Scanning Wire Beam Position Monitor for Alignment of a High Brightness Inverse-Compton X-Ray Source

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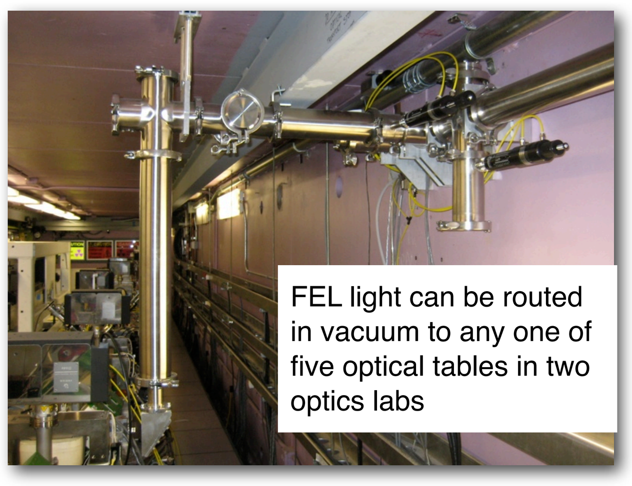
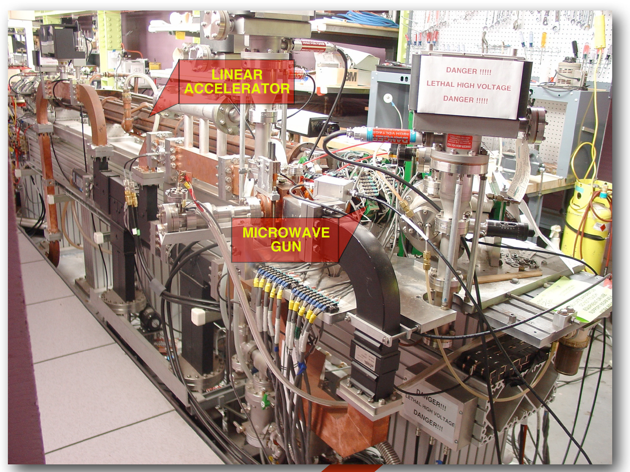
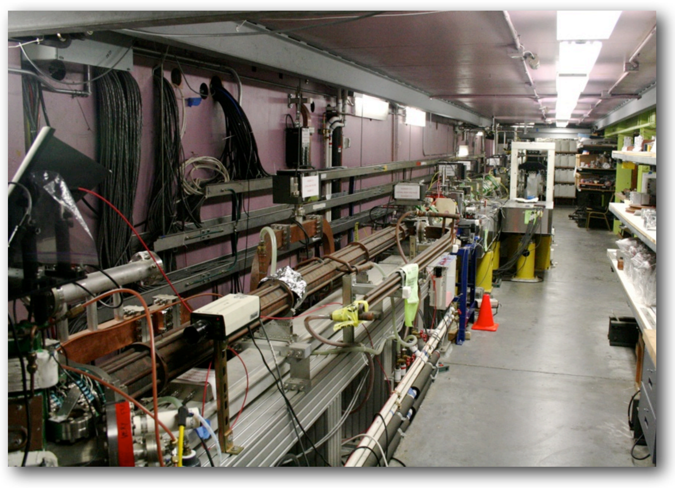
1. The University of Hawai`i Free-Electron Laser Laboratory

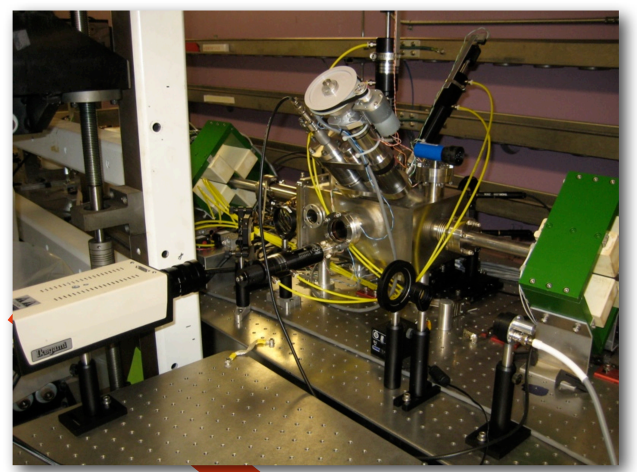
The Free-Electron Laser Laboratory at the University of Hawai`i has constructed and tested a scanning-wire beam position monitor to aid the alignment and optimization of a high spectral brightness inverse-Compton scattering x-ray source. X-rays are produced by colliding the 40 MeV electron beam from a pulsed S-band linac with infrared laser pulses from a mode-locked free-electron laser driven by the same electron beam. The electron and laser beams are focused to 60 µm diameters at the interaction point to achieve high scattering efficiency. This wire-scanner allows for high resolution measurements of the size and position of both the laser and electron beams at the interaction point to verify spatial coincidence. Time resolved measurements of secondary emission current allow us to monitor the transverse spatial evolution of the e-beam throughout the duration of a 4 µs macro-pulse while the laser is simultaneously profiled by pyrometer measurement of the occulted infrared beam. Using this apparatus we have demonstrated that the electron and laser beams can be co-aligned with a precision better than 10 µm as required to maximize x-ray yield.

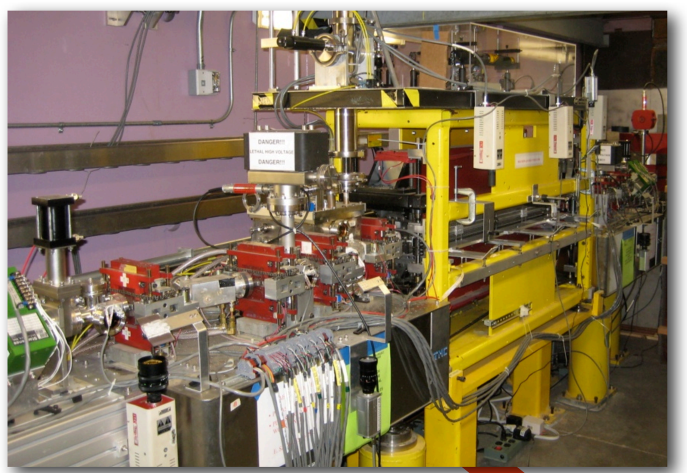


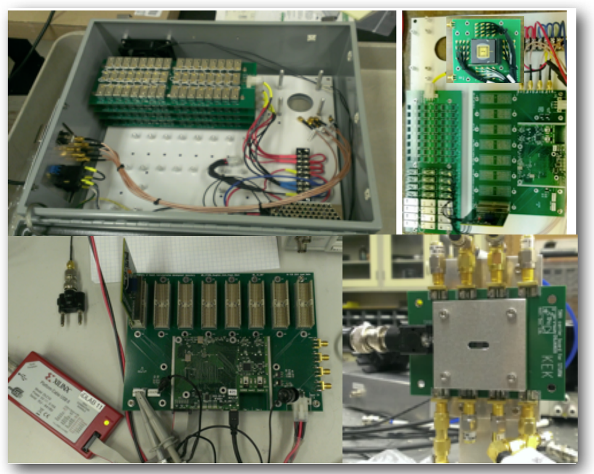
Wavelength	λ	3 µm
IP Rayleigh range	z_R	1 mm
IP spot size	w_0	31 µm
Beam crossing angle	α	5.75°
IP Divergence angle	$\theta_{\frac{1}{2}}$	1.77°
X-ray photon energy		10.4 keV
E-beam energy		40 MeV
E-beam emittance	ε_n	8π mm·mrad
μ-Pulse duration	τ_μ	1 ps

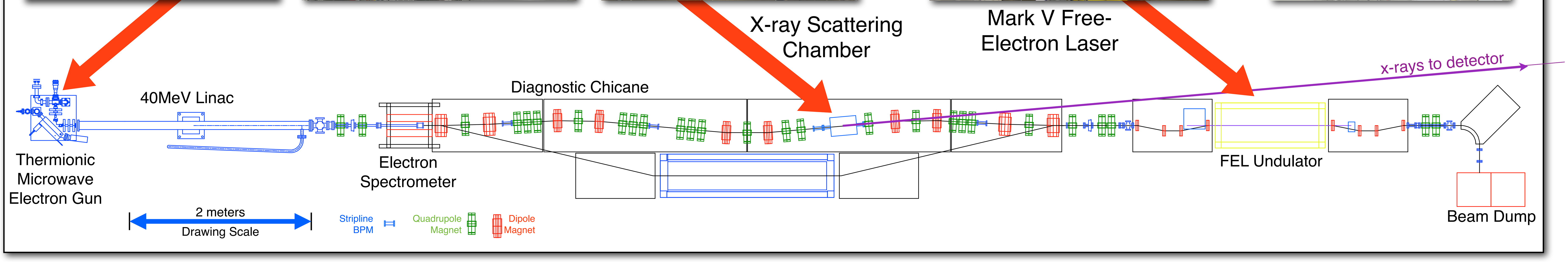








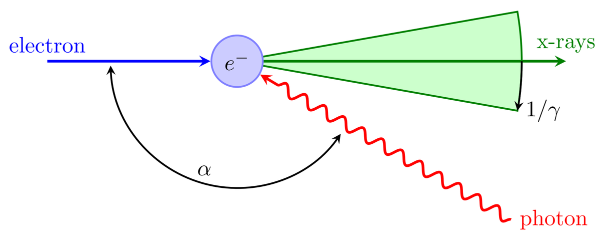




2. High-Brightness Inverse-Compton X-ray Source

Photon energy upshifted by $4\gamma^2$

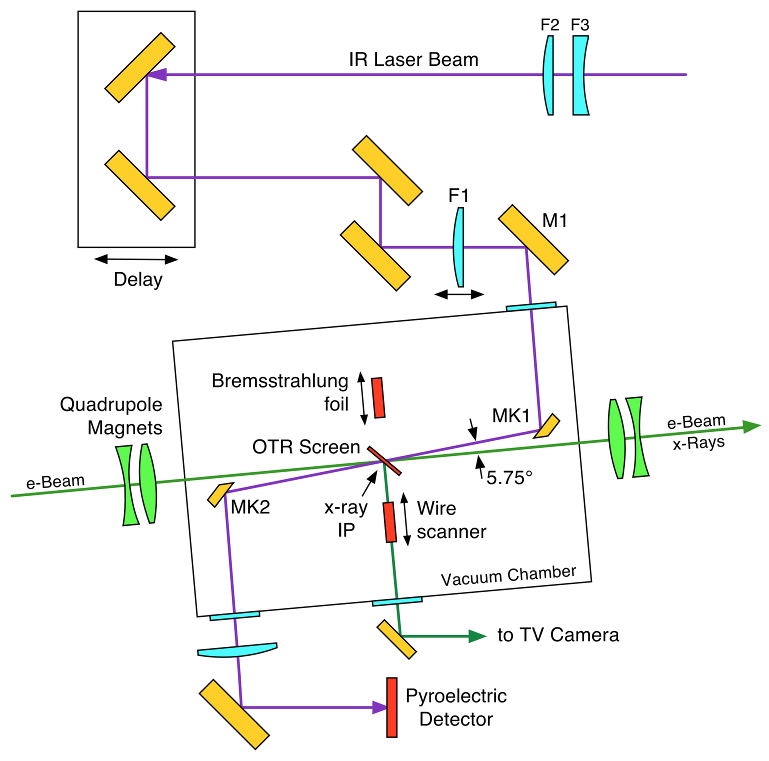
10 keV x-rays using a 40 MeV e-beam and 3000 nm free-electron laser



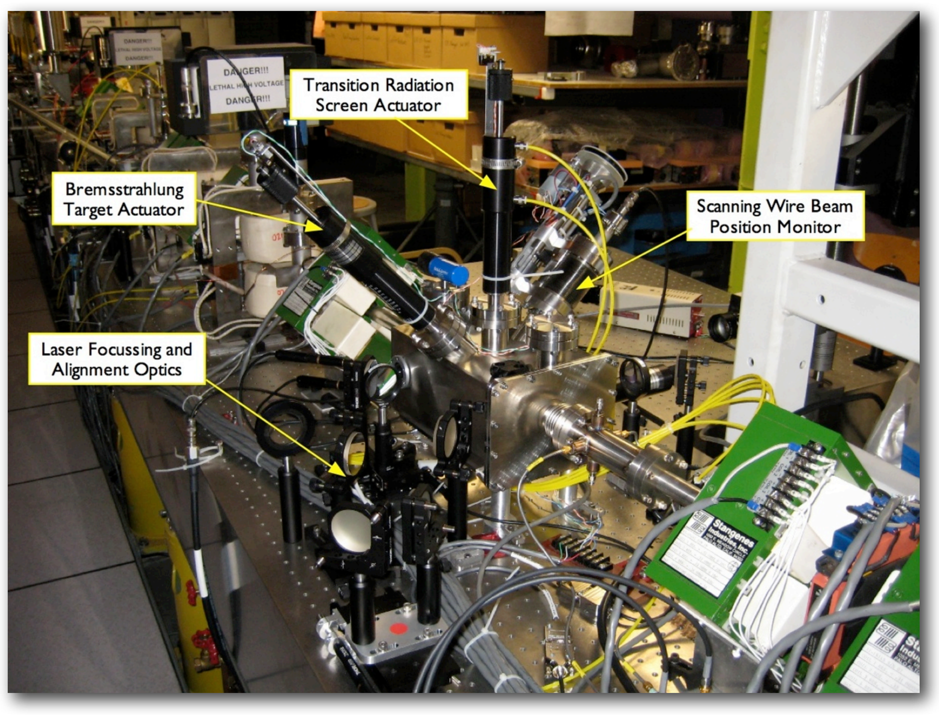
$$P_x = \frac{4\gamma^2 \tau_o \sigma_T I_e P_{\text{laser}}}{e\pi w_0^2}$$

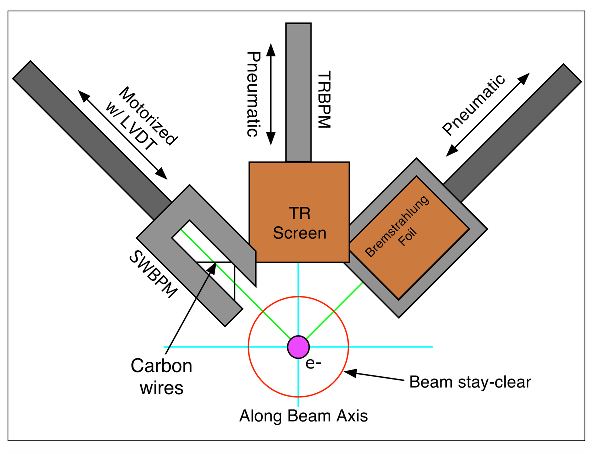
Interaction Point (IP) Space is Limited:

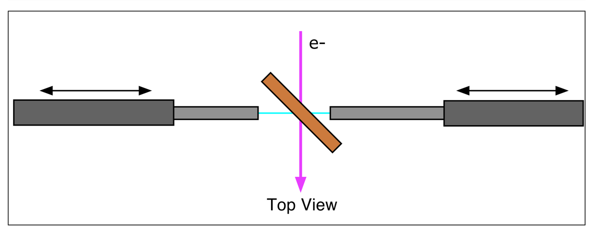
1. Focusing lens (F1) proximity to IP
2. Quadrupole magnet proximity to IP
3. Wire scanner, transition radiation (TR) screen and bremsstrahlung target share insertion point
4. Retractable laser kicker mirrors (MK1,2)



X-ray Interaction Point Optics and Diagnostics

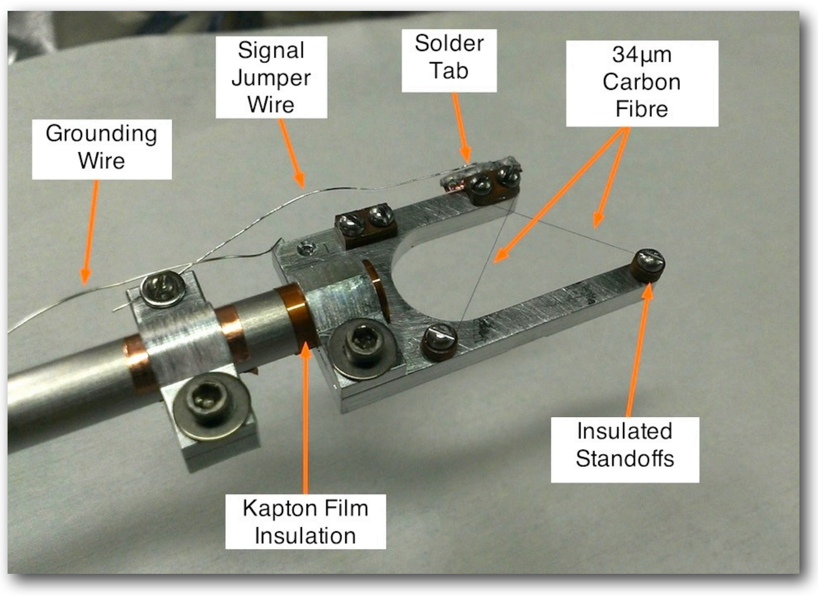


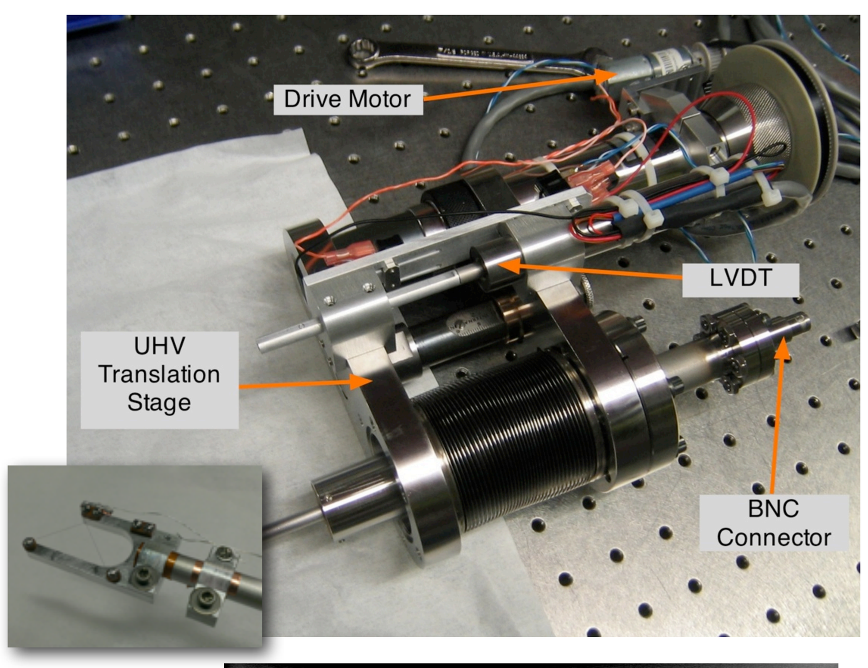


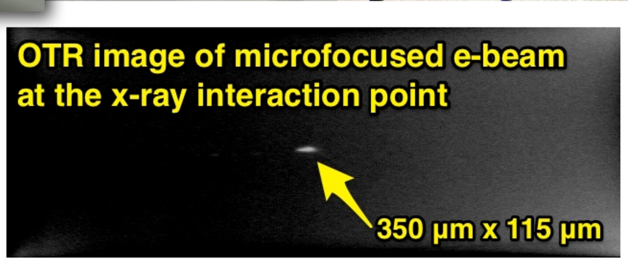


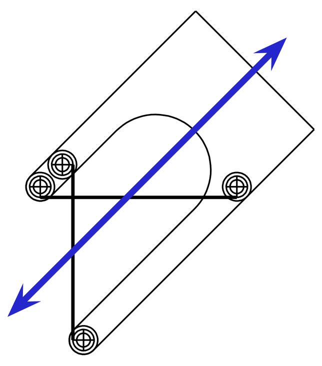
3. Wire Scanner Design

- Electron and laser beams focused to 30 µm radius
- How can beams be co-aligned to micron precision?
- Optical transition radiation (OTR) screens and beam position monitors (BPMs) limited to 100 µm resolution
- Existing wire scanner designs are incompatible with the UH e-beam and the space restrictions above
- Slow scans are needed for 4 µs e-beam macropulses; “flying wire” designs are unsuitable
- Design adapted from NBS/LANL and SLAC



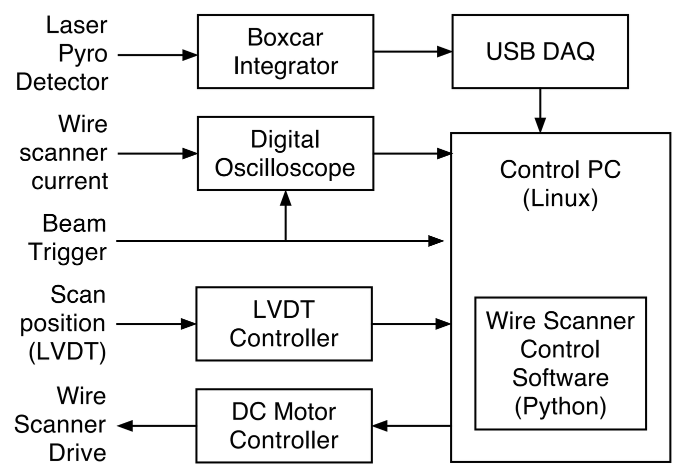




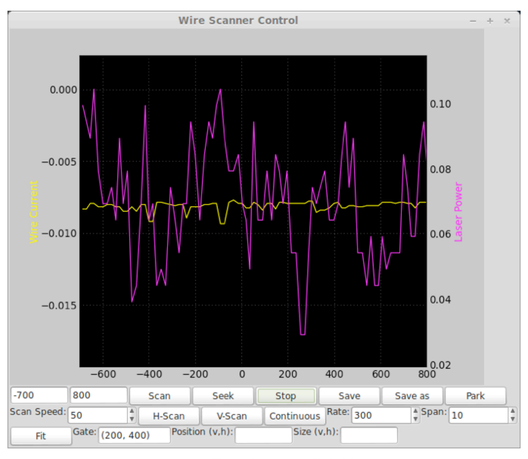


- 34 µm diameter carbon monofilament from Specialty Materials, Inc.
- 12.3 mm aperture in scanner fork
- 45° insertion allows horizontal and vertical scan on a single drive axis
- Low cost, compact linear translator from MDC Vacuum
- LVDT position read-back with 10µm resolution
- Secondary emission current extracted via shaft (bremsstrahlung backgrounds are troublesome for a linear beamline)
- Fork is grounded to prevent charge accumulation

4. Wire Scanner Control System

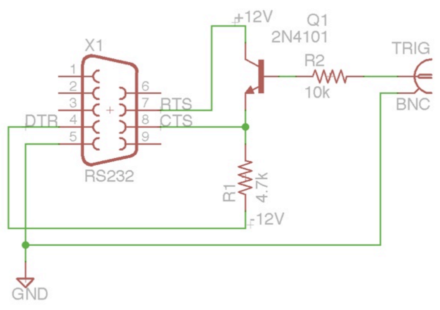


Operator Console



wxPython GUI

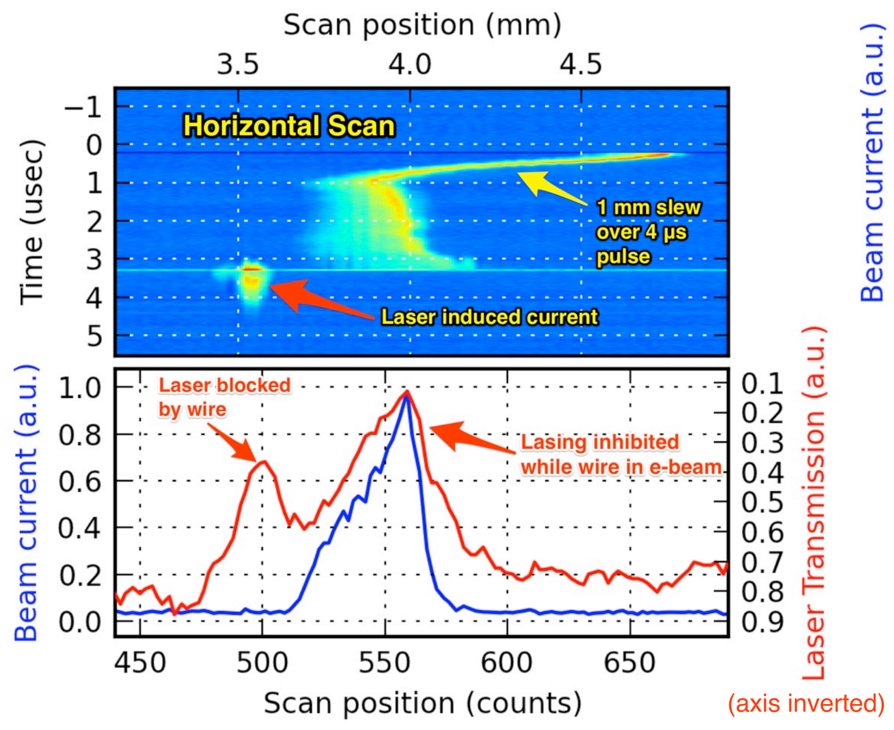
- 100 µm/sec scan speed with 5 Hz beam
- Fully automated 14 mm scans in 140 seconds
- 7.2 µm step resolution (12-bit digitizer)
- Live scan progress displayed in GUI
- Secondary emission current waveform is captured with a 300 MHz oscilloscope for every scan step
- Laser beam occlusion measured with a pyrometer sampled by a boxcar integrator and 12-bit digitizer

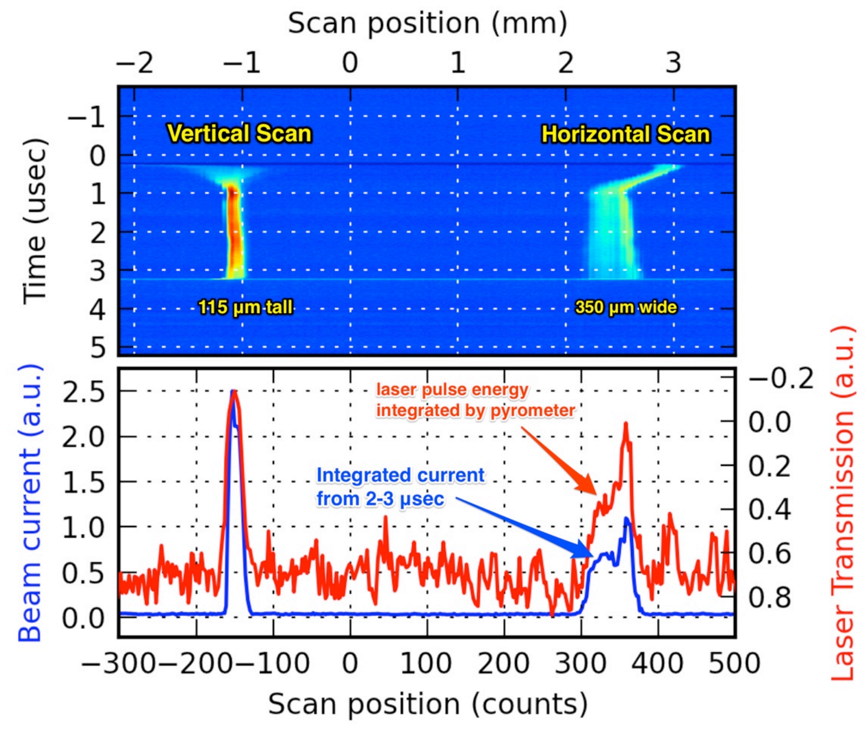


PC is synchronously triggered using a common RS232 serial port control line

- Python-based offline analysis software (cross-platform)
- Visualization of spatial and temporal beam profile

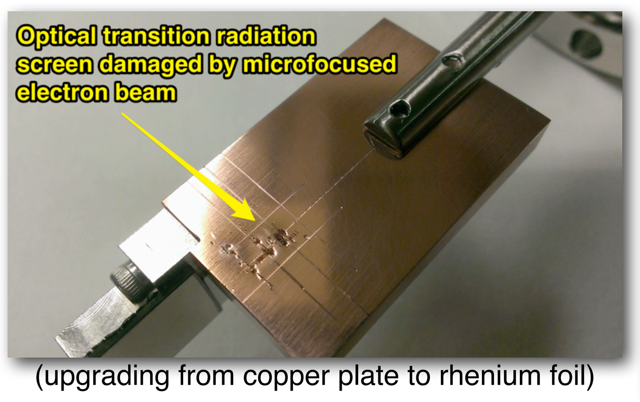
5. Results and Performance



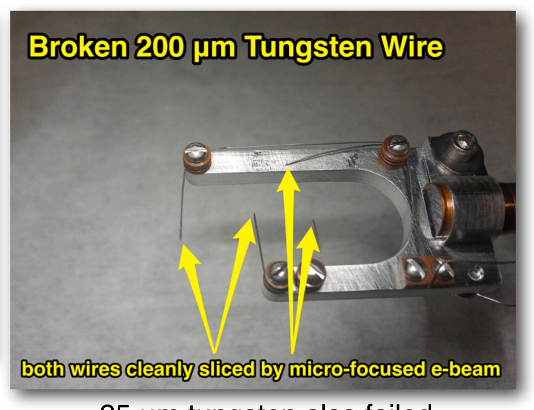


- Laser induced thermionic excitation of wire is visible in the secondary emission current signal
- Measured beam sizes include the wire diameter
- Characterization of beam slew is important to the optimization of the FEL and inverse-Compton source
- Single scan direction to avoid drive backlash of 30 µm
- Centroid measurement uncertainty: $\sigma_{x,y} = 4$ µm
- Beam width uncertainty: $\sigma_w = 9$ µm

30 µm electron and laser beams can be co-aligned with a repeatability better than 10 µm and is sufficient for initial alignment of an inverse-Compton light source.



(upgrading from copper plate to rhenium foil)



25 µm tungsten also failed
No damage to carbon fiber yet!

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Project support from:
United States Department of Homeland Security
Grant 2010-DN-077-AR1045-02
Poster presented at:
2013 International Beam Instrumentation Conference (IBIC)
16 — 19 September 2013, Oxford, England