Class Organization

	Monday	Tuesday	Wednesday	Thursday	Friday
9:00-9:30	class organization & introductions	homework discussion	homework discussion	homework discussion	Exam
9:30-11am	1. Introduction and Motivation	4. RF gun fields, dynamics w/o space charge	9. Beam Diagnostics	13. Drive lasers and cathodes	Exam
	break	break	break	break	break
11-12:30	2.a Emission statistics and cathode emittance	5. Beam dynamics with space charge: Emittance compensation	10.Beam matching and acceleration	14. Current topics of Injector Physics, I	
12:30-1:30pm	lunch	lunch	lunch	lunch	lunch
1:30-3:00	2.b Emission statistics and cathode emittance (continued)	7. Collective effects and space charge waves	11. Classes of guns: NCRF, DC, SRF)	15. Current topics of Injector Physics, II	
3-3:30pm	break	break	break	break	break
3:30-5pm	3. Space charge limited emission and the ultimate emittance	8. Beam optics & Emittance Growth	12. Architecture of Injectors	Class discussion of homework, etc.	

Please initial audit/credit form

Electron Injectors for 4th Generation Light Sources

Introduction & Motivation

- The objective of this lecture is to justify the importance of injectors for the new generation of light sources based on Free Electron Lasers. This is done from both technical and economic points of view. The evolution of injector technology and the improvement in beam quality over the years is presented.

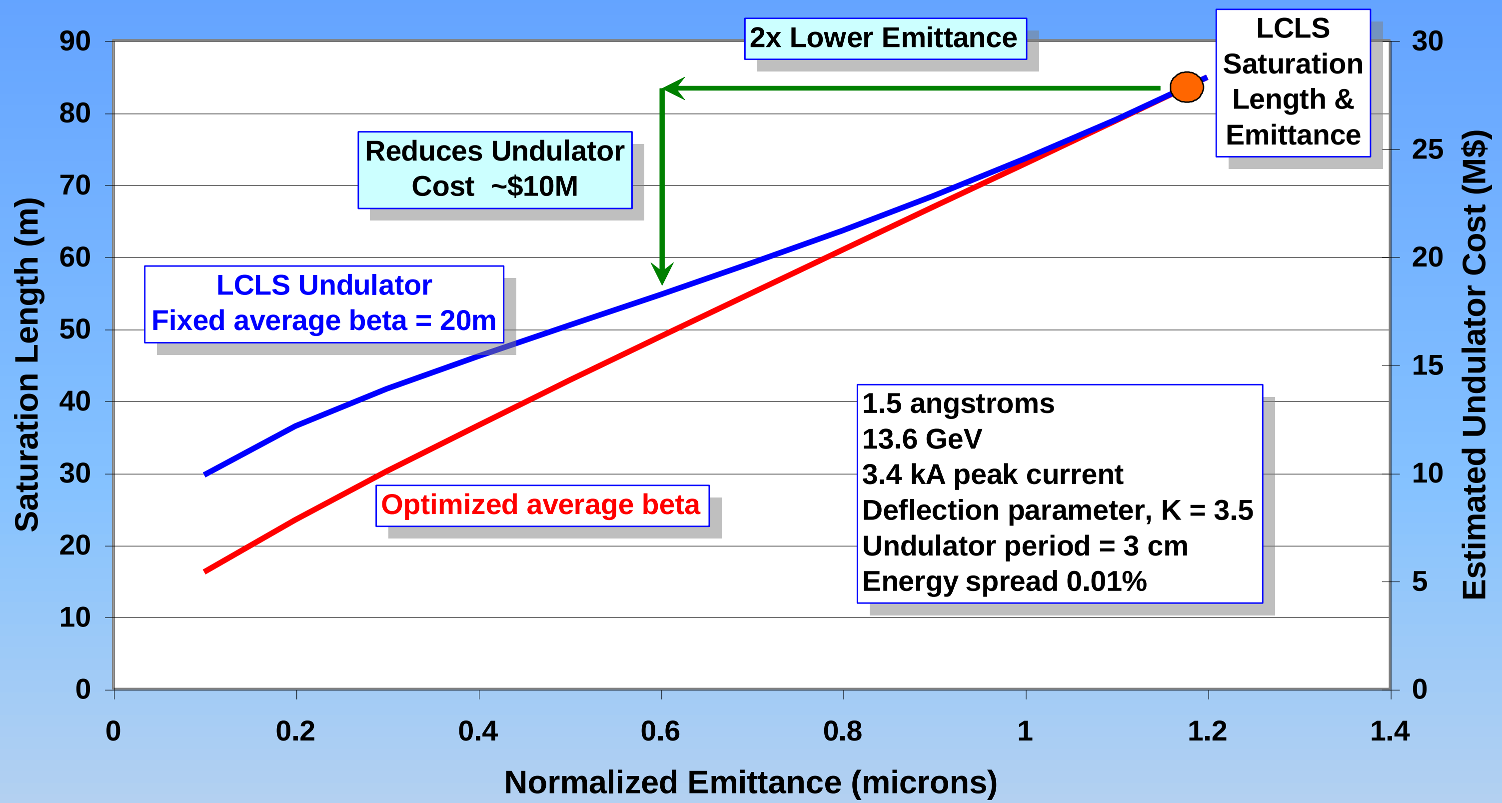
Emittance Requirement for FEL's

The importance of low-emittance can be demonstrated by evaluating the ratio of normalized emittance to beam energy required for a FEL to operate at a given wavelength, FEL, as given by the following relation,

$$\frac{\epsilon_N}{\gamma} < \frac{\lambda_{FEL}}{4\pi}$$

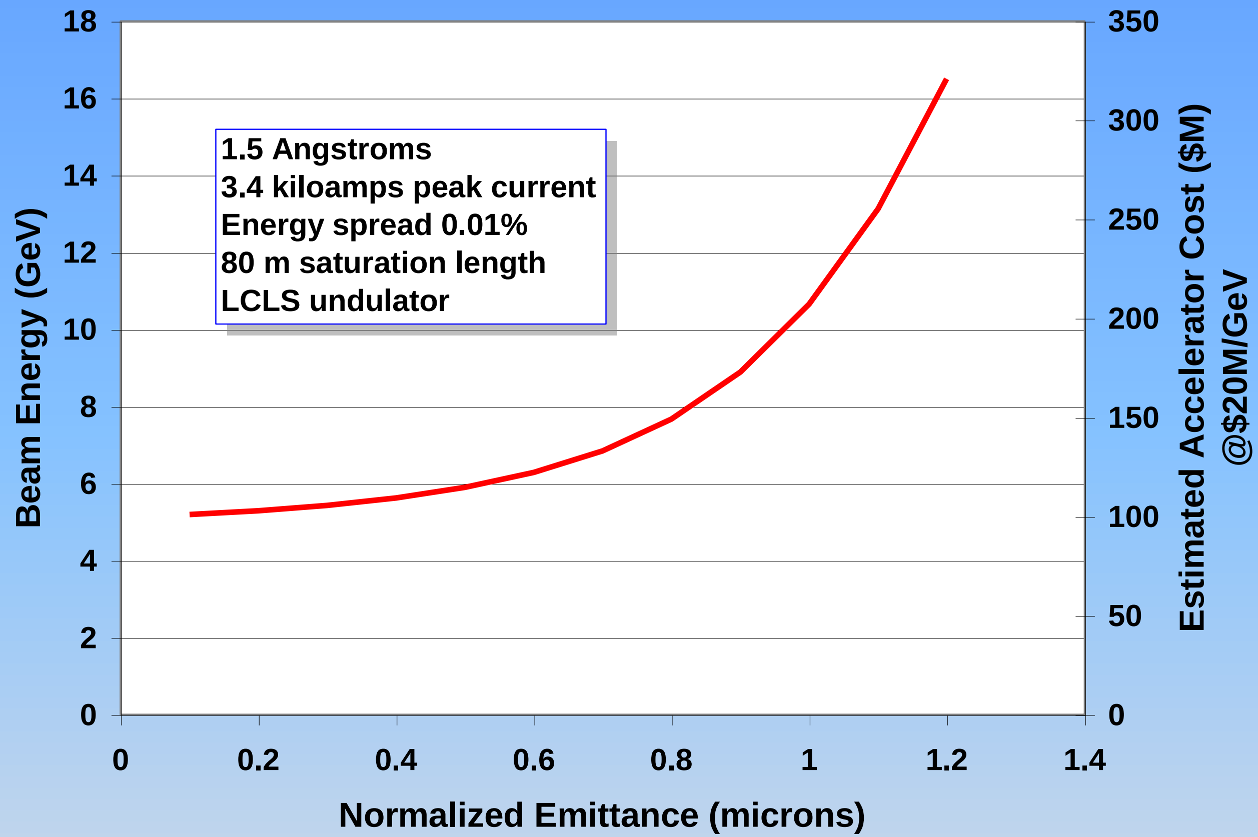
Where ε_N is the normalized emittance and γ is the reduced beam energy. Thus, it is possible for an FEL to operate at any beam emittance provided the energy is high enough to satisfy this condition. However this is done at great expense, especially for the new x-ray devices being constructed and proposed.

Economics of the Injector



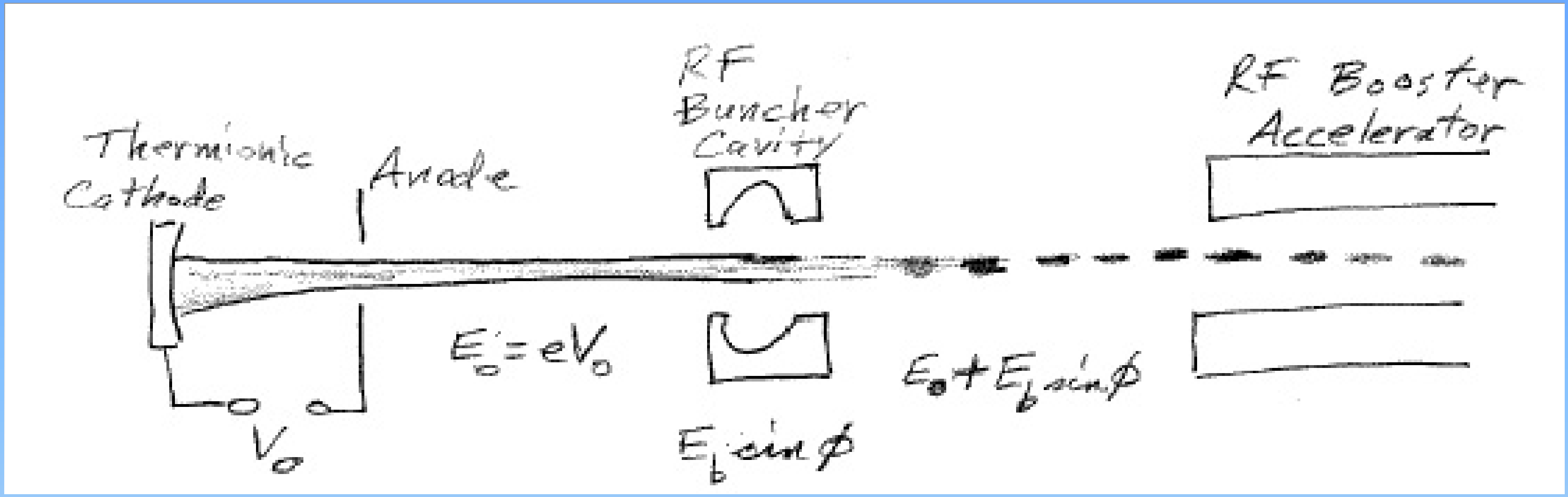
- The Linac Coherent Light Source (LCLS) design is based upon using the 13.6 GeV electron beam from the SLAC linac to reach saturated laser power within 80 meters of the undulator at a wavelength of 1.5 angstroms. To achieve this requires a normalized emittance of 1.2 microns at a bunch charge of 1 nC. Beams with emittances greater than 1.8 microns are below the lasing threshold.

Economics of the Injector



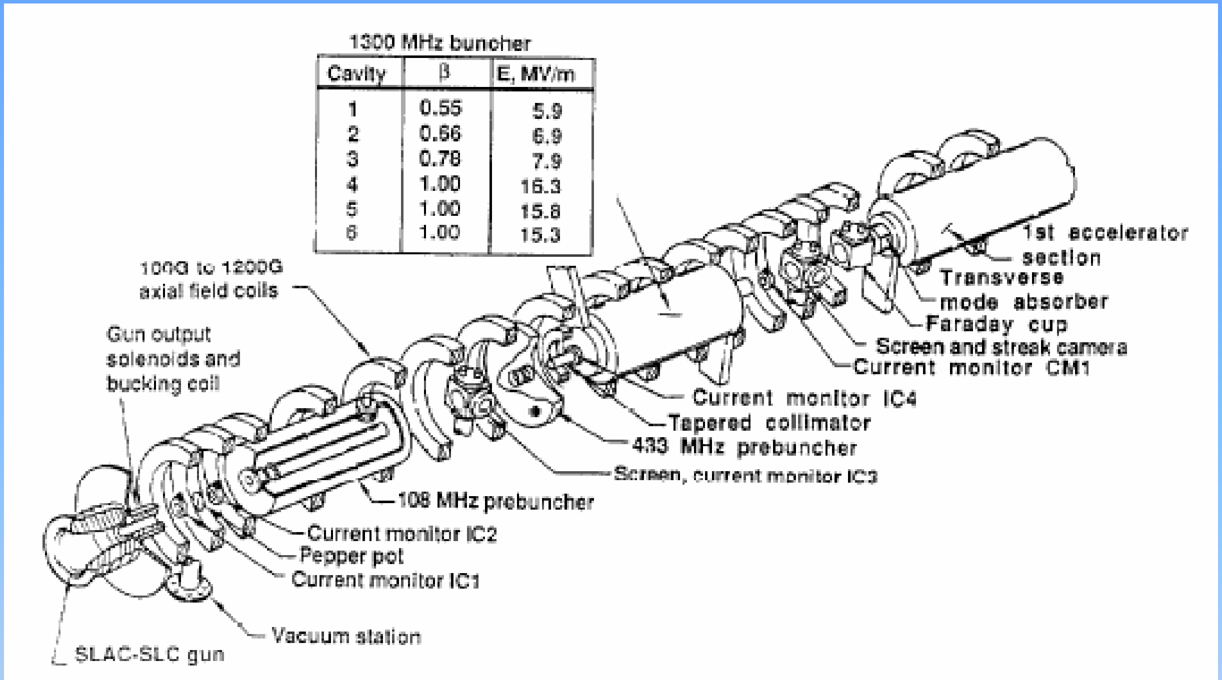
- Reduced emittance greatly lowers the beam energy and hence the cost and size of the accelerator facility. Even a modest reduction from 1.2 to 0.8 microns would lead to a savings of more than $100M in the construction of a green field x-ray FEL.

A Brief History of RF Injectors



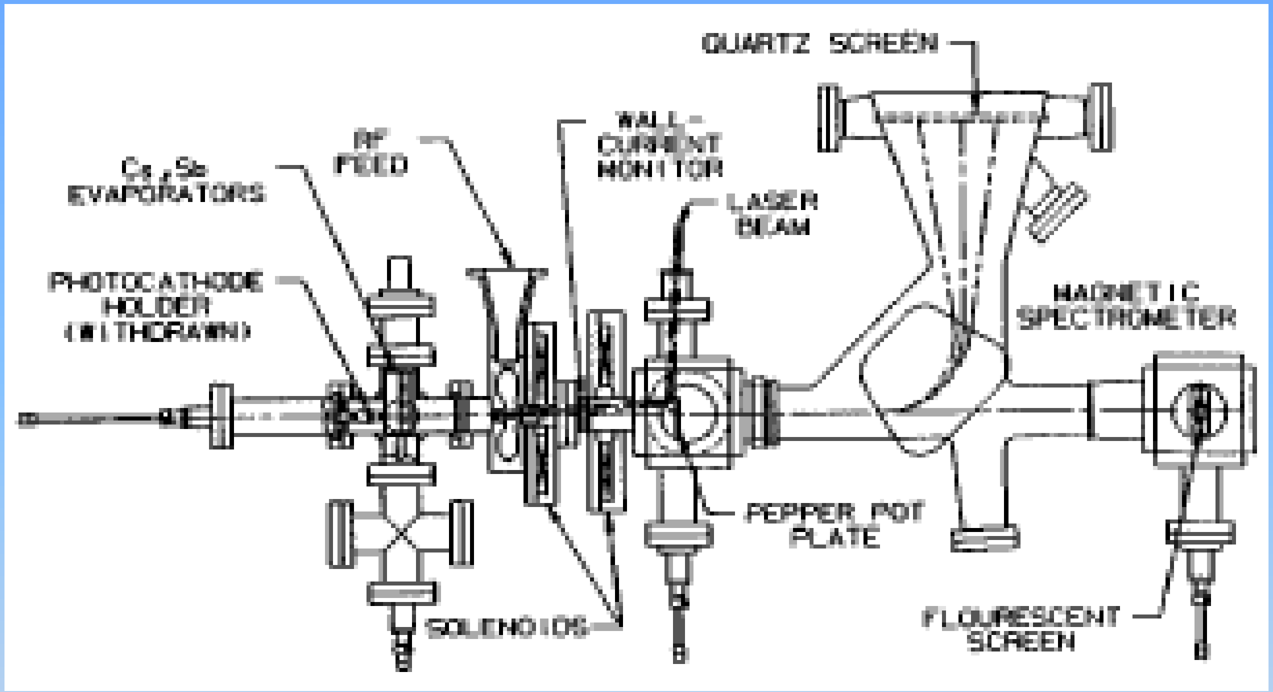
- An early injector for bunching the beam into the phase space acceptance of the booster linac. In this approach, the DC beam from a thermionic gun is first energy modulated by the buncher cavity which ballistically compresses electrons over less than 180 deg at the buncher cavity.

A Brief History of RF Injectors



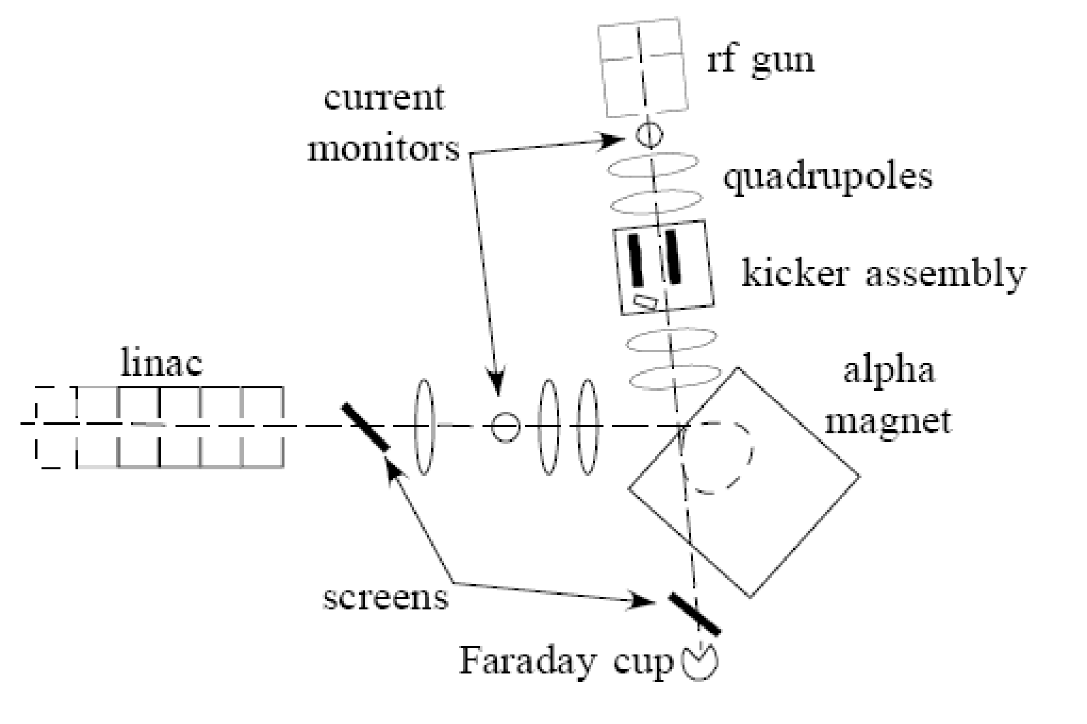
- In a considerably more complicated approach the charge per bunch is increased by using two stages of lower rf frequencies to compress more of the DC beam into the phase acceptance of the booster. The design begins with a 90 keV thermionic gun followed by first a 108 MHz and then 433 MHz prebuncher cavities which used ballistic compression before final RF compression in a tapered phase velocity buncher at the main accelerator frequency of 1300 MHz.

The first RF photocathode gun operated at Los Alamos National Laboratory in 1985.



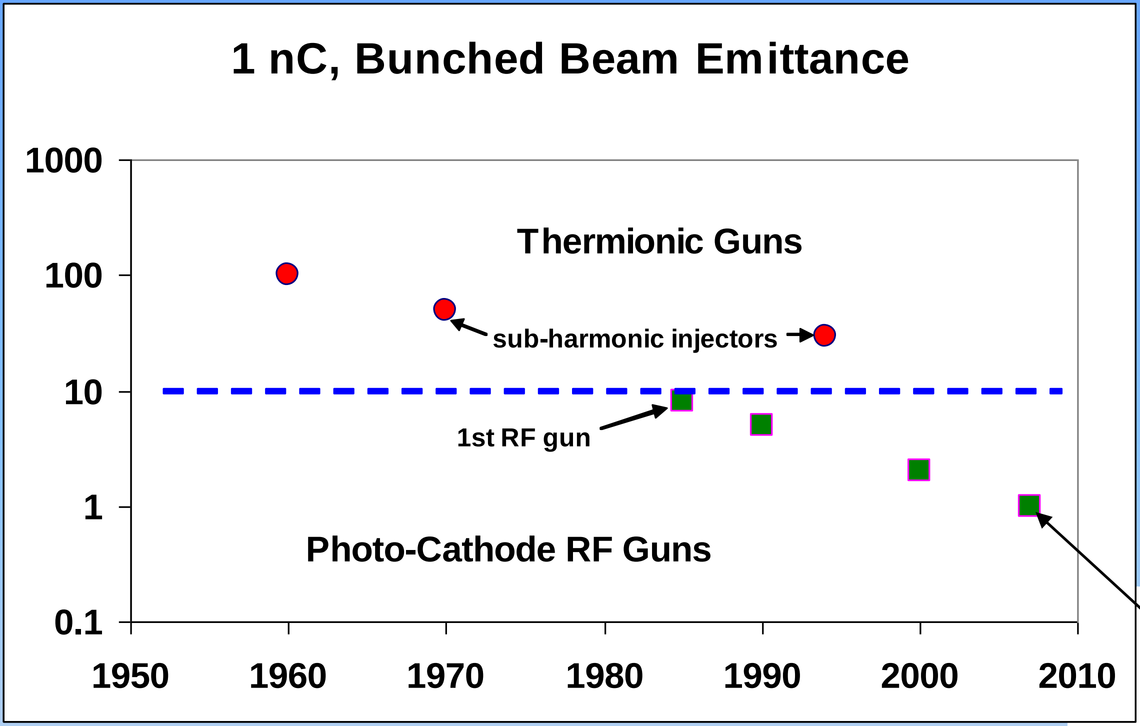
- The next stage of development was driven by the need for fast and precise control of the electron pulse shape for better beam quality and to reduce halo and beam loss. The pulsed thermionic cathode was replaced by a much faster laser driving a photo-cathode, and the photo-cathode was put into the RF cavity. With this development, the emittance was 10-times or more lower than that of the thermionic injector.

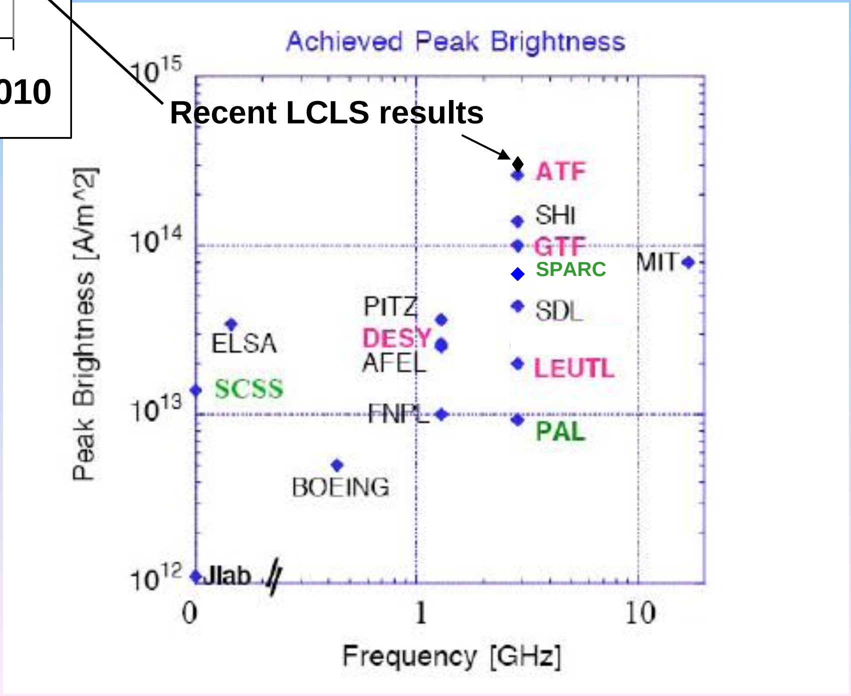
A Brief History of RF Injectors



- In a parallel development, the thermionic cathode was placed in the RF cavity to avoid needing a photocathode and drive laser. It produces a long, low charge pulse train at the gun's RF frequency which is compressed in an "alpha" magnet This type of gun is widely used for injection into 3rd generation light sources like APS at Argonne and SSRL at SLAC.

Evolution of Beam Quality





A Brief History of RF Injectors
Final Comments

- However there were and remain problems with the photo-cathode gun. Principally the laser and the cathode are problematic. Developments in laser technology have solved many of the laser problems and the advent of diode pumped solid state lasers has given us a stable and reliable source of photons. Someday perhaps even the large, microwave accelerator will be replaced with an optical scale device.
- Unfortunately there have been few improvements in the photocathodes for RF guns in recent years. Most of the photo-sensor market is based on solid state diodes like charge-coupled-devices used in digital cameras. And even photo-multiplier tubes are being replaced by avalanche photodiodes. The market for vacuum electron tubes is declining and being replaced by solid state devices.

Elements of Electron Injectors

Emission & Initial Acceleration

- Thermionic cathode
  - Gridded-DC gun
  - DC gun
  - NCRF gun
- Photo-electric cathode
  - DC gun
  - NCRF gun
  - SRF gun
- Field-emission cathode
  - Pulsed-DC
  - RF
  - Pulsed-DC+ NCRF

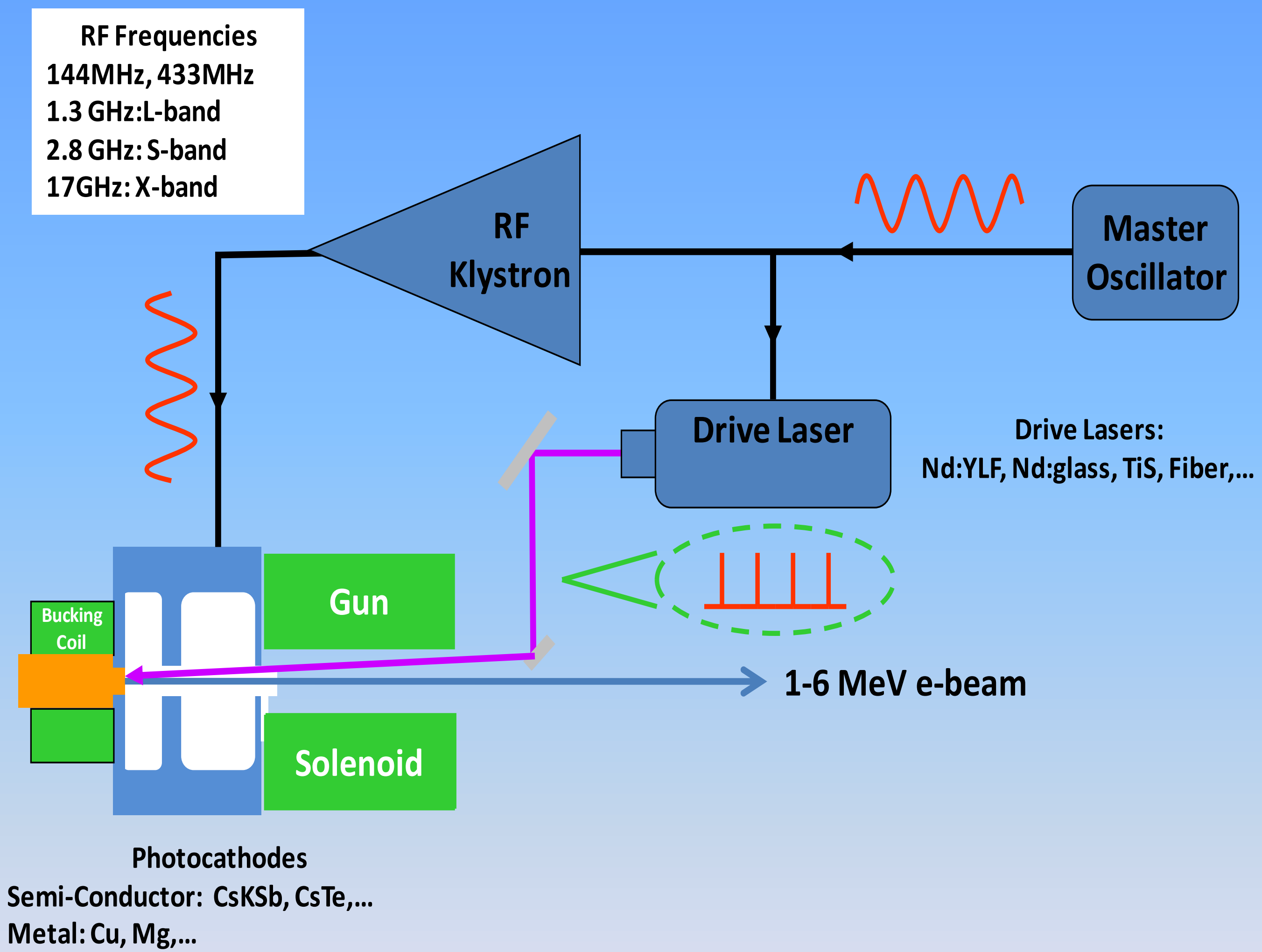
Beam Conditioning

- Emittance compensation
  - Solenoid focusing
  - RF focusing
  - Slice phase space matching
- Ballistic compression
  - Fundamental & sub-harmonic RF
  - Inductive linac
- Magnetic compression
  - RF harmonic linearizing
- RF compression
  - Solenoid focusing
  - Tapered RF phase bunching

Acceleration

- Capture into booster
- Emittance preservation
- Longitudinal phase space compensation
- Chirping for bunch compressors

- **The electron injector can be divided into three major parts, each according to their function. These components are the cathode-gun source, the beam conditioner and the accelerator. The source can be further divided into categories based upon the emission mechanism and the external field type. Later we consider three cathode types defined by the three emission phenomena: thermionic, photo-electric and field-emission. These are then matched with the commonly used accelerating fields of DC, normal conducting RF (NCRF), superconducting RF (SRF) and pulsed DC.**


RF Frequencies
144MHz, 433MHz
1.3 GHz:L-band
2.8 GHz: S-band
17GHz: X-band
RF
Klystron
Master
Oscillator
Drive Laser
Drive Lasers:
Nd:YLF, Nd:glass, TiS, Fiber,...
Bucking
Coil
Gun
Solenoid
1-6 MeV e-beam
Photocathodes
Semi-Conductor: CsKSb, CsTe,...
Metal: Cu, Mg,...

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