ϵ_n at Cu cathode	1.6 π mm mrad
$\Delta\epsilon_n$ due to self fields	3.6 π mm mrad
$\Delta\epsilon_n$ due to rf fields	1.0 π mm mrad
ϵ_n at exit	4.0 π mm mrad
Beam energy spread (dp/p)	0.8 %
Exit bunch length (σ_t)	1.87 ps
Exit bunch radius (σ_r)	5.7 mm
Exit beam divergence ($\sigma_{x'}$)	22.8 mrad
Macropulse repetition rate	5 kHz
Micropulse repetition rate F	10 kHz

Ultraviolet wavelengths near 250 nm are needed to take advantage of the high-brightness, long-life metal photocathodes being developed at BNL and tested at the ATF. For a charge of 2 nC and a copper cathode operating at maximum quantum efficiency (10^{-4}), we require 100 μJ of 250 nm light. A yttrium photocathode may be as much as an order of magnitude more efficient.

The difficulty in this design is in the pulse repetition rate. Since the double pulses are best obtained by splitting the ultraviolet pulse and delaying one half by about 10 ns (3 m of optical path), we require an output of at least 0.2 mJ per pulse in order to have the flexibility to use copper cathodes. To allow for losses and declines in cathode efficiency, up to 0.4 mJ of ultraviolet would be desirable. These specifications are possible, but not standard, and would require developing a custom system.

Regenerative amplifiers have been operated with picosecond pulses at kilohertz rates, primarily using Nd:YLF (1.05 μm) [9]. The energy per pulse has been $\approx$5 mJ. The typical efficiency

($\geq 15\%$ at this wavelength) of frequency quadrupling makes this approach particularly attractive.

An alternative approach, using Ti:sapphire for the oscillator and alexandrite for the amplifier is being explored. This system operates at 750nm to takes advantage of the higher efficiency of frequency tripling.
The high energy output combined with the higher conversion efficiency from 750 nm makes this system a good candidate for the photocathode laser.

THE SUPERCONDUCTING LINAC

Within the last fifteen years, niobium radio-frequency superconductivity has grown to a mature technology as is amply evident from the large number of superconducting cavities being built throughout the world. The advantages of a superconducting linac include the high energy stability which is obtainable with a cw machine, the ability to match the electron pulse structure to high repetition rate lasers (used either as seed for the FEL or as tools at the experimental area) and the possibility of using a low rf frequency and large apertures. A low linac frequency has the advantages of low wake fields and the possibility of using a long electron bunch. The large aperture also contributes to the reduction of wake fields and thus to a lower energy spread.

The accelerator and wiggler are shown in Fig. 1. The superconducting linac will provide an energy gain of about 80 MeV per pass by using 12 four cell cavities in 6 cryostats. Additional cryostats (with two cavities per cryostat) provide independent energy tuning for each of the FELs sharing the main recirculating linac through the pulse switching system. To reduce the cost of the linac a recirculation scheme with about three passes through the linac will be used.

Superconducting linacs are available commercially from a number of manufacturers at a few frequencies, such as 350 MHz, 500 MHz and 1300 MHz. The basic considerations for the choice of the operating frequency are shunt impedance, operating temperature, degradation of emittance or energy spread due to wake fields, the bunch pulse length and its relation to the fundamental mode curvature, cost and size. The superconducting material will be either high thermal conductivity bulk niobium or niobium sputtered on copper. At 500 MHz it is possible to operate at 4.5K, simplifying the cryogenic system and operating above atmospheric pressure. The low frequency also reduced energy spread due to wake field and pulse length.

Wavelength tuning will be accomplished by changing the energy of the electron beam rather than the wiggler parameters. A linac twin-cavity section will be placed in front of each of the two wigglers to modify the beam energy. The advantages of this method are clear: The wiggler is simplified, the tuning can be faster than the (usually) mechanical wiggler tuning and the wiggler can operate always at the highest magnetic field value and thus achieve more gain.

We provide for four independent users by using two modulation cavities per wiggler. One operates at the fundamental linac frequency, 500 MHz, and the other is detuned by half the pulse repetition rate going into the wiggler. With 5 kHz pulse repetition rate into each wiggler, the second modulation cavity will be detuned by 2.5 kHz. Thus while one cavity accelerates every beam pulse, the other will alternately accelerate and decelerate the beam pulses. Since both cavities are independent in amplitude and may also be flipped in polarity, one may program the two pulses for independent voltages. This results in two independently tunable FELs per wiggler. Naturally, two seed lasers have to provide alternating seed radiation pulses into each wiggler.

The linac parameters are given in Table 2.

Table 2. Linac Parameters

Total energy gain (one pass)	80 MeV
Number of passes, N	3
Half lattice-cell length	5.4 m
Linac final energy	250 MeV
Energy range for fast tuning	±15 MeV
Frequency f	500 MHz
Cavity TM010 four cell, active length L_a	1.2 m
Physical length of cavity	1.7 m
Aperture of cavity	16 cm dia.
Number of cavities X cryostats	2 X 6
Length of cryostat	4.6 m
Nominal accelerating gradient G	5.5 MV/m
R/Q of cavities	470 Ω
Unloaded quality factor Q_O	2×10^9
Loaded quality factor Q_L	2×10^7
Stored energy per cavity, U	30 Joule
Power amplifier peak linear power	10 kW
Number of cavities in the linac n	12
Average current I_{ave}=NFq less than	90 μA
Longitudinal loss factor per cavity	k_l=2 V/pC
Higher order mode power (linac tot., 2 nC)	6 W
Corrected wake energy spread (2 nC)	$\leq 2 \times 10^{-4}$
Energy spread due to rf waveform	$\leq 10^{-4}$
Cryostat cold mass	800 kg
Total refrigeration capacity at 4.4 K	2.2 kW
Standing / running loss per cryostat at 4.4K	20W / 100W

THE RF BEAM SWITCH

Transport lines constituting the RF beamswitch are shown in Fig. 1. The beamswitch begins at the end of the superconducting linac before the beam enters the common bending magnet, which is also part of the 83 MeV and 167 MeV return bends. On the third pass at 250 MeV it is in the first leg of the RF beamswitch.

Two FELs are shown in Fig. 1. The lower FEL is serviced by a transport line that is nearly symmetric but for the 5 MeV energy increment provided by a single superconducting RF cavity structure similar to the cavities used in the linac. The beam passes the septum magnet undeflected outside the field region.

The upper FEL is serviced by the beam reduced in energy by 5 MeV. The dispersion separates the two beams by 5.5 cm at the entrance to the septum. Both transport lines are first order achromatic and isochronous. They are designed to limit the horizontal and vertical beam sizes (1σ) to less than 5 millimeters throughout each transport line.

Rapid sequential operation of the two FELs will be achieved by controlling the frequency difference between the linac and the RF beamswitch acceleration cavity. Radiation pulses separated by 10 nanoseconds can be generated in the two FELs by operating the beamswitch cavity at 450 MHz when the linac operates at 500 MHz. Operating the electron gun, the superconducting linac, the RF beamswitch linac and additional accelerator sections in the transport lines to each FEL at commensurate frequencies will give this facility a capability for sequential radiation pulse generation with programmed timing and photon energy.

BEAM DYNAMICS

The linac optics are designed using a simple FODO lattice structure with the first section having approximately a 90 degree phase advance. Latter sections have a progressively higher phase advance for the first pass, in order to provide additional focusing for the second and third pass. The six quadrupoles are independently powered, room temperature, iron pole magnets of quite low power. The quadrupole aperture is enlarged to a 6 cm radius to provide for a large beampipe in order to reduce the wakefield effects from the transitions between superconducting cavities. Adequate space has been provided for diagnostics and vacuum system components in the quadrupole region. Beam steering will be provided by weak air core dipole magnets at the same position as the diagnostic pickups, with additional steering provided by quadrupole alignment changes.

Subsequent passes through the linac see less focusing and therefore will show longer period betatron oscillations. The amplitude of these oscillations will have higher ratio of peak to valley than the first pass but the adiabatic damping will reduce the maximum amplitude. To simplify the calculation for these passes, the recirculation lines are treated as a symmetric full wave transformer with unit magnification. Therefore the beam ellipse at the start of the second pass is the same as the output from the first pass with a change in sign of the orientation of the ellipse (alpha). This allows the tracking of the beam ellipse through all turns even before an adequate lattice is found for the recirculation lines.

Both recirculation transport lines are composed of isochronous bending arcs and symmetric transformers. The total transform is a unit matrix symmetric about the mid-point of the transport line. At the end of the linac, a single dipole provides the dispersion necessary to separate the passes into the different transport lines. The assumption that the arcs are symmetric produces a symmetric dispersion function in the arcs, making the achromatic condition easily satisfied. The arcs are made isochronous by providing a minimum of three dipoles and four quads. Although two quads are sufficient, the extra quads provide an isochronous condition independent of drift lengths.

The 90 MeV arc uses this minimum number of magnets. The second recirculation (170 MeV) has arcs consisting of four dipoles and seven quadrupoles. The quadrupoles are powered in symmetric families, reducing the number of power supplies. The long straight section between the 180 degree arcs consists of cells with a waist in the middle of the line. A phase shift delay similar to the injection chicane will be used to tune the phase of the beam at each the passes.

Recirculating a beam through a linac cavity several times can lead to regenerative multipass beam breakup. The problem is compounded by the higher Q-values associated with higher order modes (HOM's) of a superconducting cavity (SCC). The SCC drift tube therefore carries HOM couplers for damping these modes by extracting the energy deposited by the bunched beam in the corresponding modes of oscillation of the electromagnetic field in the cavity.

The beam dynamics has been simulated using the vectorized two-dimensional beam breakup code TDBBU. This code has been used to simulate inter/intrabunch collective effects in the recirculating continuous electron accelerator facility (CEBAF) and has been tested in detail against several analytic models, [10,11]. The simulations show that the three pass recirculating linac is stable up to 30 mA average current, well in excess of the required beam current.

THE SEED LASER

The FEL high repetition rate seed laser system will be based on regenerative amplifier technology [12] utilizing both Nd:YLF and Ti:Sapphire gain media. Such an amplifier can produce 10^9 gain or pulse energies in the millijoule level at kHz repetition rates.

The titanium sapphire (Ti:Sapp) is tunable from 0.7-1 μm and able to support sub-picosecond pulses. The mode-locked Ti:Sapp laser is pumped by the output of a 20 watt cw-argon ion laser to produce low energy tunable radiation. The output of the mode-locked Ti:Sapp laser is seeded into a Ti:Sapp regenerative amplifier. The amplified output should be capable of producing millijoules/pulse of output at kHz repetition rates. Subsequent frequency multiplication will produce the needed tunable visible and UV. A combination of conventional doubling, tripling and quintupling in conjunction with the FEL operating either at the fundamental, double or triple frequency of the seed will cover the required tuning range from 3000Å to 750Å.

THE WIGGLER

The expected characteristics of a superconducting wiggler are based on the design and on results obtained for the ATF FEL superconducting undulator [13]. The advantages of this undulator are high magnetic field and a very low random error without any post-manufacturing adjustment, making this a low-cost, high quality device. We expect rms field errors to be less than 0.3%. This is based on initial measurements made on the superferric short period undulator. At this level of error, steering correction stations placed at 1m intervals will keep the beam walk-off under 36μm rms, which is negligible compared to the beam size. The FEL phase error introduced under these conditions are also negligible.

For POISSON model calculations of the UV FEL-wiggler the ATF/FEL undulator design has been scaled proportionally. The poles and the wire grooves have a cross sectional area of 5.28 x 4.76 mm^2 and 5.28 x 4.63 mm^2, respectively, i.e., a wiggler period of 21.12 mm has been assumed to accommodate a layer of 12 wires with a 0.44 mm diameter. The coil is stacked in 12 layers with an alternating number of layers of 12 and 11 turns with 138 turns total. The yoke is 21.88 mm high. From the quench analysis of the measured ATF/FEL test sample we conclude that a current up to 175 A/turn should be possible.

For a 6 mm gap, POISSON predicts a linear regime extending to B=0.8 T at a current of 30 A/turn. Then saturation sets in with a nearly linear rise of the peak field at high currents. For I=140 /turn a field of B=1.7 T is predicted.

For currents above 40 A/turn the SC wiggler is expected to give higher fields on axis than a hybrid permanent wiggler. We expect the POISSON predicted saturation and hence the predicted maximum SC fields to be too optimistic. Also the quench current might actually be lower than the assumed 175 A/turn. Taking this into account by an overall scaledown factor of 0.8, fields on axis nearly twice as high as the hybrid fields are predicted, but the iron is highly saturated.

We are investigating high permeability materials other than 1006 low-carbon steel (0.6%) to obtain better saturation characteristics. Besides vanadium-permendur, very pure 10005 steel is expected to provide better permeability at high fields, and also greater chemical uniformity.

THE FREE-ELECTRON LASER

The design and theory of the UV-FEL has been described extensively elsewhere, [1,14]. In addition, we propose to use the 'Fresh Bunch' technique described in these proceedings [5]. Therefore we shall confine this presentation to a brief description of the FEL principles.

Our system utilizes a subharmonically seeded single pass FEL utilizing two wiggler magnets separated by a dispersion section. To be specific, suppose the seed to be laser light at 3000 Å. A first wiggler is used to energy modulate the electron beam. This is followed by a dispersion section to produce spatial bunching, and a second wiggler resonant at 1000 Å. Upon passing through the second wiggler the prebunched electron beam first radiates coherently, and then this radiation is exponentially amplified. Finally, a tapered section is used to extract additional power from the electron beam. In this manner we can achieve pulses of duration ≈ 10 psec with 1 mJ per pulse in 10^{-4} bandwidth, with continuously tunable wavelength in the range 750-3000 Å.

The FEL consists of an initial 2 m long wiggler resonant at 3000 Å, a dispersion section of length 20cm and 2.8 kG magnetic field, and a second wiggler resonant at 1000 Å of length 11 m. The interaction of the 3000 Å, 4.2 MW seed pulse with the electron beam produces an energy modulation at 3000 Å. This energy modulation is converted into a spatial bunching with a strong third harmonic component at 1000 Å in the dispersion section. When the coherently bunched beam enters the second wiggler magnet, there is a rapid coherent generation of 1000 Å radiation within the first meter, and the radiation has a characteristic quadratic dependence on distance traversed in the wiggler. There is then a transition to exponential growth which continues until 7 m into the wiggler, where the 1000 Å radiation approaches saturation. At this point the taper begins. The three distinct stages in the second wiggler (the quadratic "superradiance" growth, the exponential growth, and the quadratic growth in the tapered section) are shown clearly when the radiation power plotted against the wiggler length in Fig. 2.

The seeded single pass FEL has many advantages. The output bandwidth is controlled by the input seed, limited only by the pulse length, and a bandwidth of 10^{-4} is possible. Similarly, the frequency stability is also controlled by the seed; hence the electron beam energy stability influences only the output intensity fluctuations, and the requirement on the energy stability is largely relaxed. Another obvious advantage is that the mirror damage problem is eliminated. In addition, there is no need for a long train of micropulses, the electron beam can consist of single micropulses with the high repetition rate available from a superconducting linac. Thus it is possible to achieve very good energy stability and high average power.

Table 3 lists some of the FEL parameters calculated for a conservative estimate of the electron beam and wiggler parameters, at an output wavelength of 1000Å.

By using the 'Fresh Bunch' technique [5] the output power of the FEL may be increased under certain conditions by an order of magnitude or more. The results presented in Table 3 are for a seeded FEL which does not use this technique.

Table 3. Baseline FEL Parameters

Emittance used in calculation (norm., rms)	8 π mm mrad
FWHM local energy spread in calculation	0.1 %
Tuning range of wavelength by linac energy	750 Å - 3000 Å
Fast tuning range (modulators)	30 %
Input laser power	4.2 MW
Subharmonic wiggler:	
length	2 m,
λ_W	3.5 cm,
B_W	0.765 T
Dispersive section	20 cm at 0 to 0.4 T
Main wiggler:	
λ_W	2.2 cm
Exponential section:	
Length	7 m
B_W	0.748 T
Magnetic gap	6 mm
Power at the end of this section	17 MW
Tapered section:	
Length	4 m
B_W taper	quadratic, 1.2%
Power	1.55×10^8 W
Maximum output energy for a 6 pS pulse	1 mJ
Shortest pulse	0.2 pS

We have calculated the performance of the FEL at 750Å and tested its sensitivity relative to various parameters. To reach 750Å we will quadruple a 3000Å seed, and obtain an output power of 42 MW for a beam energy of $\gamma=566$ and current of 300 amperes. If the current is reduced to 270 amperes, the output power drops to 24 MW. On the other hand, a reduction of the current and emittance by 20% actually increases slightly the output power to 44 MW. The emittance of 8 π mm mrad is critical, since an increase of the emittance to 9 π mm mrad reduces the output power to 20 MW after readjustment of the input seed power and dispersive section field.

Preliminary studies of the bandwidth dependance on the micropulse energy spread show that a linear chirp of about 0.3% does not broaden the bandwidth from the transform limit but produces a slight shift of the wavelength centroid. On the other hand a non linear chirp (cubic energy vs. position) may double the output bandwidth.

THE RELAY OPTICS TO EXPERIMENTS

To provide efficient use of the FEL output, an optical system has been devised which allows the photon beam to be relayed to several laboratories. The system takes advantage of the characteristics of the FEL radiation, and the placement of the laboratory space roughly 3.5 m above the accelerator plant. Four laboratories are served directly by each wiggler line. Parabolic mirrors are used to deflect the radiation up to the lab, and focus at the experimental station. The beam can be redirected to the horizontal plane and the focus modified by use of a Kirkpatrick-Biaez pair of spherical mirrors. The parabolic focusing mirrors are mounted on manipulators so they can be placed in the FEL beam, or moved out so the light can be relayed on to the next experimental station. In this way each FEL serves only one user at a time. Another optical system is under development which allows the beam to be multiplexed from pulse to pulse between each of the four users of a particular wiggler.

This is accomplished by interposing a pair of flat mirrors which are mounted in a rotating holder [15]. The incidence angle on these mirrors is only ten degrees, so down to 500 angstroms the loss introduced by these mirrors is minimal. The mirrors are placed so that they produce a net vertical deflection but no angular deflection. The parabolic mirror can be lowered into the displaced beam and the radiation delivered to the experiment as previously described. The multiplexing mirrors can also be rotated so the FEL beam passes on to the next station to intercept either another multiplexing mirror or a stationary parabolic mirror. An arrangement of four pairs of mirrors mounted in a cylinder needs to rotate at 37500 RPM to provide a switching rate of 5 kHz. While this seems excessive, it is well within demonstrated limits for UHV rotating machinery. Turbo-molecular pumps with speeds as high as 100000 RPM are for example commercially available. Each user of the system can select the desired wavelength by optical switching of their own FEL seed laser, and programming of the energy modulating cavities prior to the wiggler.

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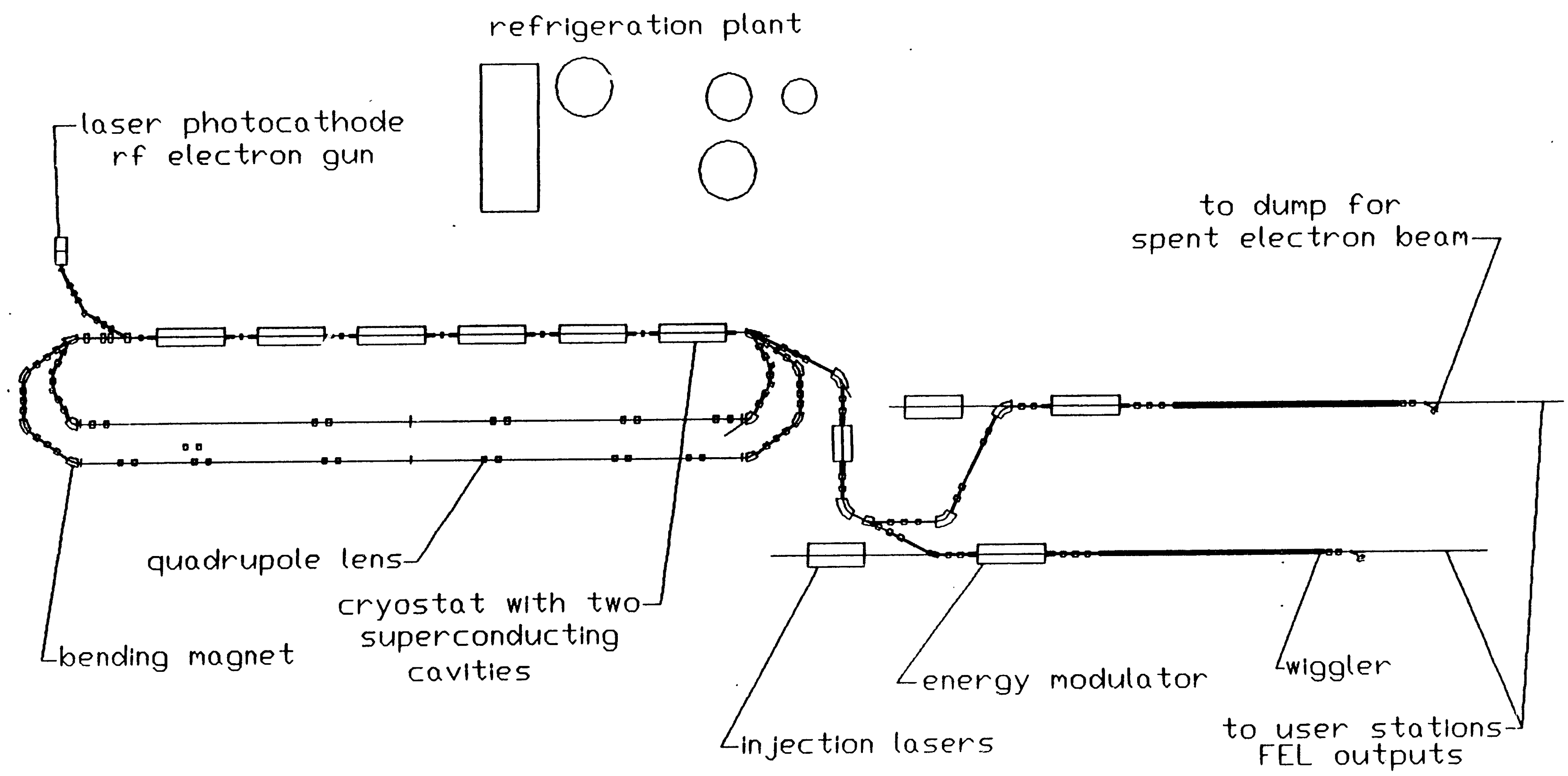
15. The suggestion of H.A. Schwettman for this device is gratefuly acknowledged.


refrigeration plant
laser photocathode rf electron gun
to dump for spent electron beam
quadrupole lens
cryostat with two superconducting cavities
bending magnet
injection lasers
energy modulator
wiggler
to user stations FEL outputs

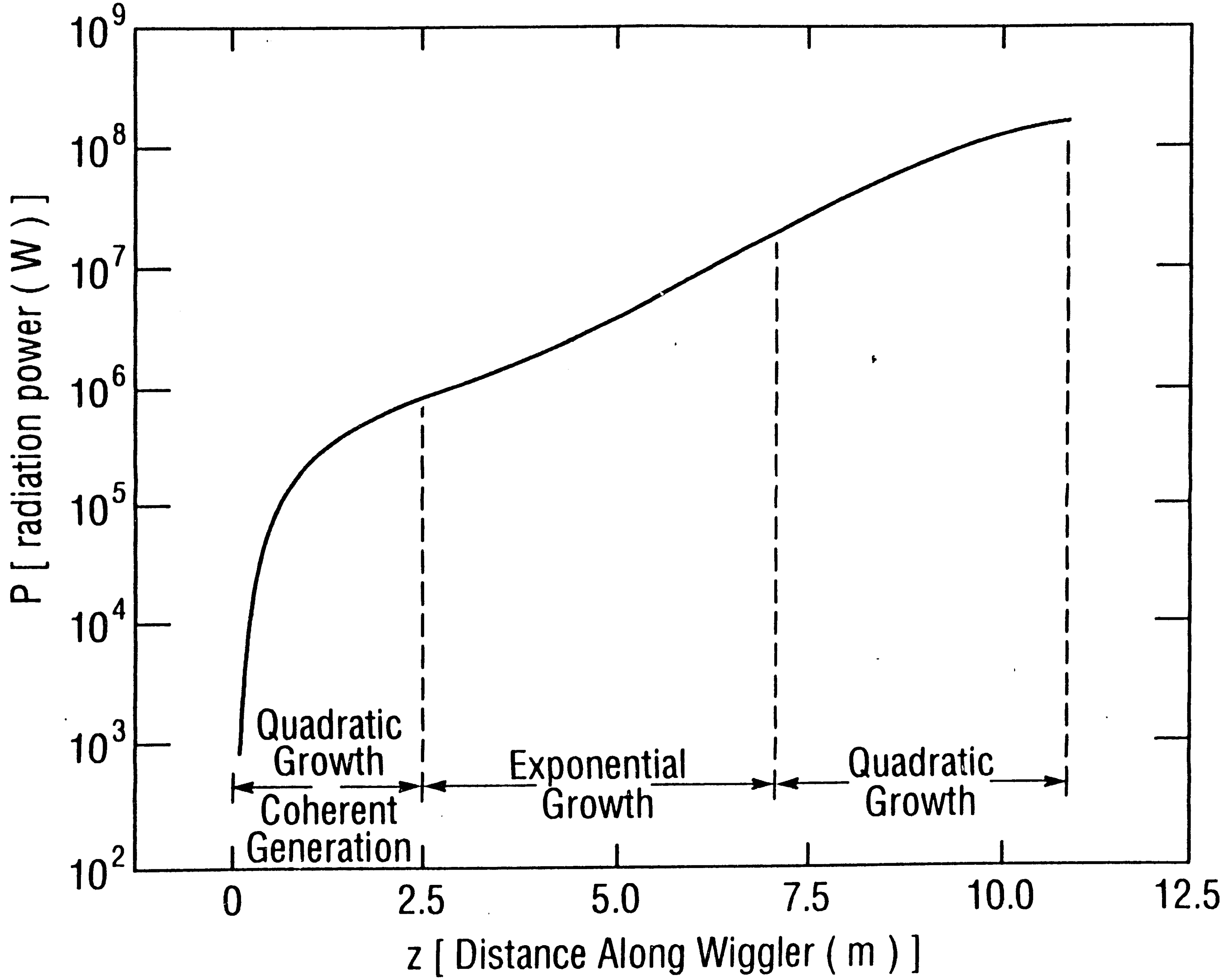

10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
P [radiation power (W)]
Quadratic Growth
Coherent Generation
Exponential Growth
Quadratic Growth
0
2.5
5.0
7.5
10.0
12.5
z [Distance Along Wiggler (m)]

Fig.2

END

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