High-flux Inverse Compton Scattering for Medical, Industrial and Security Applications

radiabeam
TECHNOLOGIES

Applications of ICS

- Medical Imaging
- Radiotherapy
- Non-Destructive Testing
- Research
- **Security/Defense**: long-range detection of special nuclear materials via photofission
  - > 6 MeV monochromatic X-ray source with low divergence
  - Recently completed a Phase I SBIR for DTRA
- *All applications require more average flux than currently produced...*
  - *10^{12} photons/second required*

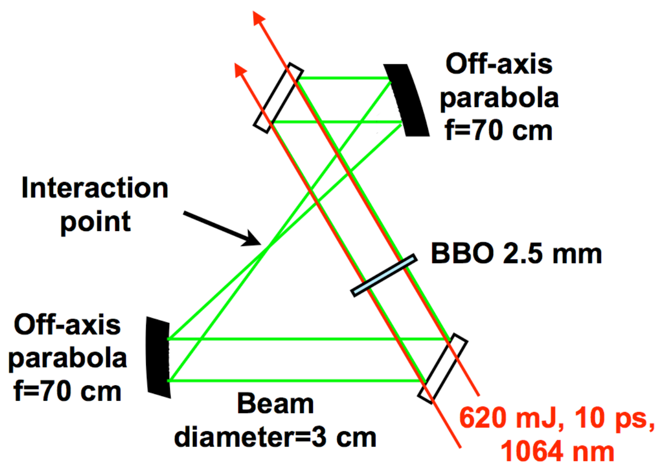
Our approach

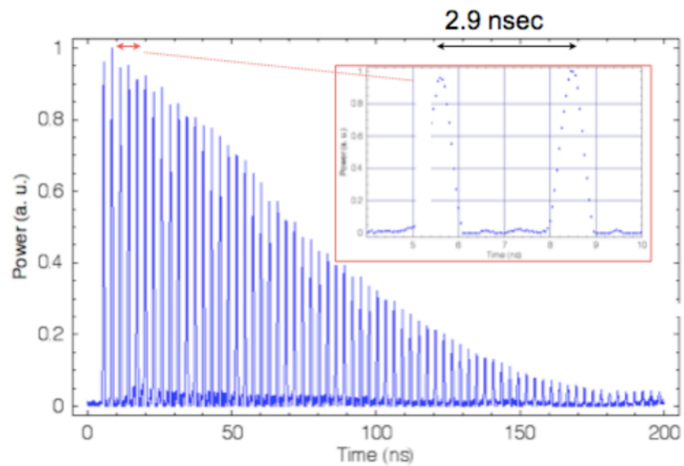
- Use proven technology (photoinjector, ultra-fast laser)
- Increase “effective” repetition rate using laser pulse recirculation, multiple electron bunches
    - Goal: X 100 increase in flux
- Use Adaptive Optics/Feedback system for laser and accelerator to increase stability
- Integrate laser recirculator/final focus and electron beam final focus system (PMQs) into a single vacuum box
- Eventually implement high-rep rate gun (1 kHz) and laser to gain another factor of 100 in flux
- ***100 - 10,000 improvement in average flux***

radiabeam
TECHNOLOGIES

Laser recirculator

- **R**ecirculation **I**njection by **N**onlinear **G**ating (**RING**)
  - Developed at LLNL [I. Jovanovic *et al*]
  - IR pulse injected and frequency-doubled
  - Green pulse recirculated through final focus
- Advantage: simple, inexpensive, can handle high power
- Disadvantage: “Ring-down”

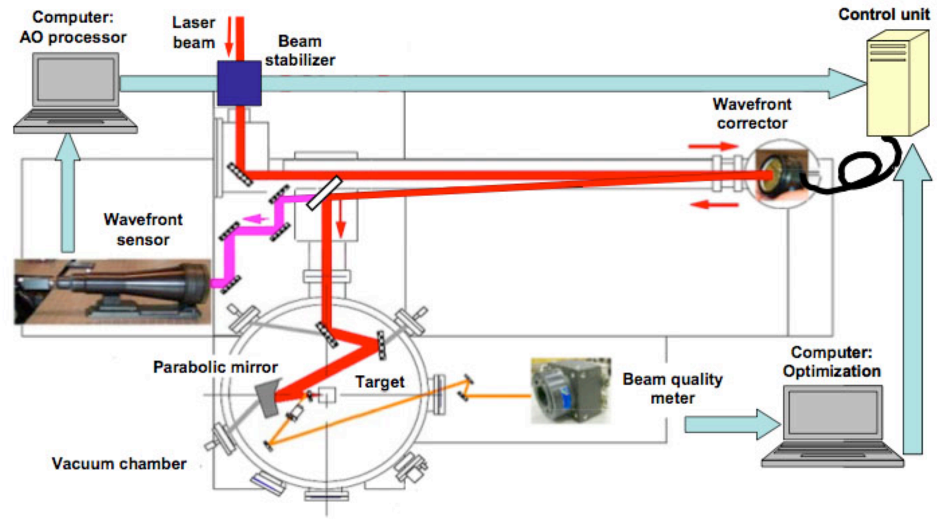




radiabeam TECHNOLOGIES

Adaptive Optics/Feedback

- Laser AO system before Interaction Region
  - Beam stabilizer: fast steering mirrors and position sensitive detectors
  - Wavefront corrector: deformable mirror and Shack-Hartmann sensor
- Accelerator diagnostics feedback to control system

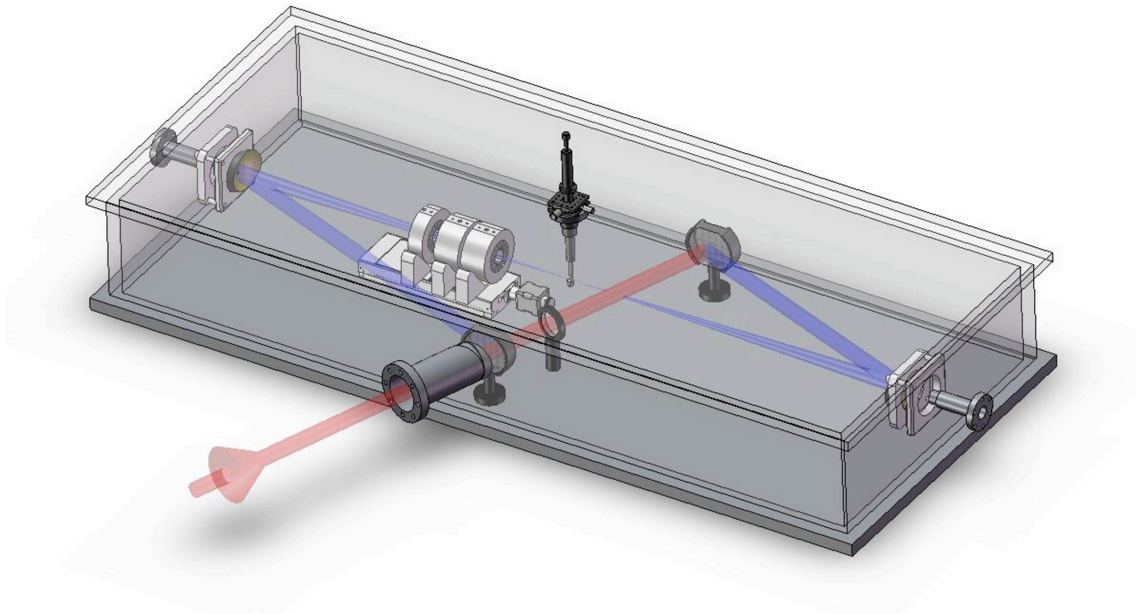


Diagnostic method	Measurable	Feedback to
Current Transformer (ICT) Faraday cup at the beam dump	Charge Current	Drive laser RF system
Button BPM at the IP	Beam position	Steering magnets
Beam profile monitor at the dispersion section	Time of arrival Energy	Drive laser RF phase shifter & attenuator
Beam profile monitor at the beam dump	Spot size	Matching quadrupoles Solenoid
Off-axis X-ray monitor	Indirect	All of the above
CER (Coherent Edge Radiation) intensity monitor	Indirect	RF system, timing system

radiabeam TECHNOLOGIES

Interaction Box

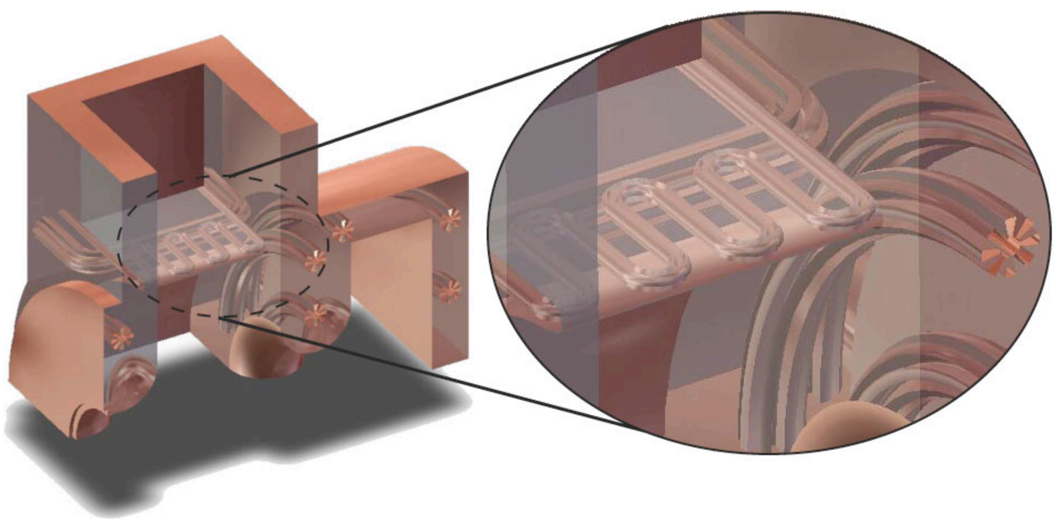
- Integrated RING and electron beam final focus
  - Adjustable Halbach-PMQ triplet
- IP diagnostic for alignment of beams



radiabeam TECHNOLOGIES

High-Rep Rate Photoinjector

- Ongoing development at RadiaBeam (not part of this proposal)
- High-gradient (> 100 MV/m), 1 kHz photoinjector
- Novel fabrication technique for copper RF structures allows better cooling



radiabeam
TECHNOLOGIES

Proof-of-Concept Experiment

- Currently awaiting Phase II funding from DTRA
- RING, PMQ system, interaction box, AO system, diagnostics, will be fabricated, tested at RadiaBeam, and installed at ATF
- ATF Nd:YAG laser will be upgraded
  - Additional amplifier stage for interaction pulse
  - Reconfigured to produce bunch train for gun
- Experiment will be performed
  - First optimize electron and laser beam transport to IP
  - Then install components, perform single-bunch ICS
  - Finally, attempt multi-bunch ICS

Parameters

Electron Beam	ATF POC	ICS (Medical)	ICS (Security)
Electron beam energy	70 MeV	40 MeV	550 MeV
Charge per bunch	1 nC		
# of bunches per train	> 50	> 100	
Macrobunch repetition rate	5 Hz	20 Hz	
Bunch length (flat top)	10 ps		
RMS spot size, σ_x,σ_y	15 μm	10 μm	7.4 μm
Laser Beam	**w/RING**	**w/RING**	**w/RING**
Fundamental wavelength	1064 nm		
Wavelength at interaction point	532 nm		
RMS spot size at the waist	15 μm	10 μm	7.4 μm
Max. Pulse energy at IP	300 mJ	600 mJ	600 mJ
Pulse duration (FWHM)	10 ps		
Dimensionless field amplitude, a_L	0.02	0.04	0.06
Spatial alignment tolerance	+/- 5 μm	+/- 3 μm	+/- 2 μm
Compton photons			
Photon energy	177 keV	50 keV	10.8 MeV
Number of photons per shot	$1.0\text{x}10^8$	$5.0\text{x}10^8$	$1.0\text{x}10^9$
Average photon flux	> $1.0\text{x}10^{10}$ γ/s	> $1.0\text{x}10^{12}$ γ/s	> $1.0\text{x}10^{12}$ γ/s
Source divergence (RMS)	7 mrad	13 mrad	1 mrad

radiabeam TECHNOLOGIES

Task	Duration
• 1) Project Management/Administration	100w
• 1.1) Project Management	100w
• 1.1.1) Project Organization	4w
• 1.1.2) Design Reviews/Meetings	40w
• 1.1.2.1) Preliminary Design Review	
• 1.1.2.2) Critical Design Review	
• 1.1.2.3) Project Review Meeting	
• 1.1.3) Reporting	100w
• 1.1.3.1) Monthly Reports	96w
• 1.1.3.2) Final Report	4w
• 1.2) ES&H	8w
• 2) Interaction Region System	40w
• 2.1) Interaction Laser RING	38w
• 2.1.1) Interaction RING Design	16w
• 2.1.2) Interaction RING Components	10w
• 2.1.3) Interaction RING Set-up/Testing	12w
• 2.2) Adaptive Optics System	40w
• 2.2.1) AO System Design	16w
• 2.2.2) AO Control System	12w
• 2.2.3) AO Fabrication/Testing	12w
• 2.3) Electron Beam Final Focus System	38w
• 2.3.1) PMQ System Design	16w
• 2.3.2) PMQ System Fabrication	16w
• 2.3.3) PMQ System Testing	6w
• 2.4) Interaction Box	38w
• 2.4.1) Interaction Box Design	16w
• 2.4.2) Interaction Box Fabrication	16w
• 2.4.3) Interaction Box Testing	6w
• 2.5) Electron Beam Feedback System	32w
• 2.5.1) Feedback System Design	16w
• 2.5.2) Feedback System Hardware	16w
• 2.5.3) Feedback System Software	16w
• 2.6) Interaction Region System Complete	
• 3) ATF Laser System Upgrade	26w
• 3.1) Front-end Reconfiguration	9w
• 3.1.1) First Pockels Cell Reconfiguration	1w
• 3.1.2) Amplifier Gain Compensation	2w
• 3.1.3) Pulse-Picking Pockels Cell	6w
• 3.2) Interaction Pulse Transport/Amplifier	17w
• 3.2.1) Amplifier Design	6w
• 3.2.2) Amplifier Components	6w
• 3.2.3) Amplifier Set-up and Testing	3w
• 4) System Integration/Test	92w
• 4.1) Accelerator Performance Optimization	52w
• 4.2) System Installation at ATF	12w
• 4.2.1) MELISA Installation	12w
• 4.2.2) E-Beam Feedback System Installation	12w
• 4.2.3) X-Ray Diagnostics Installation	12w
• 4.3) Experimental Demonstration of IGS	40w
• 4.3.1) Single-bunch Experiment	16w
• 4.3.2) Bunch-train Experiment	24w