Approaches to High Average Flux, High Brightness X-ray Sources Based on Inverse Compton Scattering

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Abstract

The desire to produce high fluxes of nearly monochromatic x-rays leads to the consideration of inverse Compton scattering based sources utilizing high average-power electron and laser beams. Both high efficiency per pass and high repetition-rate interactions are required to achieve high output flux in a linac based system. The generation and manipulation of such high energy beams is challenging, therefore methods that most efficiently utilize the available beams are desired. Here we present a set of approaches which combine high repetition-rate, multibunch, high-brightness photoinjectors with recirculated high-energy laser pulses. We discuss typical beam parameters which can be matched to available lasers. We also describe a conceptual system for preserving the interaction efficiency while allowing for the laser recirculation.

Introduction

Both high efficiency per pass and high repetition-rate interactions are required to achieve high output flux in a linac based system

High brilliance ICS ⇒ <1 photon/electron

High brightness ⇒ ~1nC/pulse

Common RF Photoinjector ⇒ 10Hz

∴ $<10^{11}$ photons/second

In practice, a flux several orders of magnitude lower is achieved

Many applications require higher flux or narrower bandwidth.

Table: Baseline parameters for the ICS system driven by short pulse versus a long pulse laser, both producing 15 keV X-rays.

Parameter	Short pulse (Ti:S)	Long Pulse (YLF)
e-Beam Energy	25 MeV	29 MeV
e-Beam Charge per Bunch	1 nC	
e-Beam Bunch Length	1 psec	10 ps
e-Beam Focal Spot (s)	10 mm	
Laser Energy	100 mJ	1 J
Laser Wavelength	800 nm	1064 nm
Laser Pulse Length	1 ps	10 ps
Laser Param. a_L	0.08	0.12
Number of laser periods	375	2819
Ng/N_e	0.02	0.32
X-rays per pulse, Ng	$3x10^7$	$2x10^9$

In a practically realizable system, efficiency is not imperative; cost, size, and complexity are.

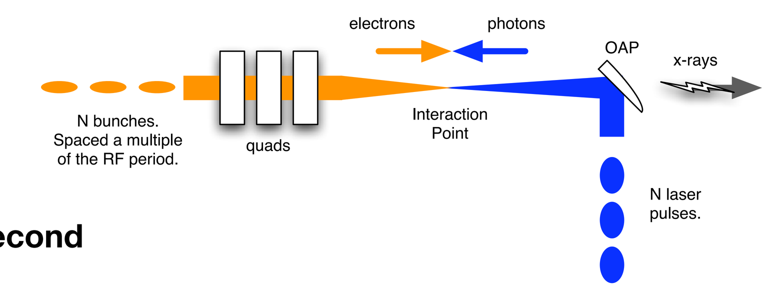
Method	Mono-chromatic	Frequency-tunable	Ultrafast	High-brightness	Cost	Flux
ICS	Yes	Yes	Yes	Yes	Moderate	Low-High
Bremsstrahlung	No	Yes	No	No	Low	Low
Line ionization	Yes	No	No	No	Low	Low
X-ray FEL	Yes	Yes	Yes	Yes	High	High
Synchrotron LS	Yes	Yes	No	Yes	High	High
Laser-plasma	Moderate	No	Yes	Moderate	Moderate	Low

An ERL provides a path to high flux with added complexity and still requires the other advances discussed here.

A combination of high repetition-rate, multibunch, high-brightness photoinjectors with recirculated laser pulses can produce high flux

Example:
1 kHz
100 bunches
100 recirculations

⇒ 10^5 more photons/second



Approach

Development in a number of key technology areas is ongoing and required to realize such an ICS system

❶ High repetition rate photoinjector
❷ Electron beam optics
❸ High Power capable support systems
❹ Laser beam recirculation

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High brightness RF photoinjectors are being designed to operate at high average powers

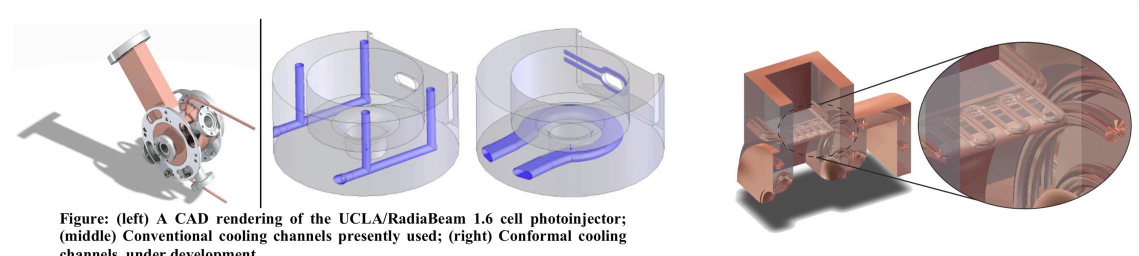

Figure: (left) A CAD rendering of the UCLA/RadiaBeam 1.6 cell photoinjector; (middle) Conventional cooling channels presently used; (right) Conformal cooling channels, under development.

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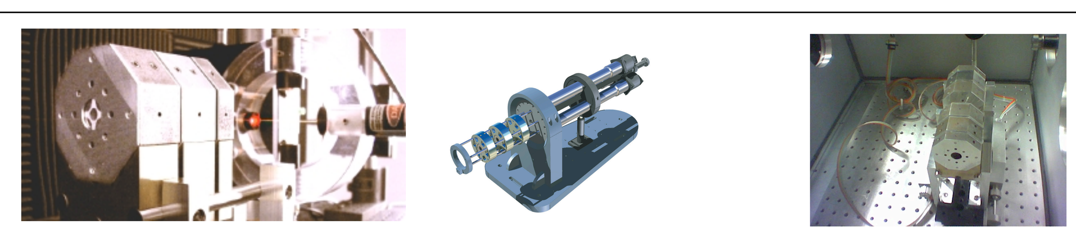
At lower beam energies, focal lengths are very short and beam manipulation is critical



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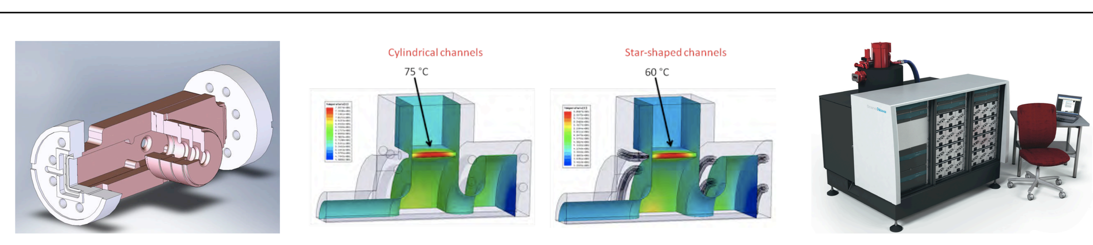
Solid state modulators; high repetition rate, cooled linac and gun sections and associated systems are all being or have been developed



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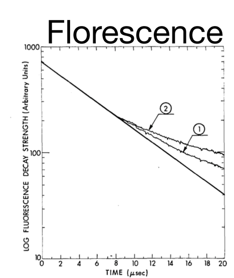
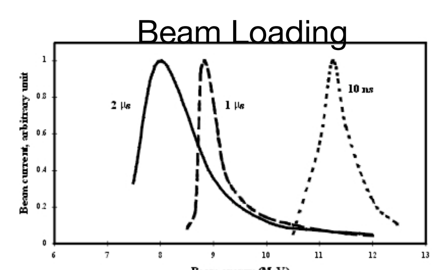
Producing multiple electron bunches costs a little laser power and a little RF power



~3 μsec



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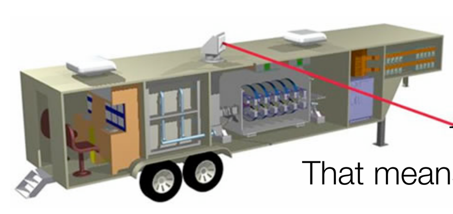
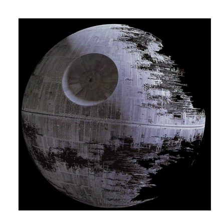
Producing multiple ICS laser pulses costs a lot of laser gain and is technically unrealizable today



1 J/pulse
1KHz rep rate
100 pulses per train
That means 100kW average power laser



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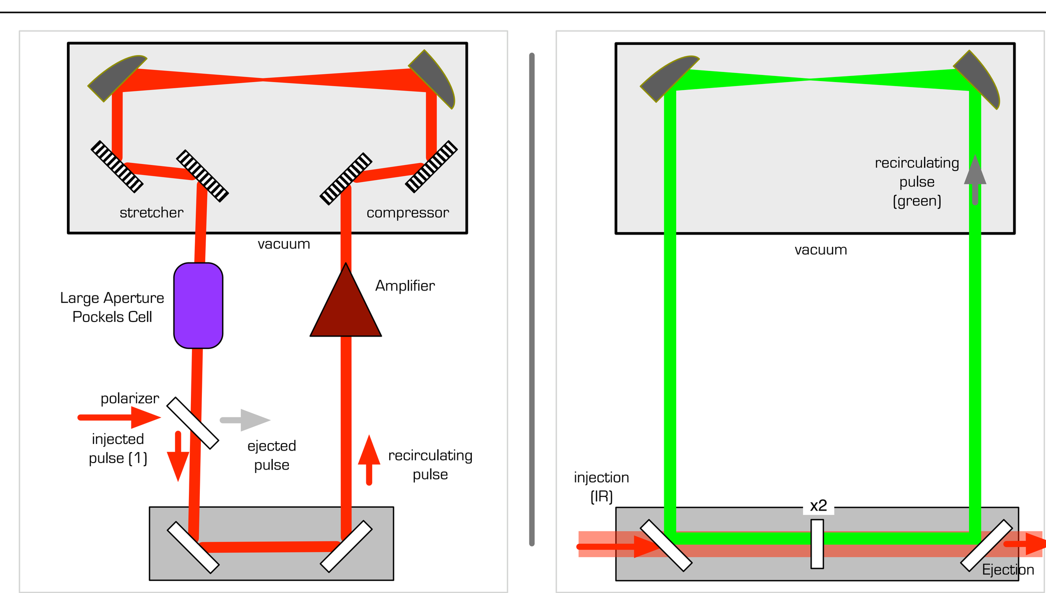
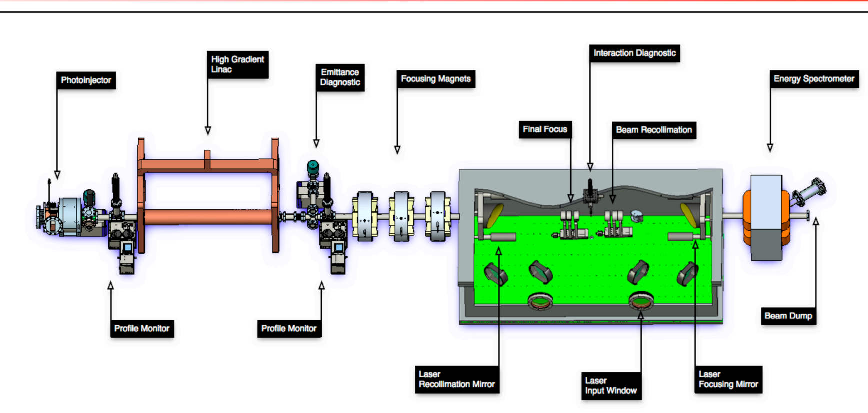
Recirculating the laser, while not trivial, is a path to generating many interactions per second



Next Steps

Developing an integrated interaction point system and deploying a full system

- Vacuum enclosure;
- Laser focusing OAPs with holes for electron beam propagation;
- Cooled and motorized mounts;
- Permanent Magnet Quadrupoles (PMQs) for electron beam focusing and recollimation;
- IP Diagnostic (diamond cube) for spatial and temporal overlap; and,
- Feedback alignment diagnostics.



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