

Some Thoughts on Figures of Merit, SC and RT Facilities

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Day Of Action Dawns With Excitement; Protests Underway

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Amazing Inspiring Funny Scary Hot Crazy Important Weird

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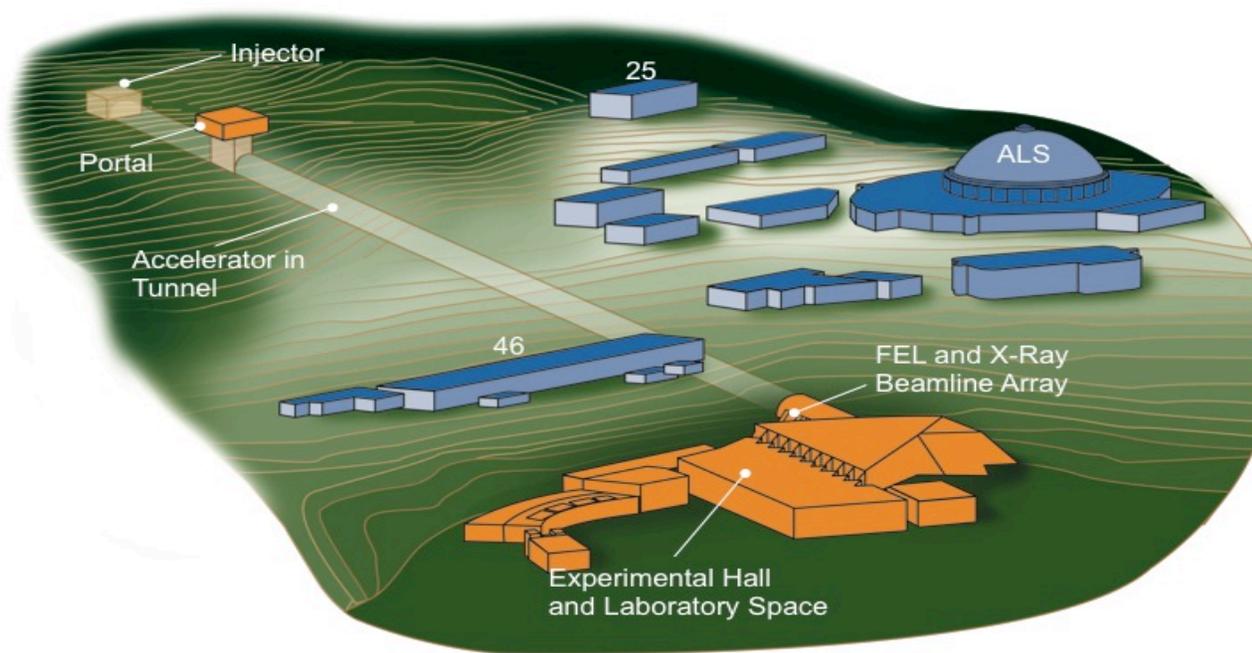
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Students, professors, teachers and unions around the country will organize today to protest America's imperiled system of education with more than 100 events in 32 states.

The movement started in California, where the

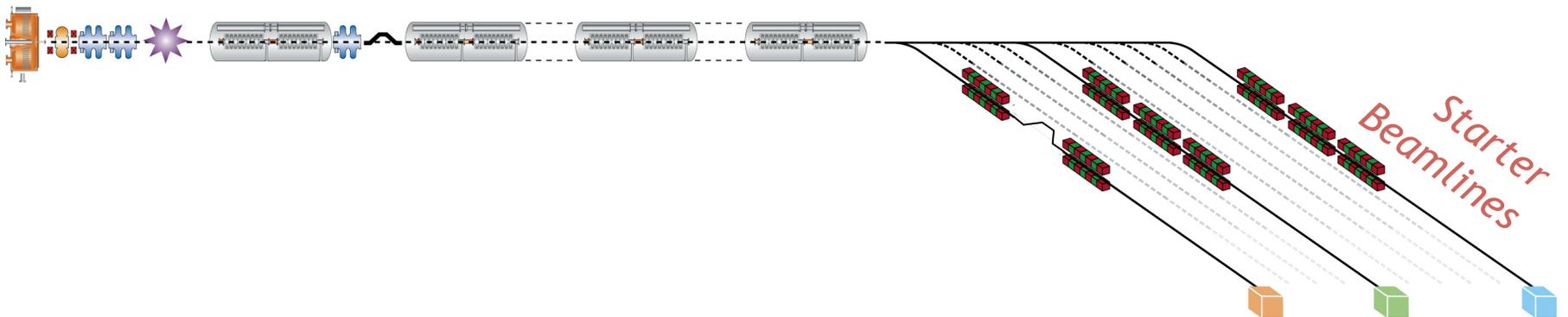
Future Light Source



High Repetition Rate
Electron Source

2.0 - 2.5 GeV
CW SC LINAC

Capability for
10/20 FEL beamlines



Some Thoughts on Figures-of-Merit

- A **GeV/\$** metric seems more appropriate for **high energy particles physics** applications than for **light sources**
 - and even in particle physics, **luminosity/\$** is at least equally important
- for a future taxpayer-funded light source, **opening of new experimental territory** / enabling of “high impact” and/or “grand challenge” science is obviously important
 - yet difficult to predict, and even more difficult to quantify
- for an experimental photon science facility, some primary figures-of-merit probably ought to refer to **photons** and to **experiments** with them, in addition to **time** and **cost** constraints:

$$\frac{\text{useful photons}}{\$}$$

$$\frac{\text{useful photons}}{\text{second}}$$

$$\frac{\text{experiments served}}{\text{week}}$$

- **costs (\$)** might include operational and some suitably amortized fixed costs
- “**useful**” varies with experiment, and encapsulates numerous features (*wavelength, bandwidth, duration, spot size, divergence, photons per pulse, peak brightness, jitter, repetition rate and timing structure, pulse shape, polarization, chirp, tunability, synchronizability, etc.*)
 - but very generally means: **the right numbers of photons (neither too few nor too many) of the right colors and right polarizations in the right places in the right directions at the right times....**

A sample of user requests

- High average flux and brightness
- High pulse repetition rates (≥ 100 kHz at each experimental end-station)
- Low pulse repetition rate (< 1 kHz suffices)
- Pulse durations ranging from attoseconds to hundreds of femtoseconds
- Temporal coherence of the FEL output pulses (close to the Fourier transform-limit)
- Control of the time duration, bandwidth, and other longitudinal features of the pulses (i.e., certain envelope shaping, modulation, or structuring)
- Capability for excellent spectral resolving power without the need for monochromators
- Synchronization of the FEL pulses to the seed laser or other IR or Terahertz references (with jitter or timing errors on the order of 1 – 10 fs)
- FEL output wavelength tunability
- Capability for precision x-ray pump- x-ray probe experiments
- Capability for precision pump-probe experiments with combined x-ray/optical/IR/THz bands
- Transverse coherence (approaching diffraction limits)
- Soft x-ray
- Hard x-ray

One machine will not satisfy all users: different classes of science can be accessed by different machines. What are the critical beam physics issues and facility issues to address among all the experimental desires?

Figures-of-Merit and SC RF

- These figures-of-merit support argument in favor of superconducting accelerating structures:
 - Optimal radiation phase space is obviously strongly dependent on experiments in which it is to be used, BUT
 - Numerous potentially interesting experiments involve BOTH
 - » poor SNR because of small cross sections, low contrast, inefficient detectors, large backgrounds, etc.
 - » low-ish photon thresholds for sample damage, disruption, or disturbance
 - These classes of experiments need sufficient peak rightness but cannot use nor tolerate excessive **peak brightness**, but definitely require high **average brightness**
- For these experiments **high repetition rates** will be essential for data acquisition in reasonable time
- **At needed electron energies and bunch charge, and with constraints on size/facility costs and power requirements/operating costs, design is pushed to superconducting RF**
- High repetition rates offer additional ways to improve figures-of-merit:
 - **multiplexing** electron bunches to multiple radiation beam lines
 - supports simultaneous experiments using independently-configurable FELs
 - lowers **marginal costs** of adding additional radiation beams
 - allows high-speed, high-gain **feedback** and control
 - feedback possible on RF, electron bunches, and/or x-ray pulses
 - lower uncertainties in and fluctuations of electron bunch and x-ray pulse properties
 - highest possible stability expected in **CW** operation
 - higher overall **energy efficiency (not as high as pulsed SC, however)**
 - including cryogenics

SCRF CW linac soft x-ray FEL example

- Electron beam parameters determined by consideration of:
 - radiation requirements (x-ray wavelength, bandwidth, brightness, etc.)
 - technological constraints (injectors, linacs, undulators, etc.)
 - economic constraints (“million dollars per meter”)
 - help determine electron beam requirements:
- Working backwards from these constraints:
 - 2.5 GeV electron energy: chosen to achieve 1nm (1.2 keV) x-rays with realistic (SASE or seeded) FEL technology
 - other e-bunch goals include 10 pC - 1 nC bunch charges, 1 mm mrad or less transverse slice emittance, 100 keV or less energy spread, 250 as to 500 fs pulse duration
 - assuming ~10-15 MW power consumption and ~20% wall-to-accelerator efficiency
 - ~1 MHz bunch repetition rates in linac are feasible
 - ~1 mA average current
 - ~100 kHz x-ray pulse repetition rates in each of ~10 FEL beamlines
 - ~10⁻⁵ overall power efficiency
 - size/cost constraints additionally suggest cavity gradients of ~10 MV/m (effective gradient is less)
- These energy, charge, repetition-rate, and power requirements **virtually necessitate SC technology**
 - warm copper structures would be limited by resistive heating to about 1 kHz CW
- **If the goal is to provide CW electron bunches at rates approaching 1 MHz, SC is, at least now, the appropriate technology choice.**

Room Temperature

- LCLS is not optimized for high repetition rate.
- Higher repetition rate can be reached using higher frequency RF and lower gradients.
- Conclusions taken from Tantawi Talk on Wednesday:
 1. With recent advances on high gradient accelerator structures and related RF systems, it is possible to think of an "efficient" room temperature high repetition rate low gradient linacs.
 2. Reduced power levels/unit length "easily" permit designs with gradients of 10 MV/m-20 MV/m at repetition rates of 1 kHz-250 kHz
 3. System optimization may allow us to think of higher repetition rates, say 10 kHz, and perhaps higher gradients
 4. We assumed a very modular system architecture that does not contain any pulse compression system for optimum efficiency
 5. Wall plug power of these system range between 1- 3 MW for 2 GeV beam
- RT facilities based on high frequency RF will have significantly lower beam average beam power and hence photon power. They may have other advantages and disadvantages.
- We need a better understanding of the science reach, flexibility and costs of RT and SC machines

Closing Thought

- Given the major investment required to develop ANY X-ray FEL USER facility ($\sim \$10^9$) we should pursue innovation (and other roads to cost reductions) in all areas:
 - * Detectors
 - * Optics
 - * Wigglers
 - * Guns
 - * Injectors
 - * FEL concepts
- AND
- * We need enough facilities/funding to develop, innovate and test new ideas (a world wide effort). Making the best decisions requires ongoing R&D. Everyone wins if these facilities can have the same user base and science reach at lower costs.

Major construction projects should be built to last for many decades. The SLAC linac is a great example of building for the long-term.