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

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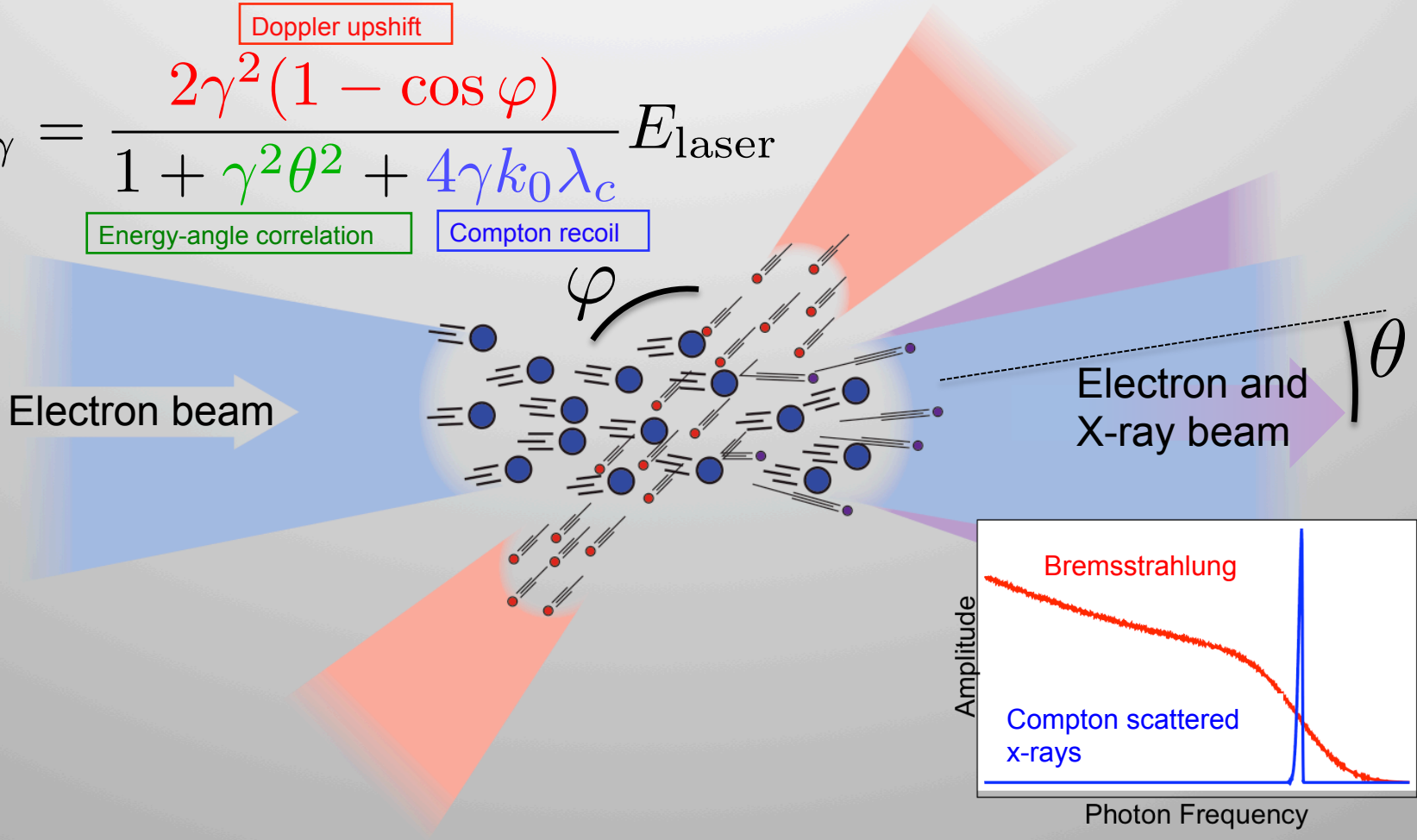
Scattering optical photons off an electron beam generates a keV-MeV photon beam.

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

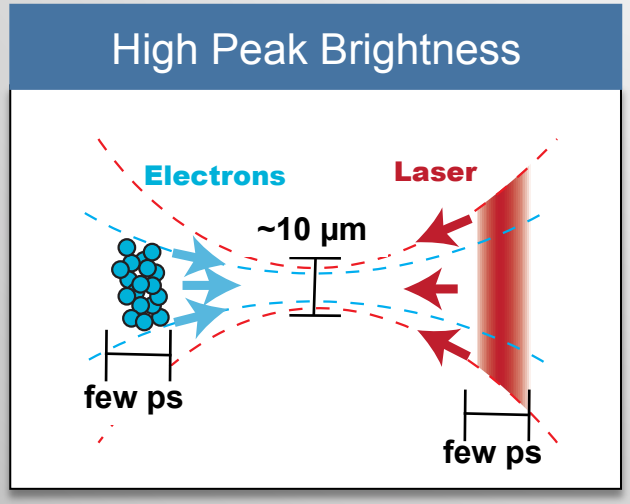
Doppler upshift

Energy-angle correlation

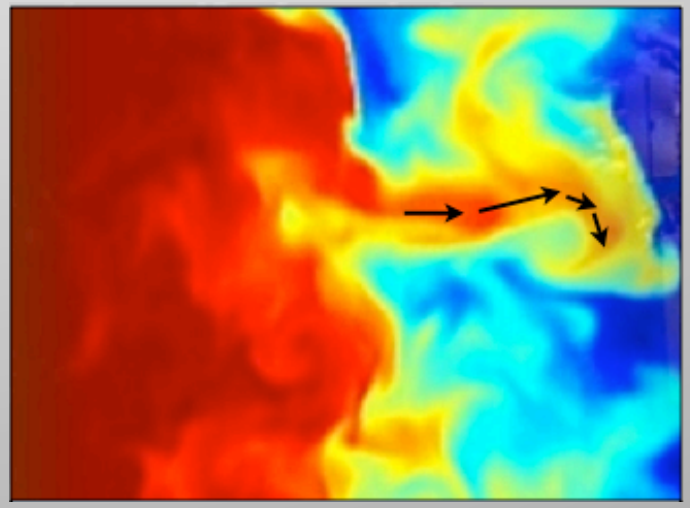
Compton recoil



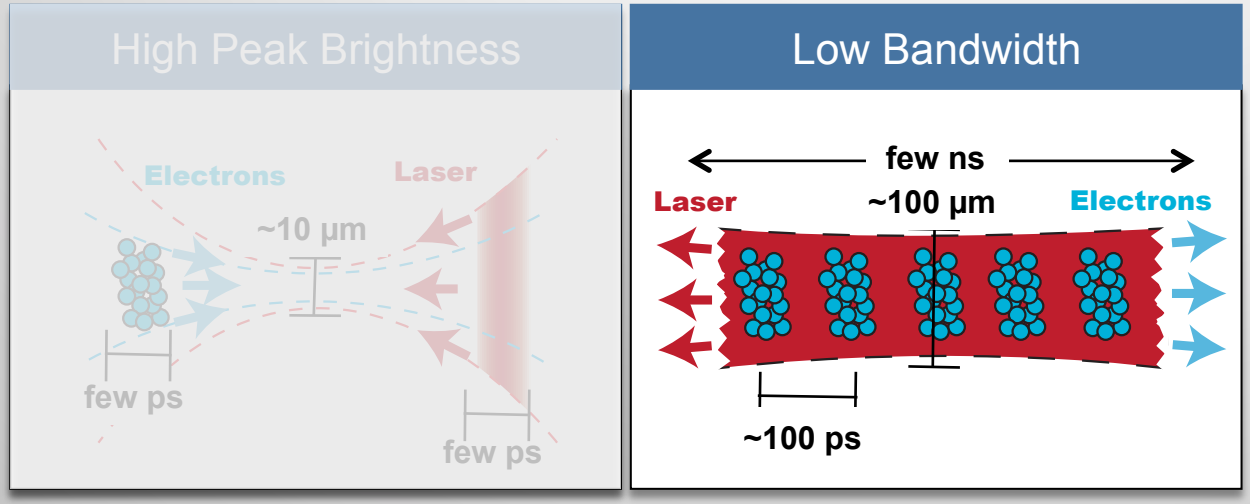
Interaction Pulse Formats: High Peak Brightness



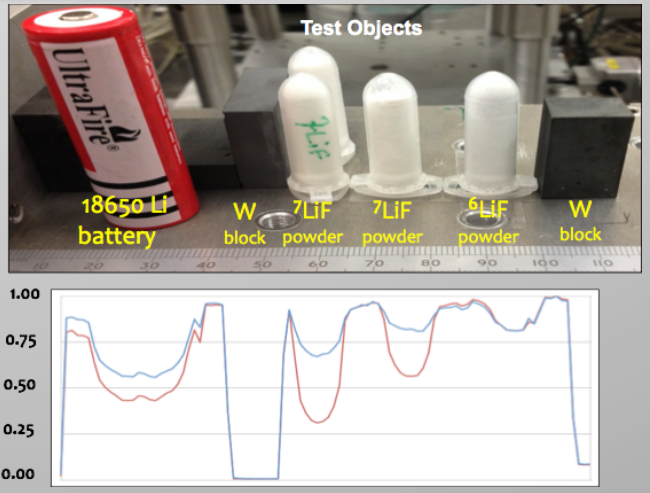
- Single electron bunch, 1 J, few ps laser
- ~2 ps x-ray burst
- Useful for fast, time-resolved measurements of dense material



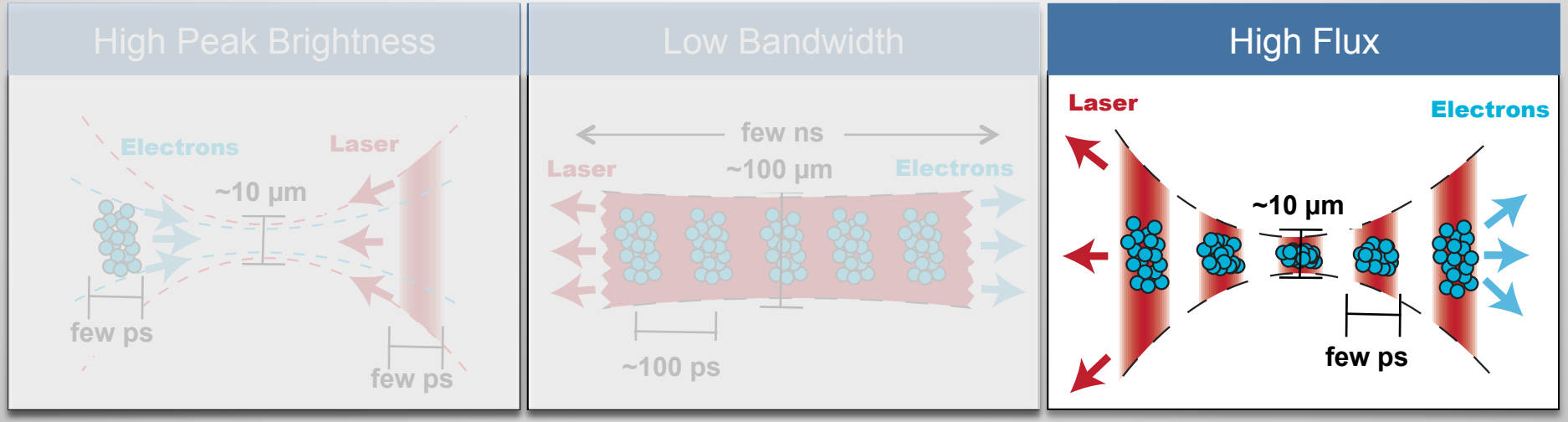
Interaction Pulse Formats: Optimizing for Bandwidth



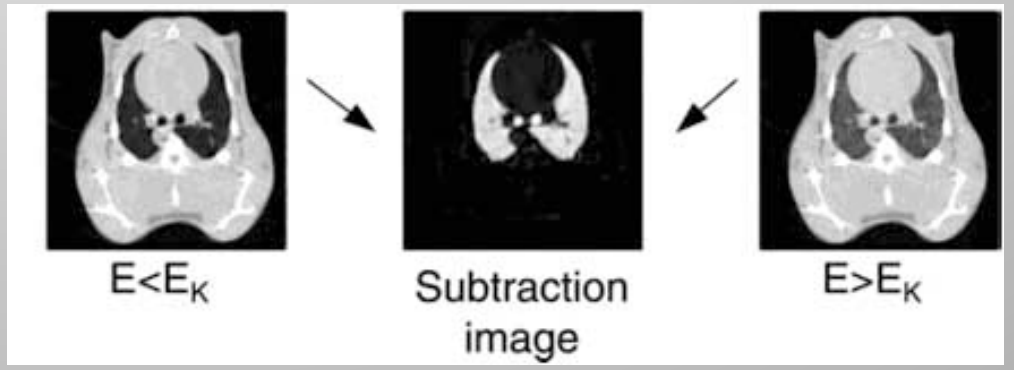
- No electron focus to avoid angular spectral blurring
- Large laser spot size for long Rayleigh range
- Lower electron density results in lower flux



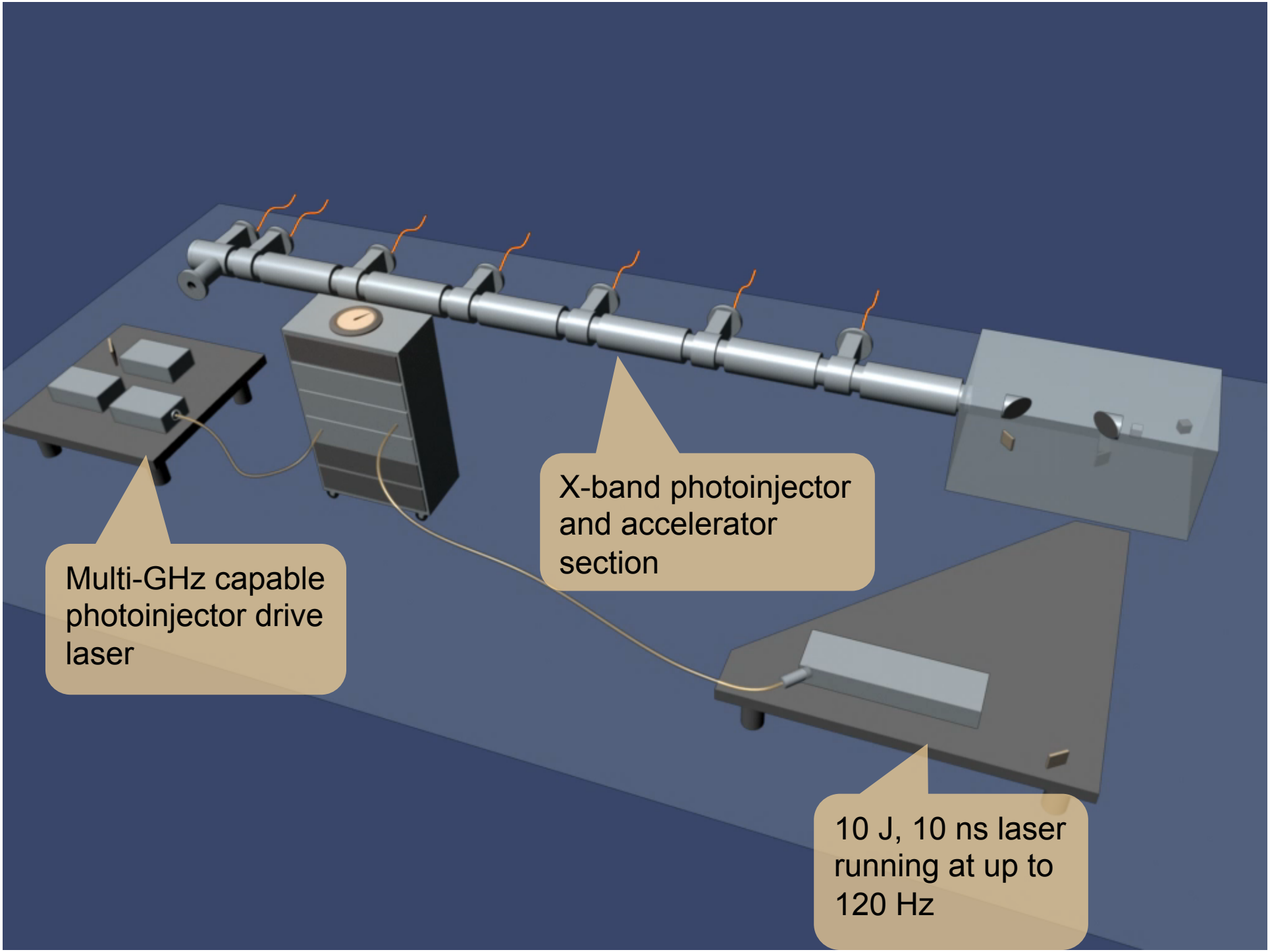
Interaction Pulse Formats: Optimizing for Flux

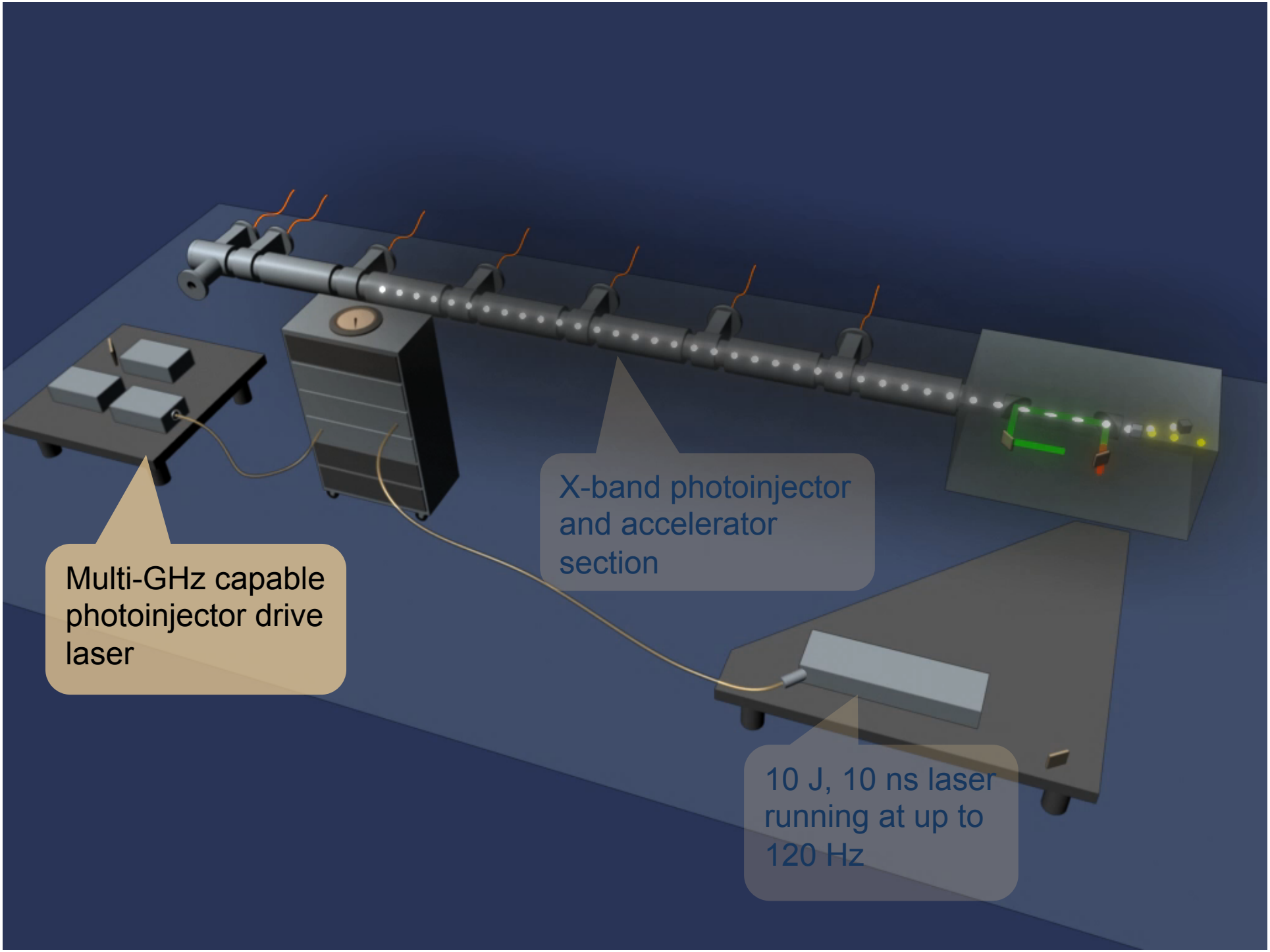


- Tight focus to maximize flux at expense of bandwidth (few %)
- Good for radiography and atomic identification (e.g. Iodine k-edge imaging)



Bayat, et al., J Appl Physio. (2006)


Multi-GHz capable photoinjector drive laser
X-band photoinjector and accelerator section
10 J, 10 ns laser running at up to 120 Hz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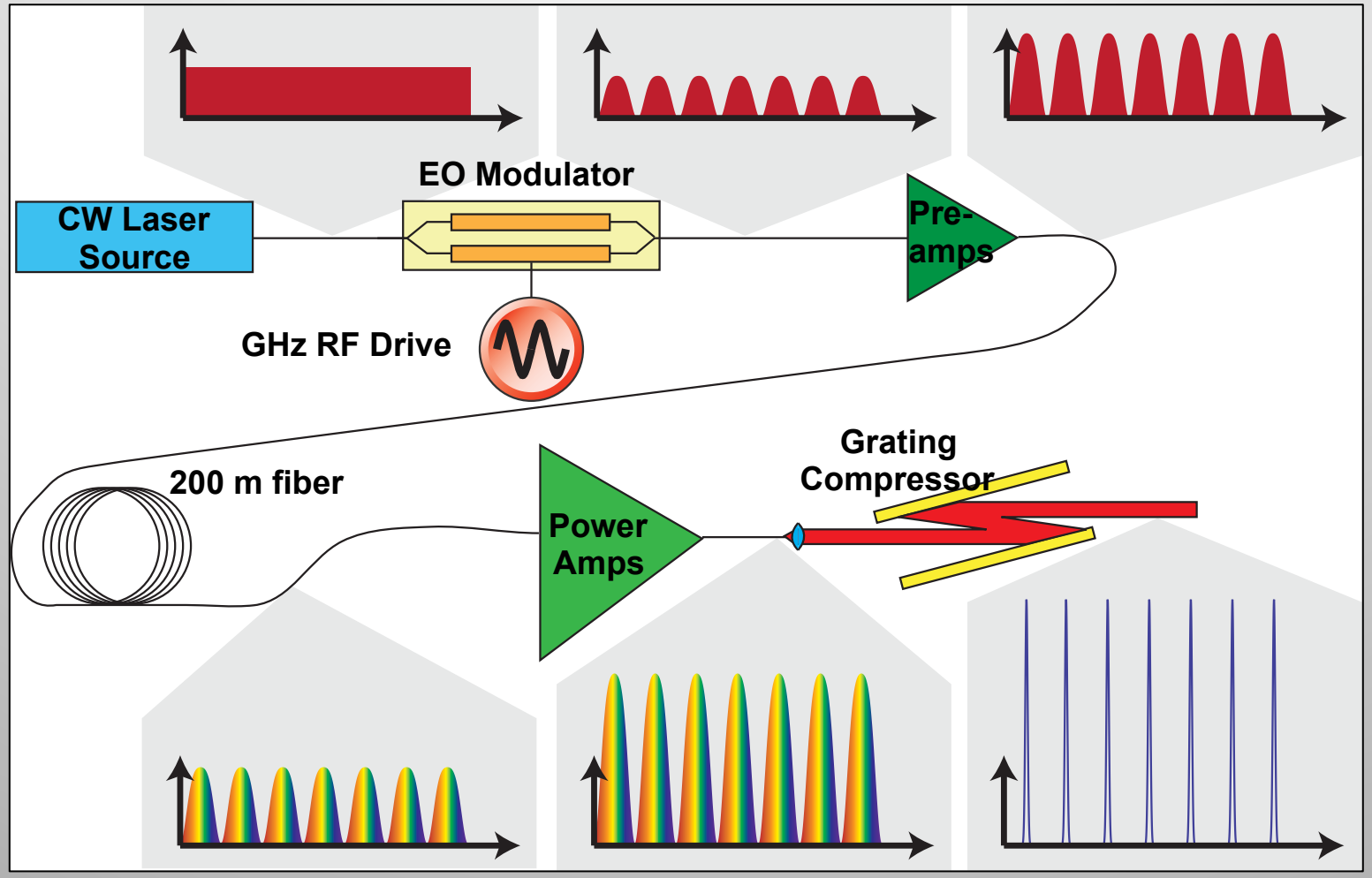
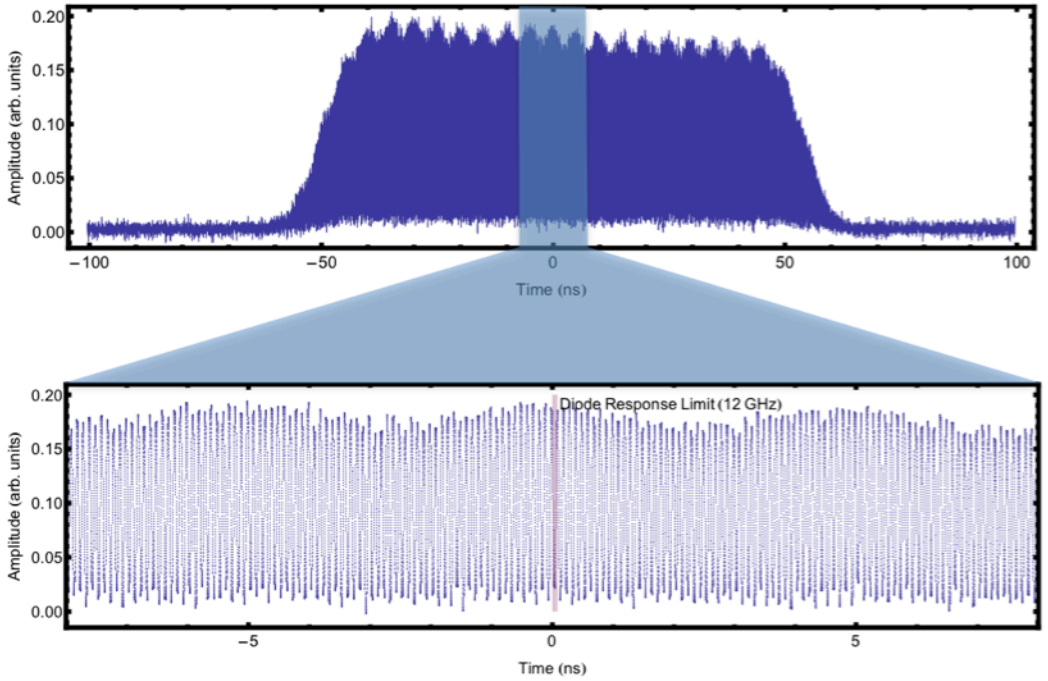
RF phase locked laser pulse train generated without a mode-locked oscillator

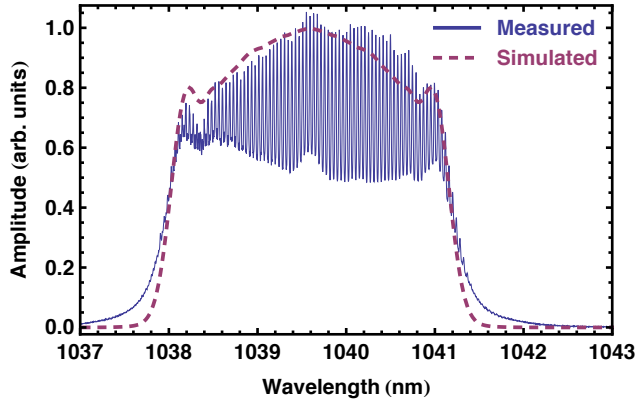


Laser produces ps-duration pulses with 11.424 GHz bursts

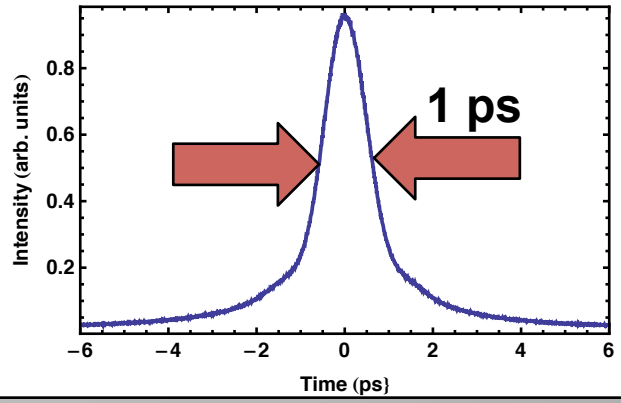
Burst Temporal Profile



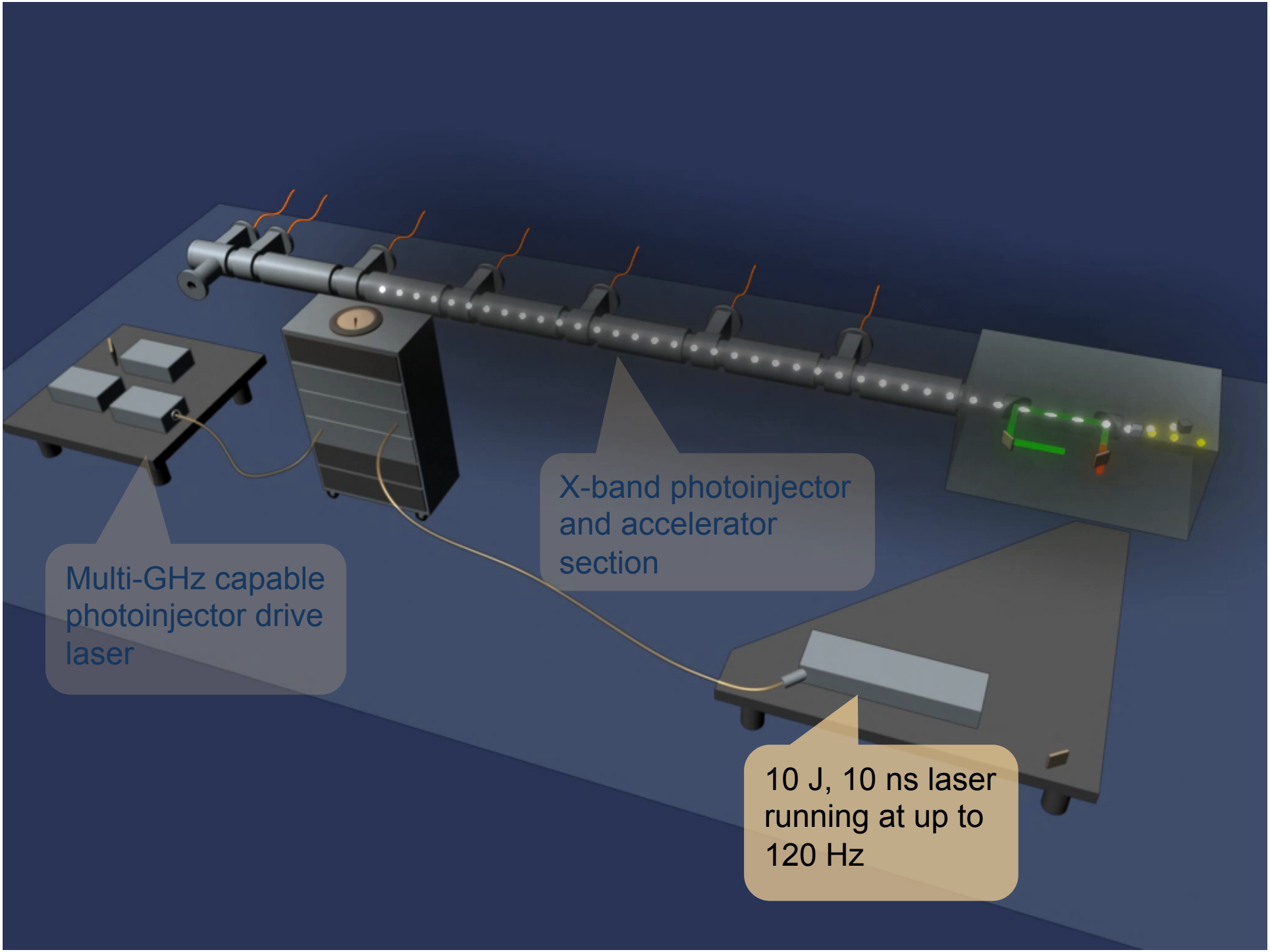
Spectrum



Autocorrelation



500 pulses, 11.424 GHz spacing, 2.5 μJ each

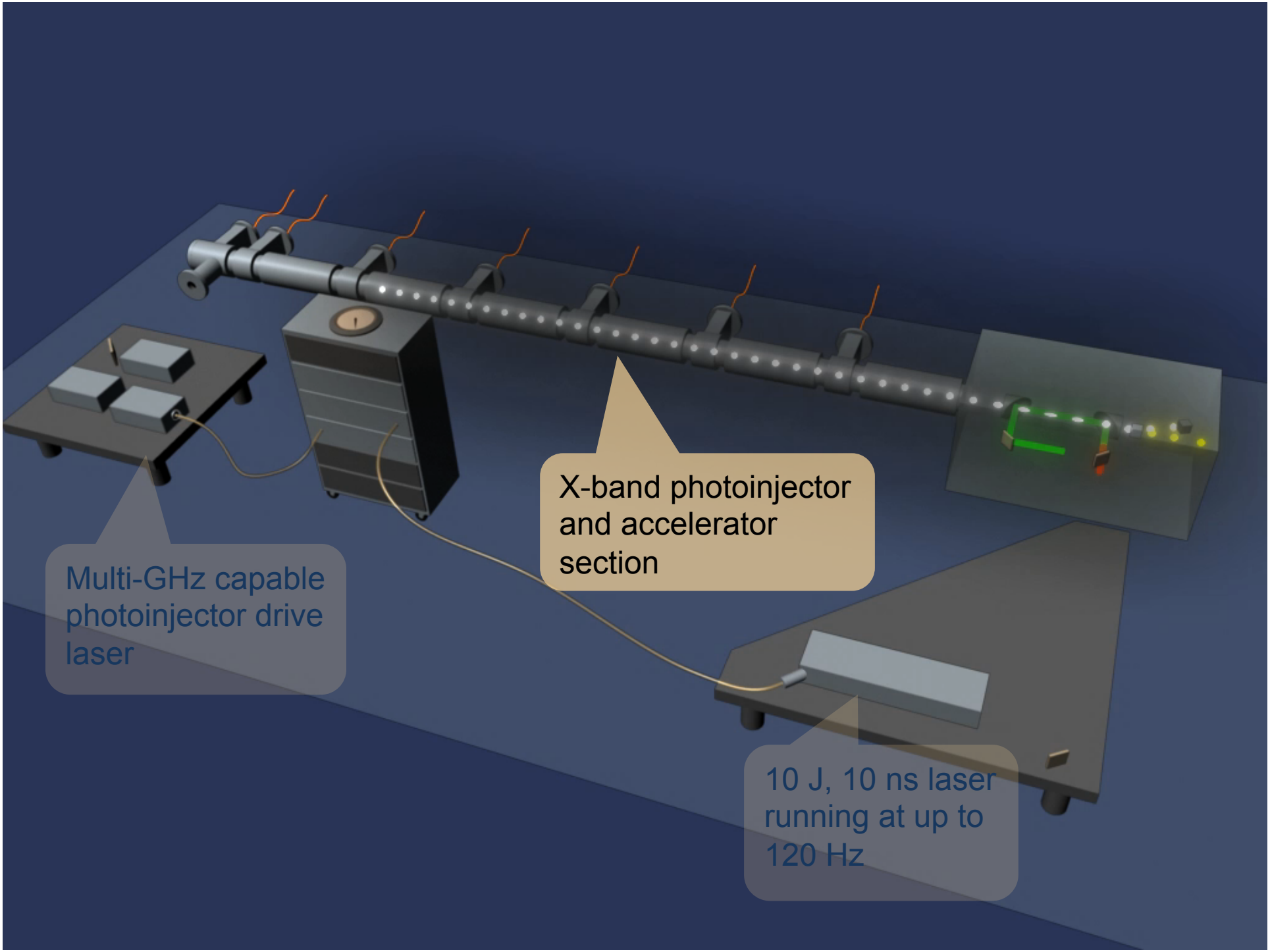

Multi-GHz capable photoinjector drive laser
X-band photoinjector and accelerator section
10 J, 10 ns laser running at up to 120 Hz

Diode stack: 120 Hz, 126 kW

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

2 J commercial amp, adequate for tight-focus geometries

2J diode-pumped Nd:YAG head


X-band photoinjector and accelerator section
Multi-GHz capable photoinjector drive laser
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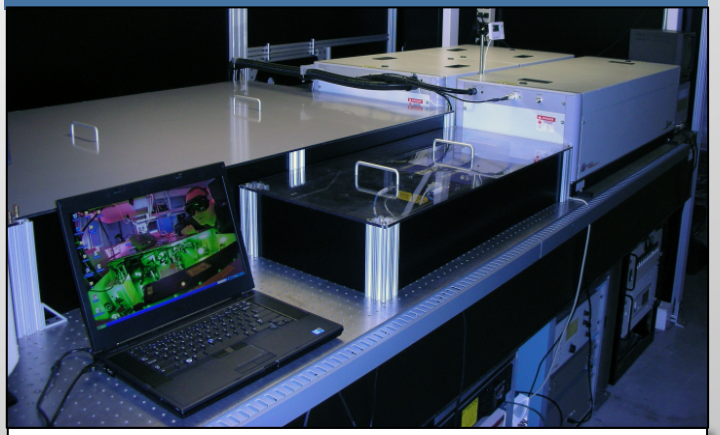
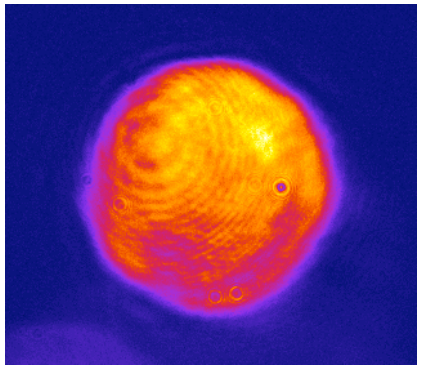
Surrogate Photoinjector Drive Laser

- 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)

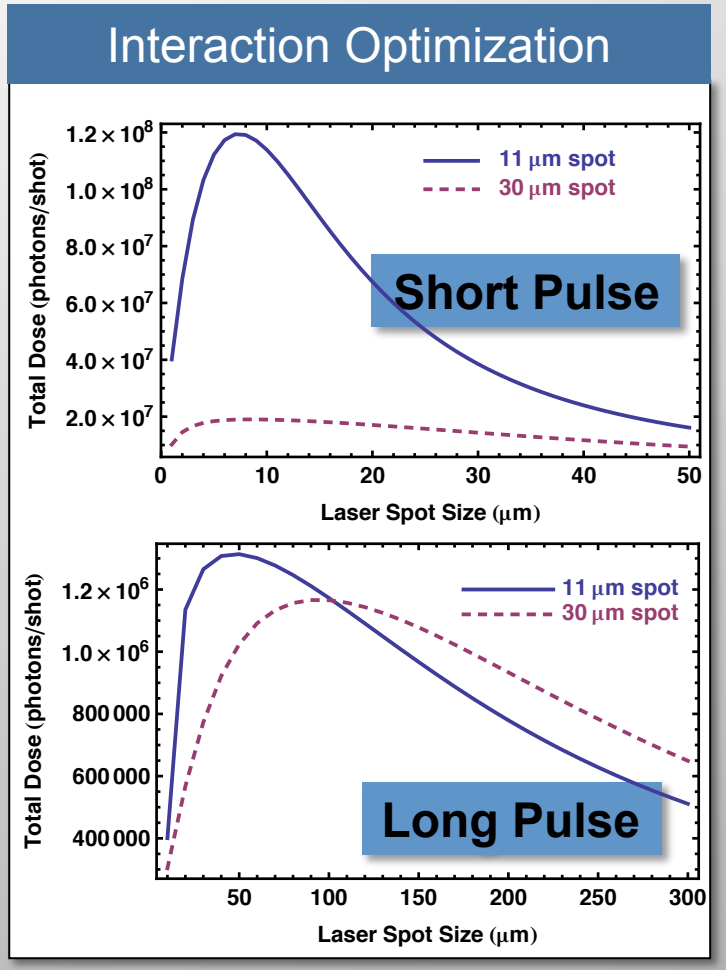
Photoinjector Drive Laser



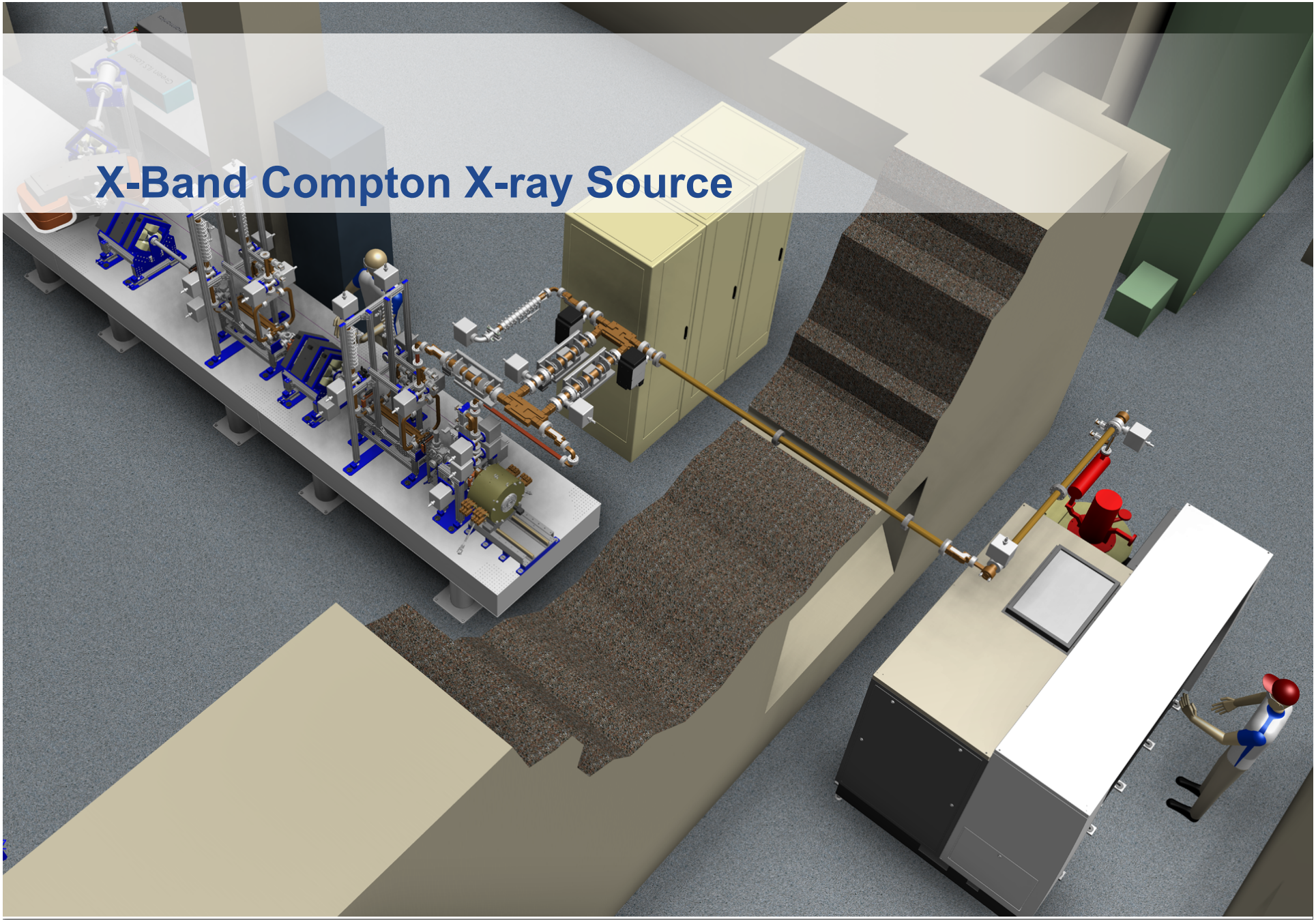


Surrogate Interaction Laser

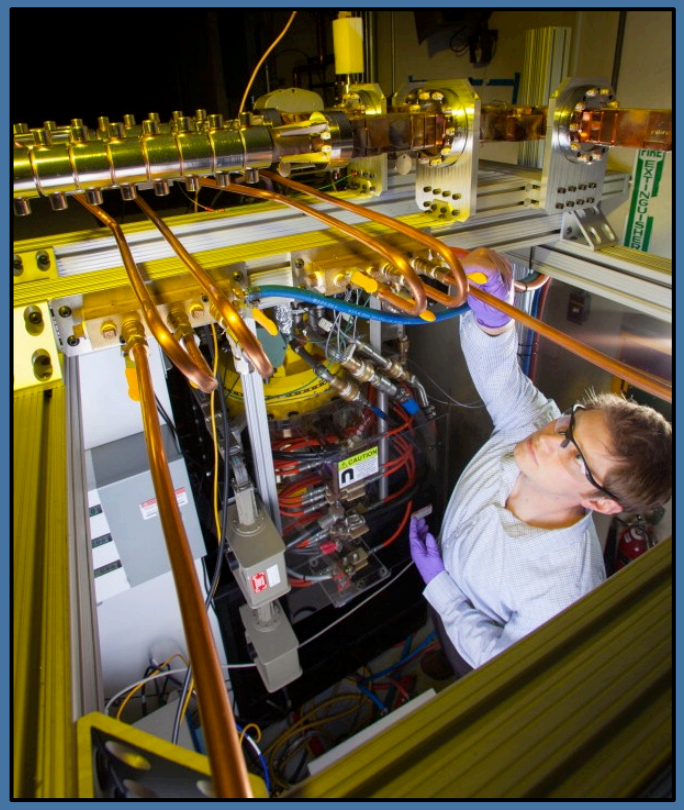
- Continuum Powerlite DLS 8010
  - 750 mJ, 6 ns, 532 nm pulses
- Long laser pulse reduces expected x-ray flux by a factor of 100.

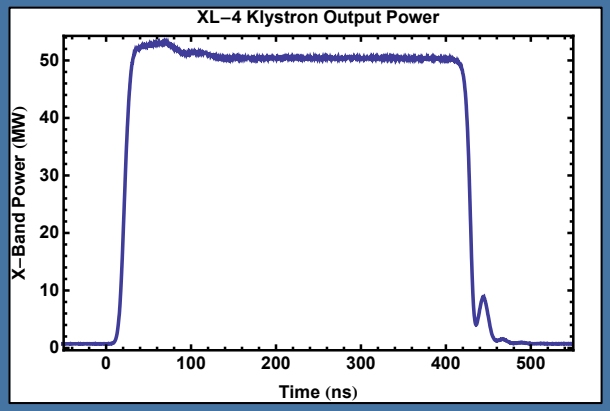


X-Band Compton X-ray Source



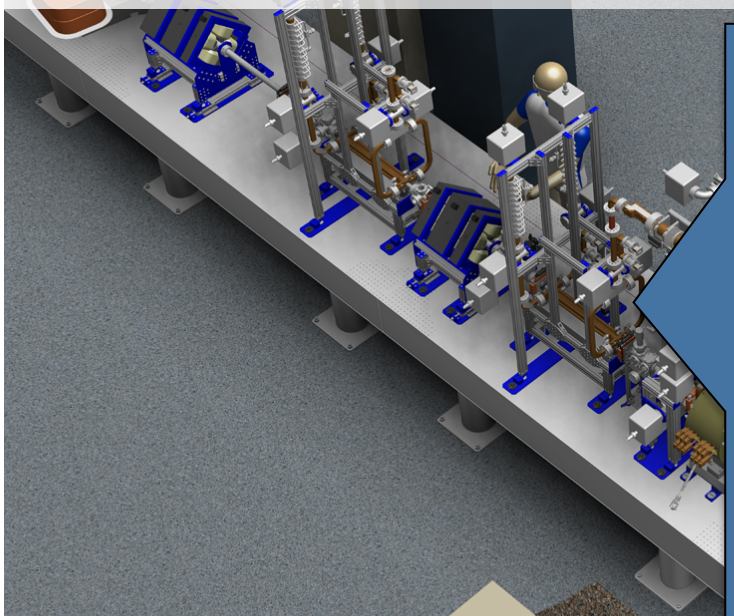
X-Band Compton X-ray Source

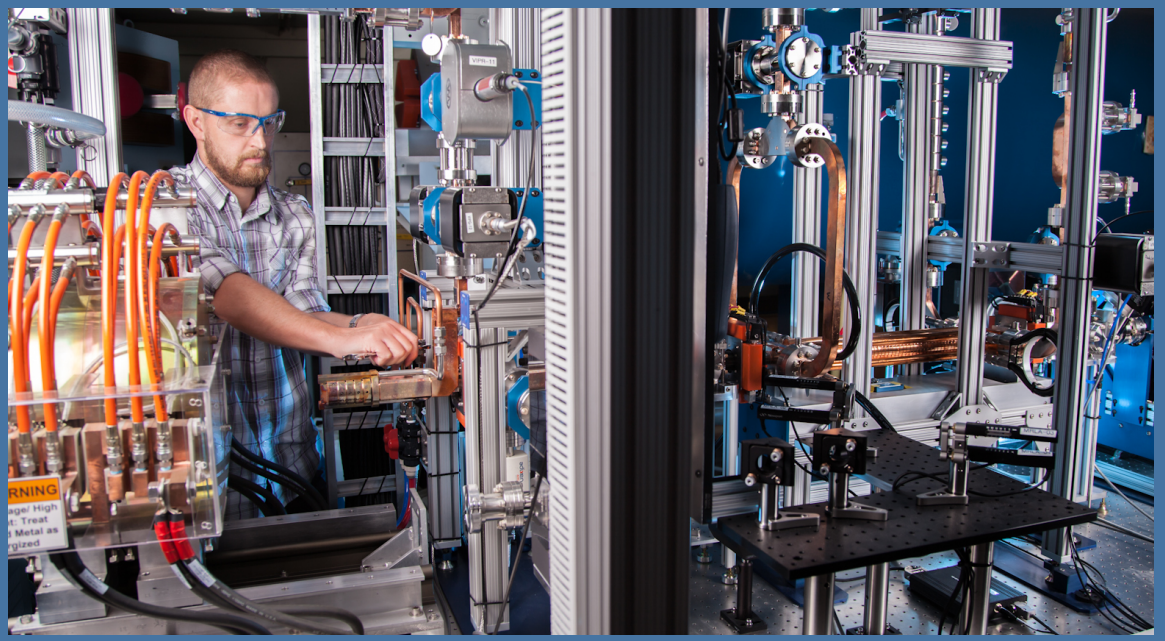




- RF Source:
  - SLAC XL-4 Klystron
  - Scandinova Modulator
  - 50 MW, 400 ns pulse, 60 Hz
- Stability:
  - Flatness: 0.1%
  - Shot-to-Shot: 0.01%
  - Phase: <0.5°

X-Band Compton X-ray Source



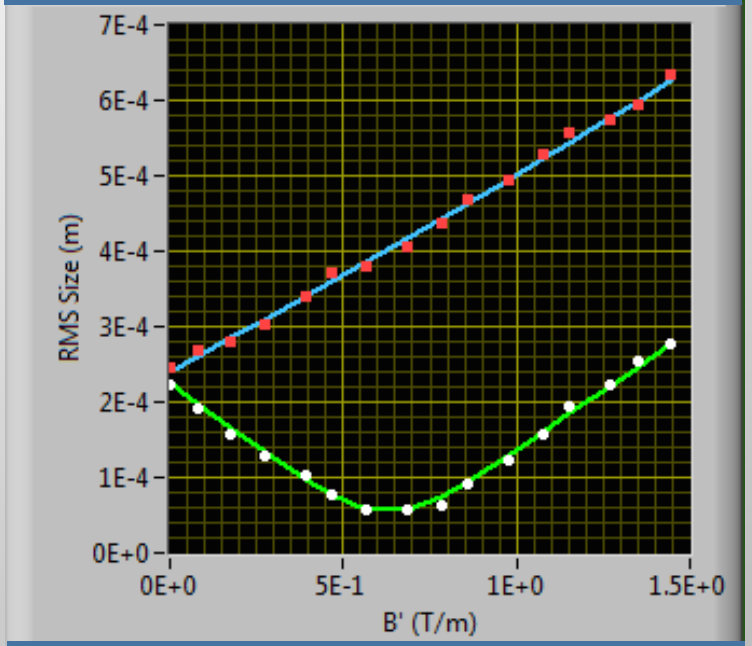


- Photogun:
  - 5.59 cell standing wave
  - Cu Photocathode, QE=3 x 10^{-5}
  - Peak field: 200 MV/m
- Section:
  - T53 Travelling wave section
  - Gradient: 70 MV/m
  - Output Energy: 31 MeV

Initial electron performance

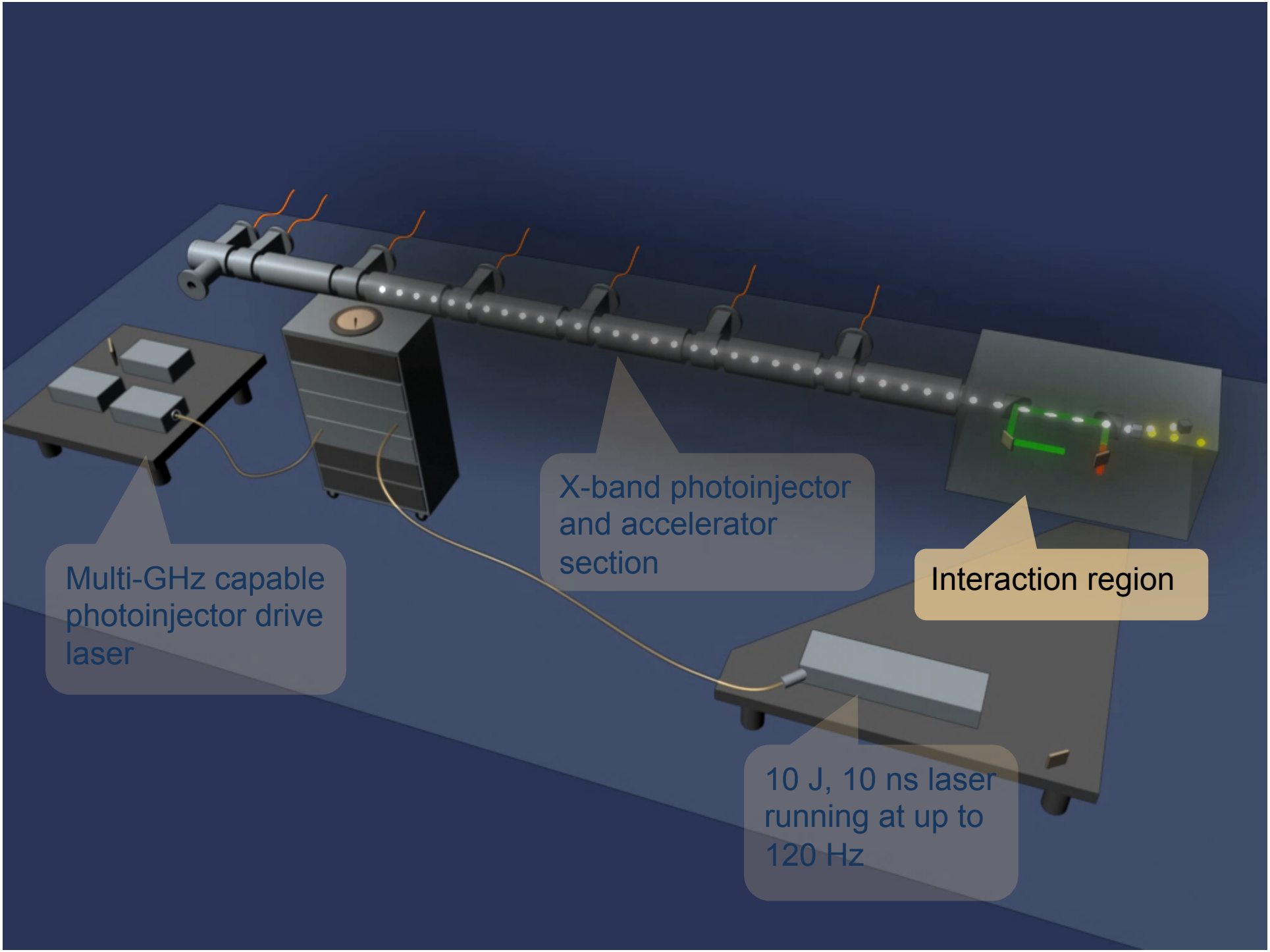
- Typical RF operation:
  - 52 MW, 120 ns pulse, 10 Hz
  - 180 MV/m in gun
    - Breakdown rate <1/hr @ 10 Hz
  - 45 MV/m in section
- Typical e-beam operation:
  - 20° injection phase
  - 75-100 pC
  - 27 MeV final energy

Normalized Emittance

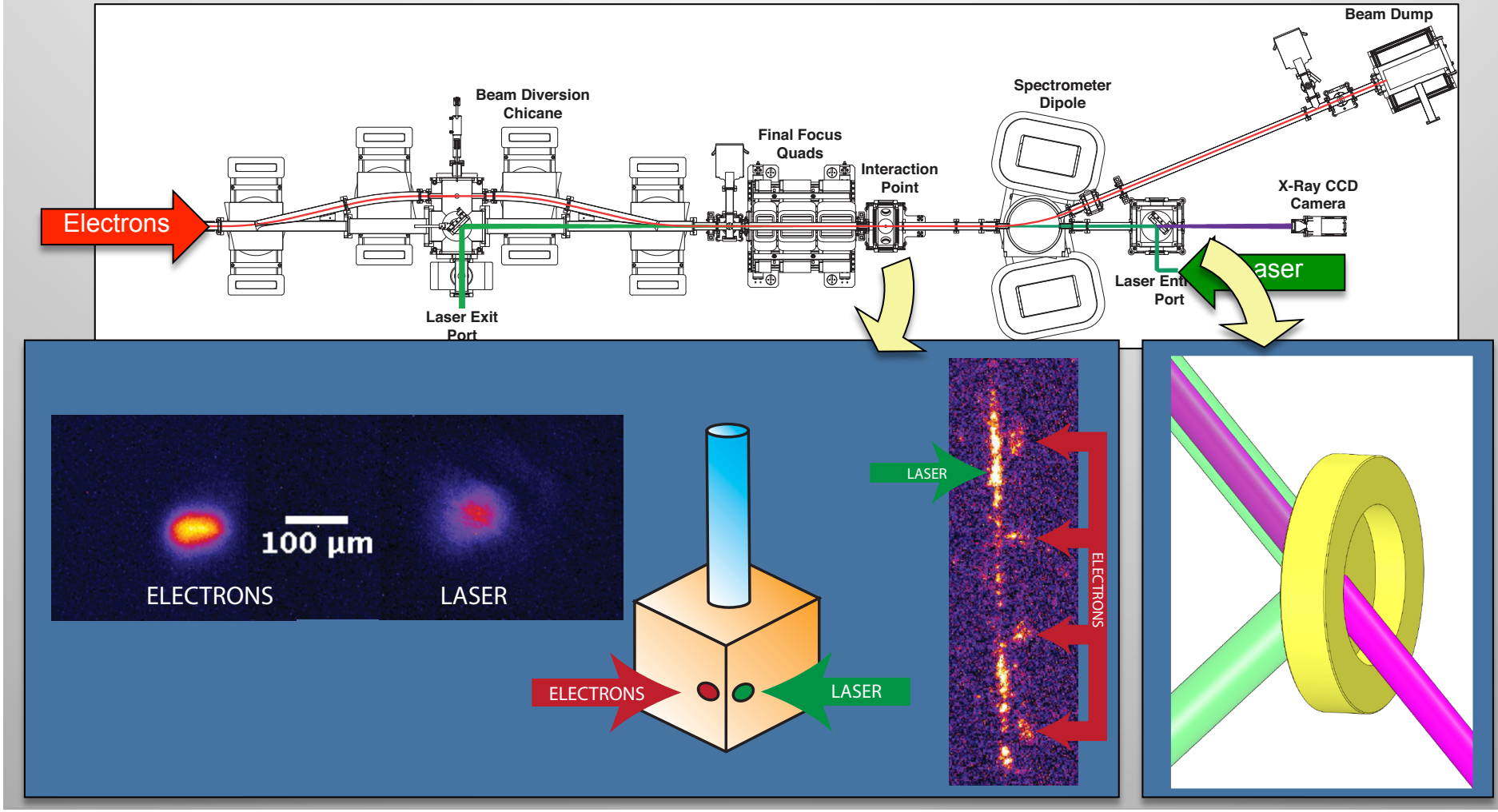


ε_{nx}, ε_{ny} = 0.3 μm at 75 pC

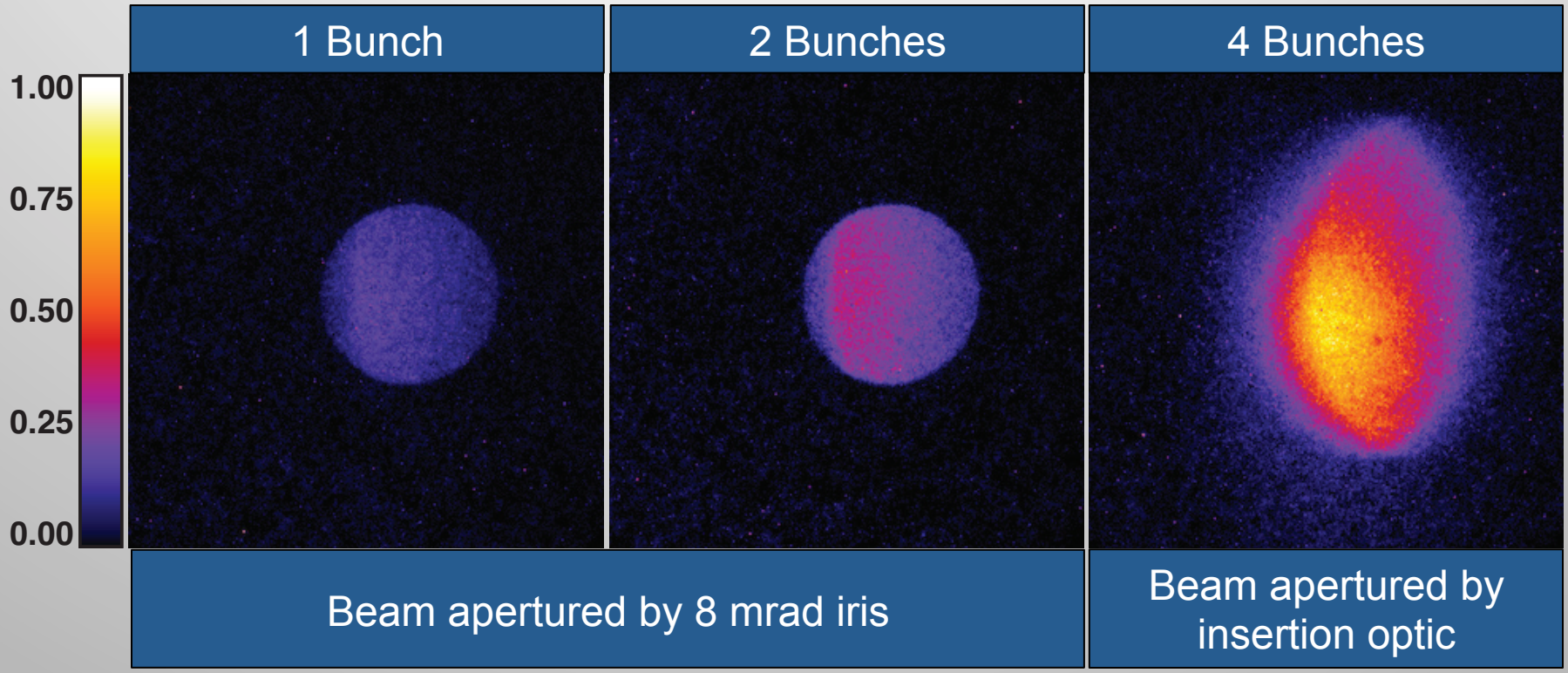
Beam performance nearly matches PARMELA simulations.
Poster today: TUPMA025


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



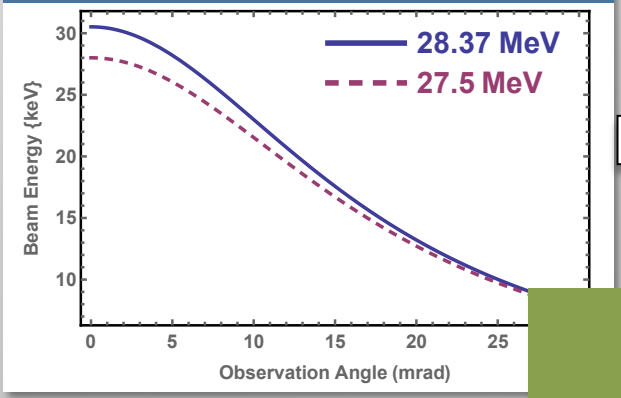
X-ray flux increases with number of electron bunches



The next step is calibrating the CCD camera response and comparing with simulations

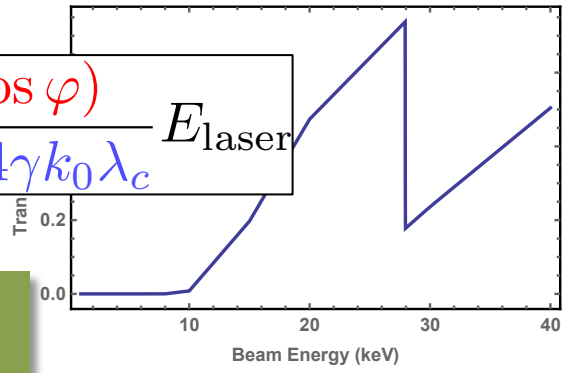
The Indium k-edge provides a marker to indicate the spectral variation of the x-ray beam

Angular-Spectral x-ray Correlation

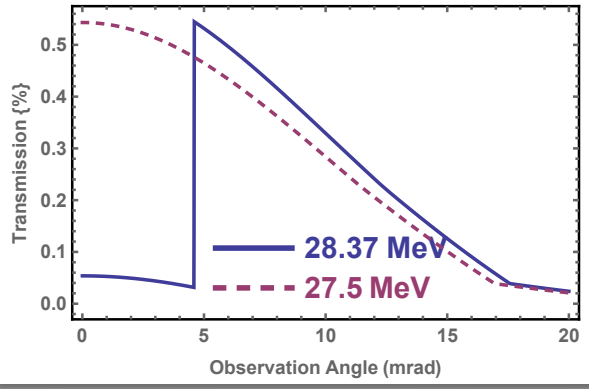


$$E_\gamma = \frac{2\gamma^2(1-\cos\varphi)}{1+\gamma^2\theta^2+4\gamma k_0 \lambda_c} E_{\text{laser}}$$

Indium Transmission

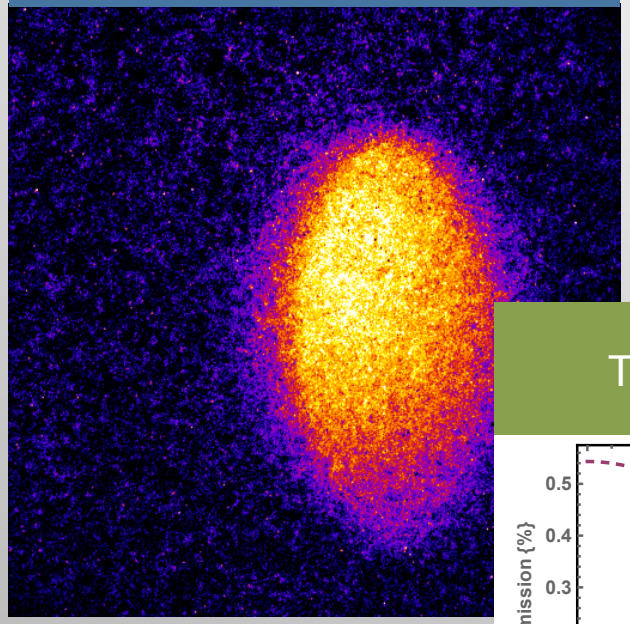


Transmission Profile

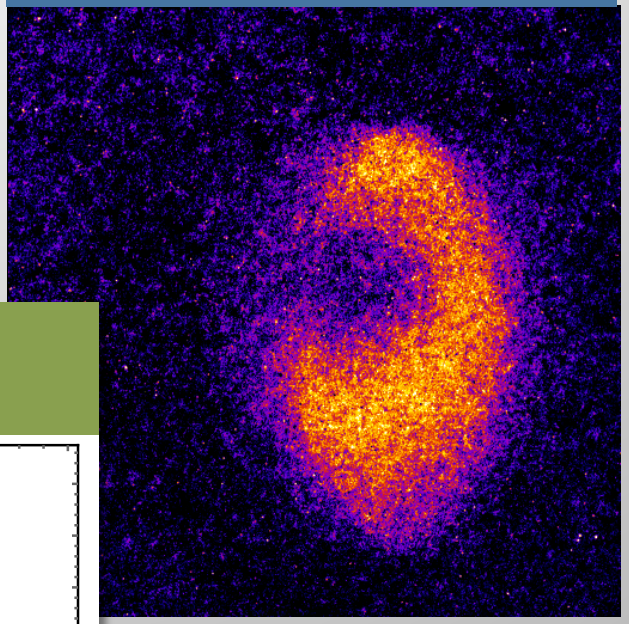


Four electron bunches generating x-rays, observed through Indium foil

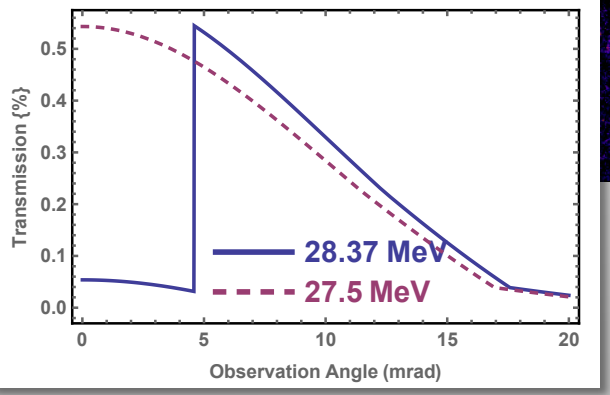
E-Beam Energy: 27.5 MeV
x-ray Energy: 28.0 keV



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



Transmission Profile



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.

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