Multi-GHz Pulse-Train X-Band Capability for Laser Compton x-ray and γ-ray Sources.

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Scattering optical photons off an electron beam generates a keV-MeV photon beam.

\[
E_{\gamma} = \frac{2\gamma^2(1 - \cos \varphi)}{1 + \gamma^2\vartheta^2 + 4\gamma k_0 \lambda_c} E_{\text{laser}}
\]

- **Doppler upshift**
- **Energy-angle correlation**
- **Compton recoil**

Electron beam

Electron and X-ray beam

Bremsstrahlung

Compton scattered x-rays

Photon Frequency

Amplitude

Electron beam
Interaction Pulse Formats: High Peak Brightness

- Single electron bunch, 1 J, few ps laser
- ~2 ps x-ray burst
- Useful for fast, time-resolved measurements of dense material
Interaction Pulse Formats: Optimizing for Bandwidth

- No electron focus to avoid angular spectral blurring
- Large laser spot size for long Rayleigh range
- Lower electron density results in lower flux
Interaction Pulse Formats: Optimizing for Flux

- Tight focus to maximize flux at expense of bandwidth (few %)
- Good for radiography and atomic identification (e.g. Iodine k-edge imaging)

10 J, 10 ns laser running at up to 120 Hz

X-band photoinjector and accelerator section

Multi-GHz capable photoinjector drive laser

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Multi-GHz capable photoinjector drive laser

X-band photoinjector and accelerator section

10 J, 10 ns laser running at up to 120 Hz
RF phase locked laser pulse train generated without a mode-locked oscillator

- CW Laser Source
- GHz RF Drive
- 200 m fiber
- EO Modulator
- Pre-amps
- Grating Compressor
- Power Amps
Laser produces ps-duration pulses with 11.424 GHz bursts

- **Burst Temporal Profile**
- **Spectrum**
- **Autocorrelation**

500 pulses, 11.424 GHz spacing, 2.5 µJ each
10 J, 10 ns laser running at up to 120 Hz

Multi-GHz capable photoinjector drive laser

X-band photoinjector and accelerator section
2 J commercial amp, adequate for tight-focus geometries

10 J custom amp, using high-power diode arrays and high-speed He cooling

Diode stack: 120 Hz, 126 kW

2J diode-pumped Nd:YAG head

2 J commercial amp, adequate for tight-focus geometries
Multi-GHz capable photoinjector drive laser

X-band photoinjector and accelerator section

10 J, 10 ns laser running at up to 120 Hz
**Surrogate Photoinjector Drive Laser**

- Amplitude Ti:Sapphire system
  - 120 µJ, 10 Hz, 200 fs, 260 nm pulses

- Pulse shaping
  - Imaged clipping aperture for hard radial edge
  - Pulse stacker to generate multiple pulses

- 10 µJ/pulse on cathode (typical)
Surrogate Interaction Laser

- Continuum Powerlite DLS 8010
  - 750 mJ, 6 ns, 532 nm pulses
- Long laser pulse reduces expected x-ray flux by a factor of 100.
X-Band Compton X-ray Source
X-Band Compton X-ray Source

- **RF Source:**
  - SLAC XL-4 Klystron
  - Scandinova Modulator
  - 50 MW, 400 ns pulse, 60 Hz

- **Stability:**
  - Flatness: 0.1%
  - Shot-to-Shot: 0.01%
  - Phase: <0.5°
X-Band Compton X-ray Source

- **Photogun:**
  - 5.59 cell standing wave
  - Cu Photocathode, QE=$3 \times 10^{-5}$
  - Peak field: 200 MV/m

- **Section:**
  - T53 Travelling wave section
  - Gradient: 70 MV/m
  - Output Energy: 31 MeV
Initial electron performance

- Typical RF operation:
  - 52 MW, 120 ns pulse, 10 Hz
  - 180 MV/m in gun
    - Breakdown rate <1/hr @ 10 Hz
  - 45 MV/m in section

- Typical e-beam operation:
  - 20° injection phase
  - 75-100 pC
  - 27 MeV final energy

Beam performance nearly matches PARMELA simulations.
Poster today: TUPMA025
Multi-GHz capable photoinjector drive laser

X-band photoinjector and accelerator section

Interaction region

10 J, 10 ns laser running at up to 120 Hz
Interaction Region

[Diagram of a particle accelerator with labels for Beam Diversion Chicane, Final Focus Quads, Interaction Point, Spectrometer Dipole, Laser Entrance Port, Laser Exit Port, Beam Dump, and X-Ray CCD Camera with a focus on Electrons and Laser interactions]
X-ray flux increases with number of electron bunches

The next step is calibrating the CCD camera response and comparing with simulations.
The Indium k-edge provides a marker to indicate the spectral variation of the x-ray beam

\[ E_{\gamma} = \frac{2\gamma^2(1 - \cos \varphi)}{1 + \gamma^2 \theta^2 + 4\gamma k_0 \lambda_c} E_{\text{laser}} \]

Angular-Spectral x-ray Correlation

Indium Transmission

Transmission Profile
Four electron bunches generating x-rays, observed through Indium foil

E-Beam Energy: 27.5 MeV
x-ray Energy: 28.0 keV

E-Beam Energy: 28.4 MeV
x-ray Energy: 29.8 keV

Transmission Profile

- 28.37 MeV
- 27.5 MeV
Summary

- We have commissioned an X-band accelerator, designed for Compton-scattering light source applications.
  - Emittance results match simulations, and we are still working on optimization
- We have demonstrated x-ray production from the system
  - Up to 34 keV photon energies
  - We are in the process of quantifying the x-ray flux
- We have demonstrated a GHz-capable photoinjection drive laser architecture
- We are developing a 10 J, 120 Hz interaction laser system
- We have made initial studies of e-beam performance and x-ray flux for few-bunch trains, and are exploring the charge and bunch spacing limits.