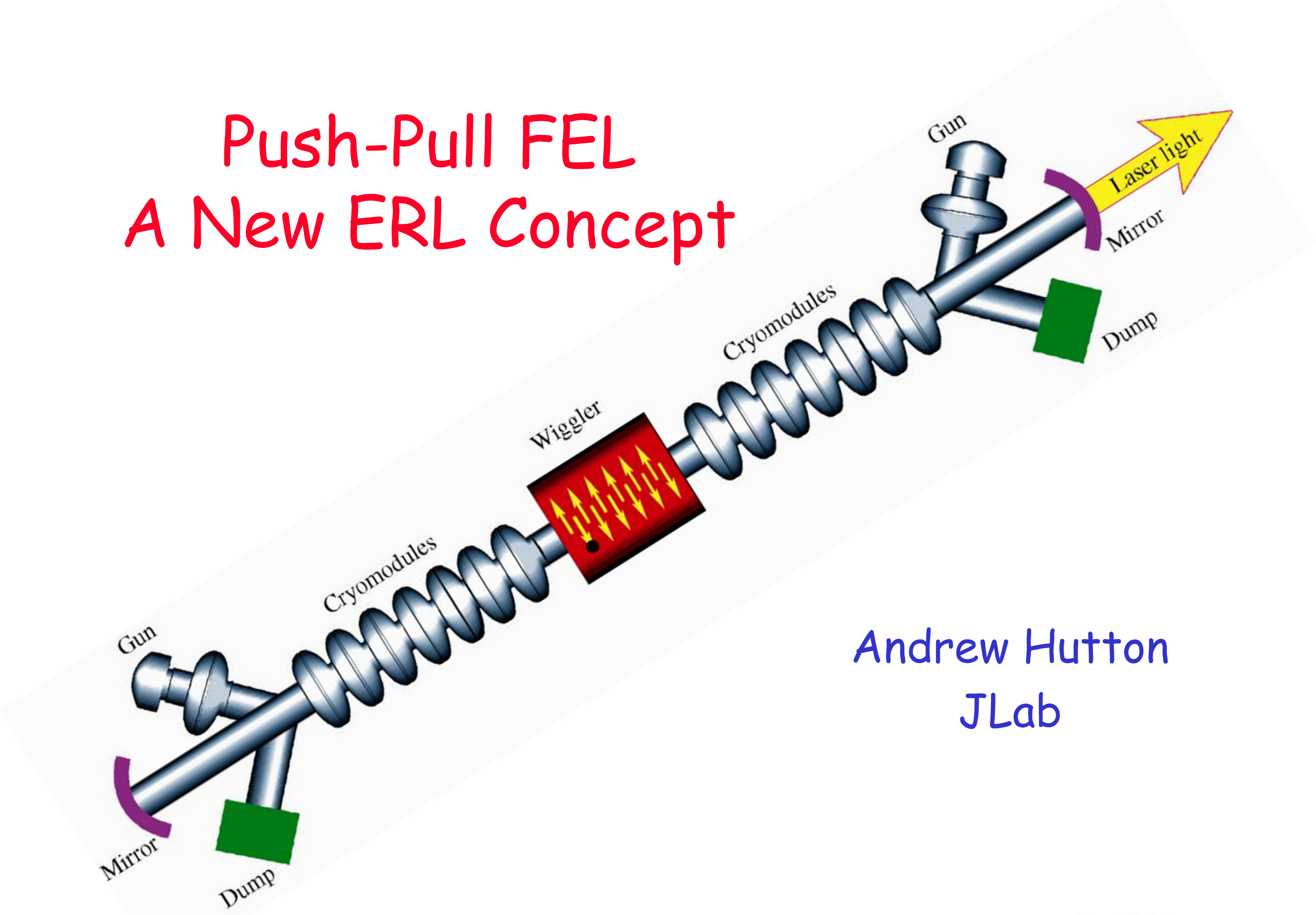
Push-Pull FEL
A New ERL Concept



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Drivers for a New Concept

- The ILC will use superconducting technology
  - Many components of the X-FEL at DESY are similar
- Most components of a superconducting accelerator are being, or will be, industrialized for the ILC and the X-FEL
  - Cryomodules
  - Injector
  - RF power sources

Concept - design an FEL based on "cheap" ILC components

- Modifies the design of the electron optics in favor of:
  - more cryomodules
  - more injectors
  - less beam transport

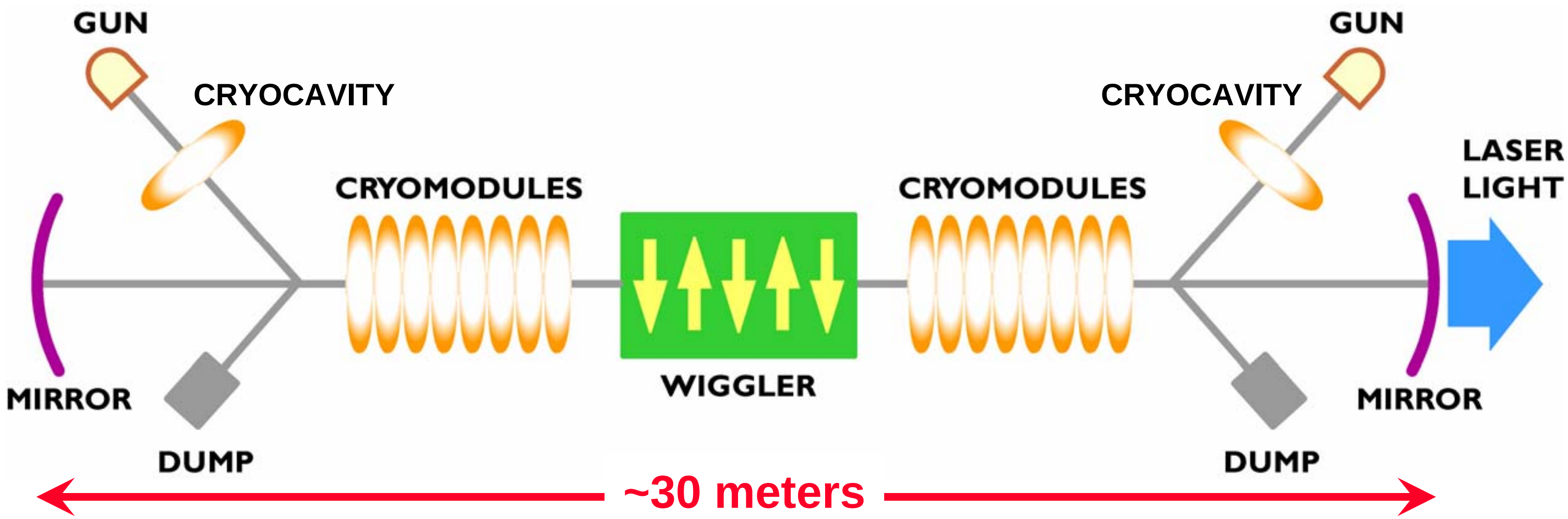
New Concept - Electrons

- New concept uses two sets of superconducting cavities with two identical electron beams going in opposite directions
- Each set of superconducting cavities accelerates one electron beam and decelerates the other beam
  - The energy used to accelerate one beam is recovered and used for the other beam
- The difference between this proposal and other energy-recovery proposals is:
  - Each electron beam is accelerated by one structure and decelerated by another
  - This is energy exchange rather than energy recovery

Concept - Light

- A further simplification can occur if the superconducting cavities produce sufficient energy
- The superconducting cavities can be contained within the optical resonator with the light pulses traversing them
- This arrangement leads to an extremely compact layout suitable for a university laboratory

Conceptual Layout



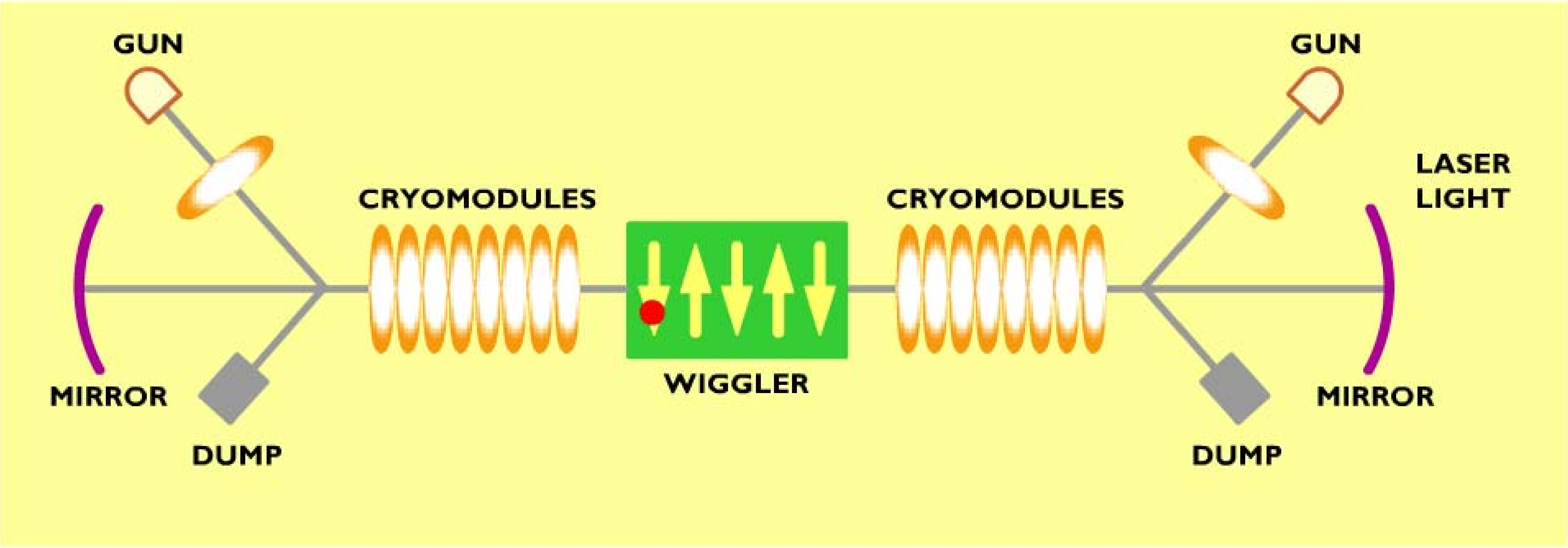
The two cryomodules containing the superconducting cavities flank a wiggler that is used to produce coherent light

The addition of a pair of mirrors outboard of the cryomodules completes the free Electron Laser (FEL) optical cavity

On either end, there is a 10 MeV injector (gun + cryocavity) that can either be a copy of that used at the Jefferson Lab FEL or (better) an SRF gun

The electron beams are brought onto the acceleration axis by a separator magnet, which also serves to bend the spent beam to a dump

Illustration of the Concept



Animation by Tom Oren

Energy Balance

- RF energy in the cryomodules is recovered completely
- RF energy given to the beam by the injector is partially converted to FEL light and partially dissipated in the dump
  - The bend magnet needs to be carefully designed to transport electrons with a large (~50%) energy spread to the dump with extremely small losses
  - Better alternative is to do energy compression

- So the maximum FEL power that can be extracted is some fraction (up to about 50%) of the power in the injector

Example Parameter Set

- An example of a parameter set has been calculated
  - Compared to design parameters of 10 kW JLab FEL
  - Design power output has been achieved, so parameters are within the state of the art
- The superconducting cavities are based on DESY X-FEL prototypes
  - Cryomodule contains eight 9-cell superconducting cavities operating at 23 MV/m for a total of 190 MV
  - The superconducting cavity in the injector is one of the same cavities operating at less than 10 MV/m
    - Injection energy should be less than ~10 MV to avoid neutron activation of the dump

Parameter Example

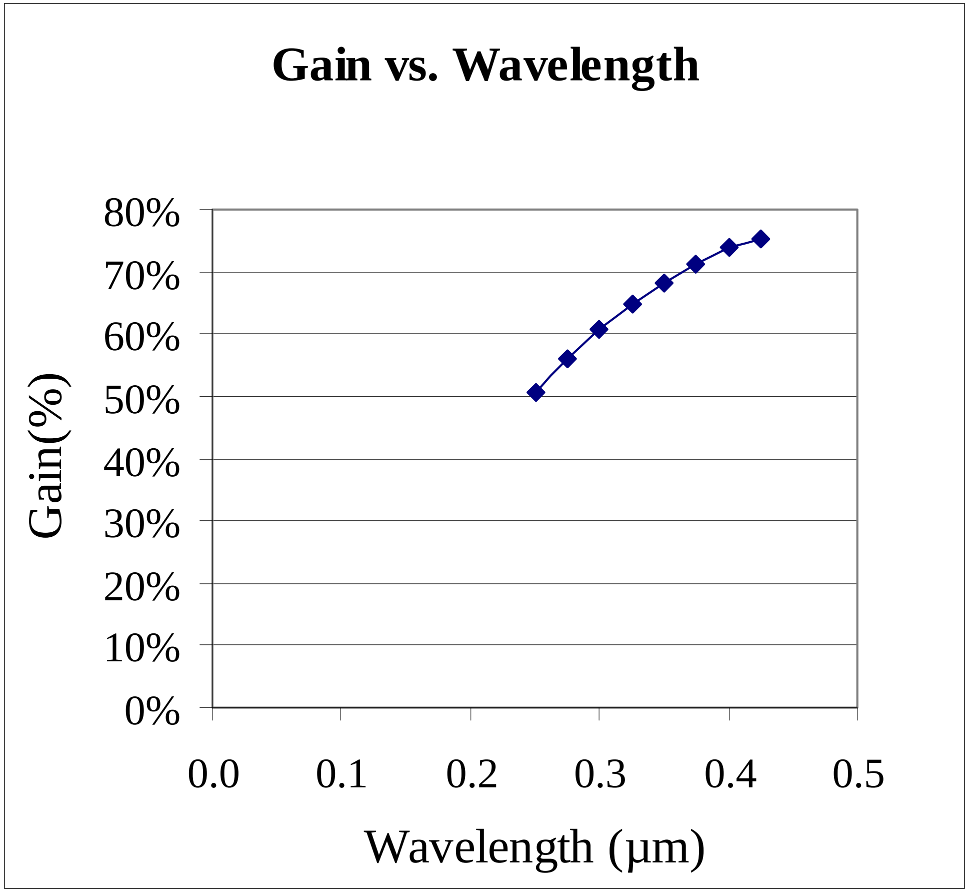
Parameter	10 kW JLab FEL Design	Push-Pull FEL Design
Maximum Beam Energy	80 – 210 MeV	200 MeV
Injector Beam Energy	10 MeV	10 MeV
Beam Current	10 mA	2 x 0.5 mA
Beam Power	800 – 2100 kW	2 x 100 kW
Non-Recovered Beam Power	100 kW	2 x 5 kW
RF Frequency	1500 MHz	1300 MHz
FEL Repetition Rate	3.9 – 125 MHz RF Frequency/(4 – 384)	5.078 MHz RF Frequency/256
Optical Cavity Length	32 meter	29.539 meter
Bunch Charge	135 pC @ 75 MHz	100 pC
Energy Spread after Wiggler	10% of 210 MeV	2.5% of 200 MeV
Energy Spread at Dump	~2% of 10 MeV	50% of 10 MeV
FEL Output Power	10 kW in the Infrared 1 kW in the UV	> 1 kW in the UV with bunch compression

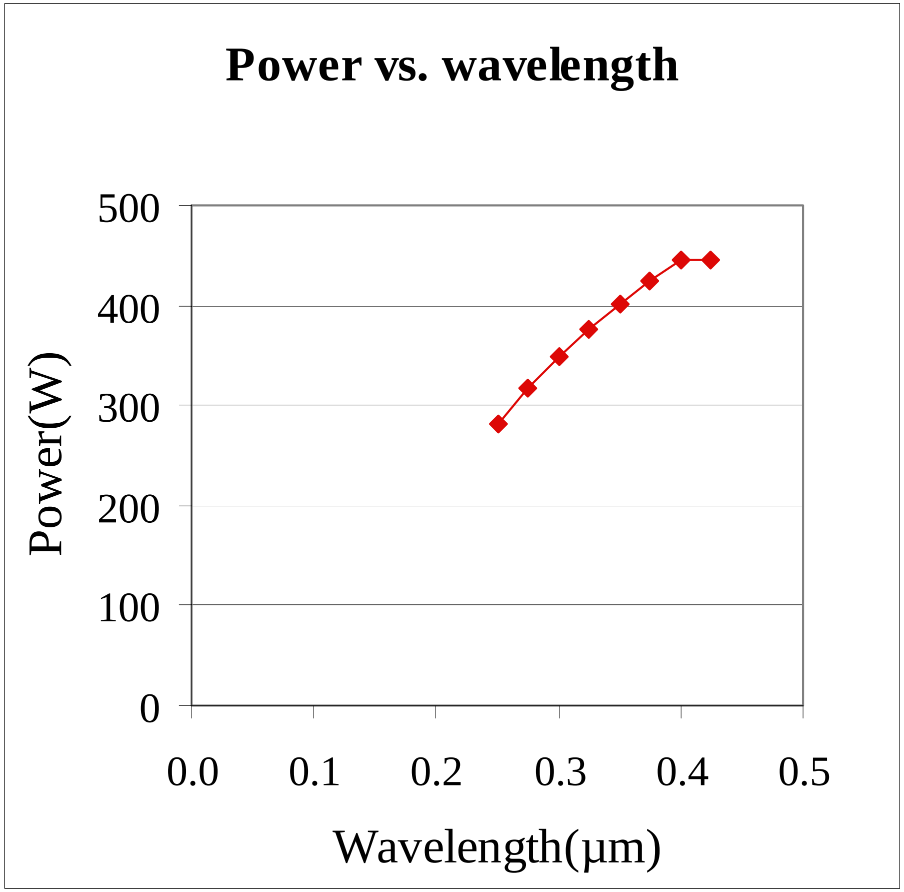
Light Output Estimated by Steve Benson (1)

- The first case assumes that the electron bunches are not compressed, which gives the most compact system
  - Since the energy is 200 MeV and the charge is 100 pC the obvious application for the driver is for a UV laser
  - Undulator A from ANL, wiggler design that worked well for the UV and for a 200 MeV beam was assumed
- With this wiggler and a 2 psec FWHM bunch length there is a gain of about 60% in the UV and the power estimated by the spreadsheet is a few hundred Watts

- Since the bunch is so long, the spreadsheet assumption that there is a single super-mode breaks down so the power may be much higher

Long Bunch Characteristics



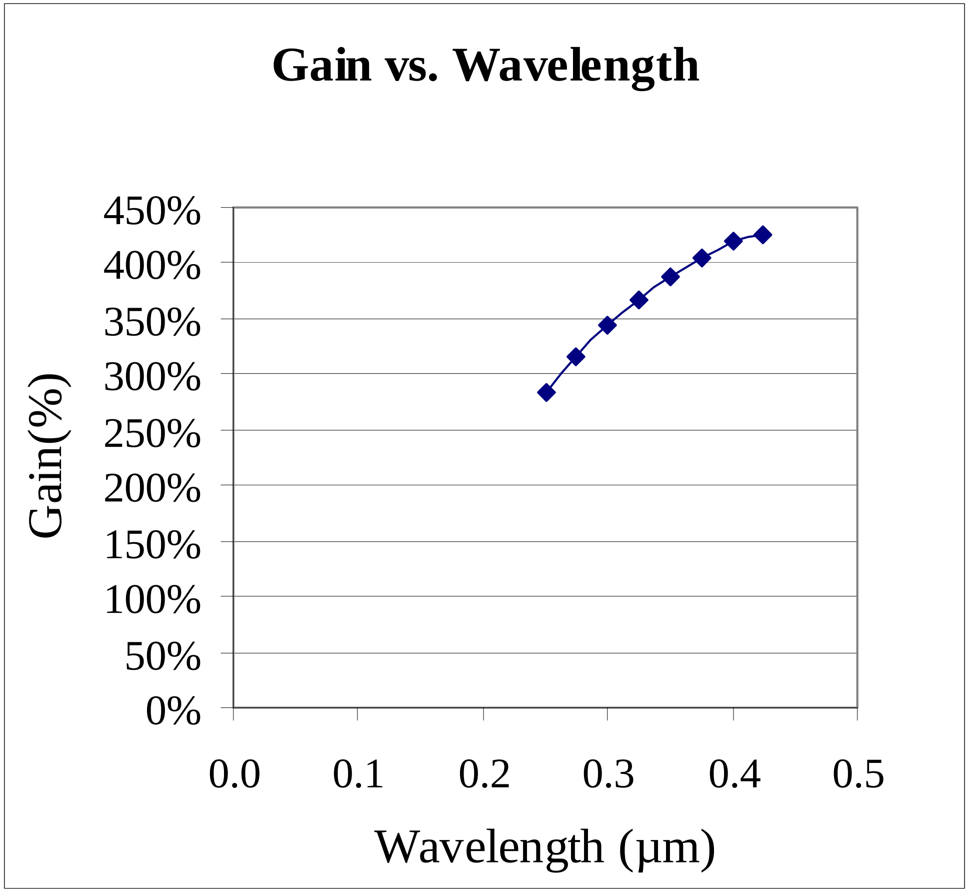


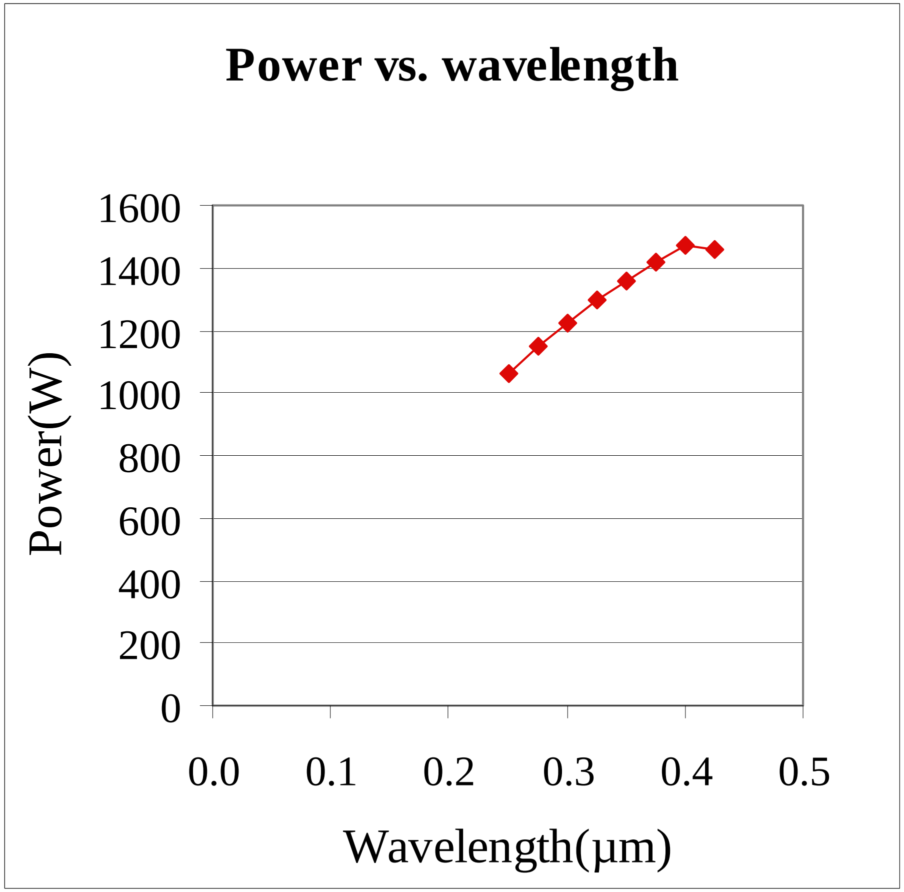
Courtesy of Steve Benson

Light Output Estimated by Steve Benson (2)

- The second scheme assumes a buncher/debuncher system which can bunch down to 1/3 of a psec FWHM
- This gives very high gain of several hundred percent
- The power is estimated to be more than 1 kW
  - This is high enough that the power limit will be the optics and not the electron beam

Short Bunch Characteristics





Courtesy of Steve Benson

Other Hardware

- RF Power source
  - The klystron being developed at Cornell for the ERL Light Source would be perfect for this application
    - Enough power for injectors and one cryomodule
- RF Distribution and Low-Level RF control
  - The RF power distribution system and LLRF control adopted for ILC is perfect for this application
  - Will act on fast ferrite tuners to apply power to individual cavities

Beam Optics by Dave Douglas (1)

- The optics for the Push-Pull FEL will be based on a quadrupole doublet at each Injector and two quadrupole doublets each side of the wiggler
- The optics is designed to focus a round beam at the cathode to a round beam at the center of the wiggler
- Since a vertically focusing quadrupole for the accelerating beam will be vertically defocusing for the decelerating beam and vice versa, the vertical beta functions for the accelerating beam will be identical to horizontal beta functions of the decelerating beam and vice versa
- This design automatically provides well behaved optics for both beams
  - It is well suited to the beam with nominal bunch length

Operated by the Southeastern Universities Research Association for the U.S. Department of Energy

Beam Optics by Dave Douglas (2)

- The output power can be considerably enhanced by using a chicane to bunch the beams more tightly
- In this case, the edge focusing of the chicane bends is independent of the direction of the particle
  - This destroys the anti-symmetry of the simple focusing scheme and requires the use of chicane magnets with carefully shaped poles
  - Still working on detailed layout
- This will be the subject of a later paper

Outstanding Questions

- Drive laser rep rate (5 MHz) is not easy
  - Lasers like high rep rate or low rep rate
  - A few MHz is currently difficult
  - The most stable solution uses a single drive laser with a splitter providing light to both guns
    - Needs precisely calibrated optical delay
    - Avoids problem of precisely synchronizing two separate lasers
  - Drive laser needs real work

- Complete a detailed design
  - No obvious problem areas other than the laser
  - Integrate bunch compression/energy compression

Summary

A new ERL concept is proposed

- Small footprint and few tunable parameters
  - Optimal for a university laboratory setting
- Uses components being developed for the ILC
  - Should become cheap and reliable

Design studies will continue

Awaiting a User with deep pockets!

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