# High Repetition Rate Laser Wire Scanner for High-Current Beams

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*23 March, 2015*
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# Outline

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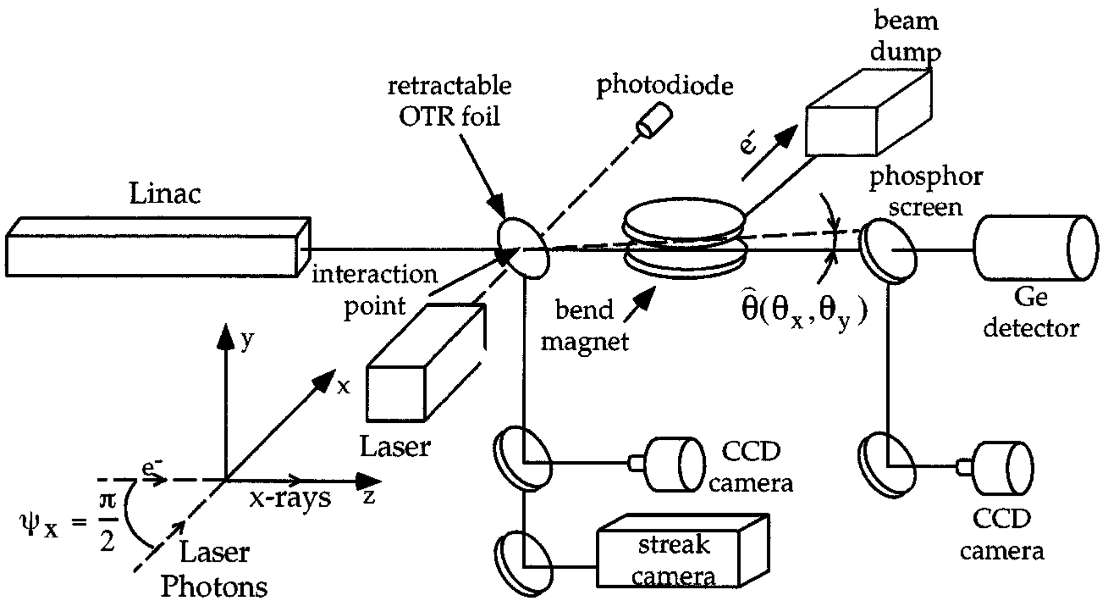
- Laser wire scanner background
- System development
- Verification plans and conclusions

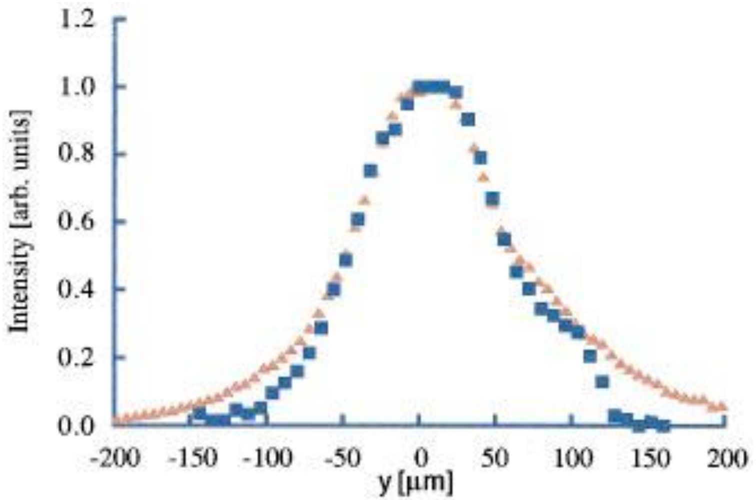
**Abstract:**

Laser wire scanner (LWS) devices capable of obtaining the pulse-averaged 2D and 3D current distribution profiles of accelerated electron beams have been demonstrated using high-intensity lasers, with ~ joule-class pulse energies at low repetition rates. These laser systems are exotic, expensive, and require expert operators in contrast with multi-MHz repetition rate systems which have high average power with low pulse energy and are cheaper and more reliable. The timing of such laser systems is more closely matched to the high repetition rates typical of DC gun and superconducting RF photoinjector systems which will enable future high-brightness light sources and energy recovery linacs. RadiaBeam Technologies in collaboration with the Cornell Energy Recovery Linac research group are developing a LWS prototype to meet these needs. Here we present the progress towards a high-repetition rate laser wire scanning 3D diagnostic.

# Background

- **Laser wire scanner background**
- System development
- Verification plans and conclusions



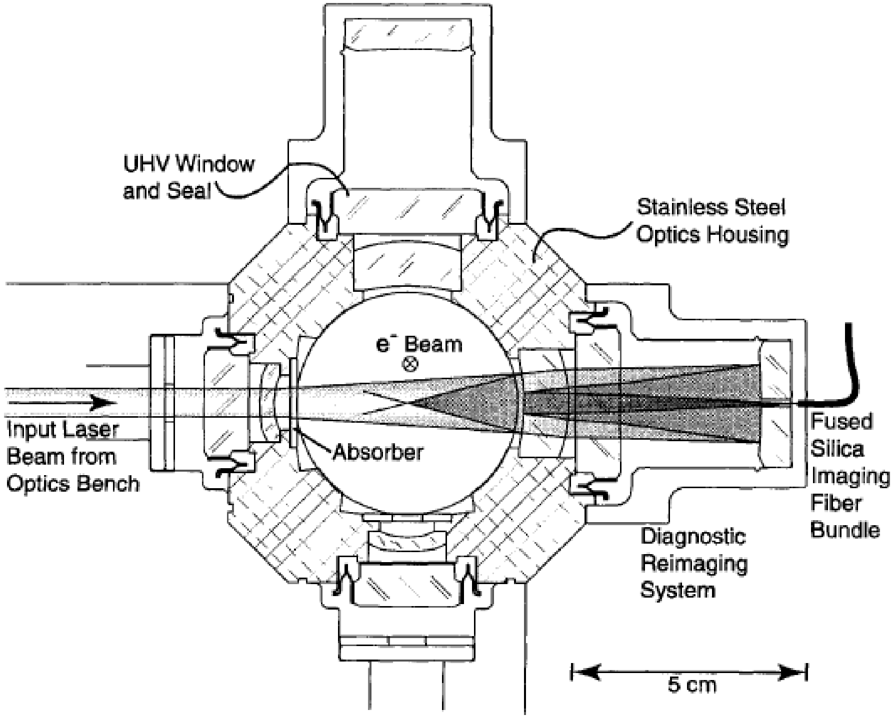



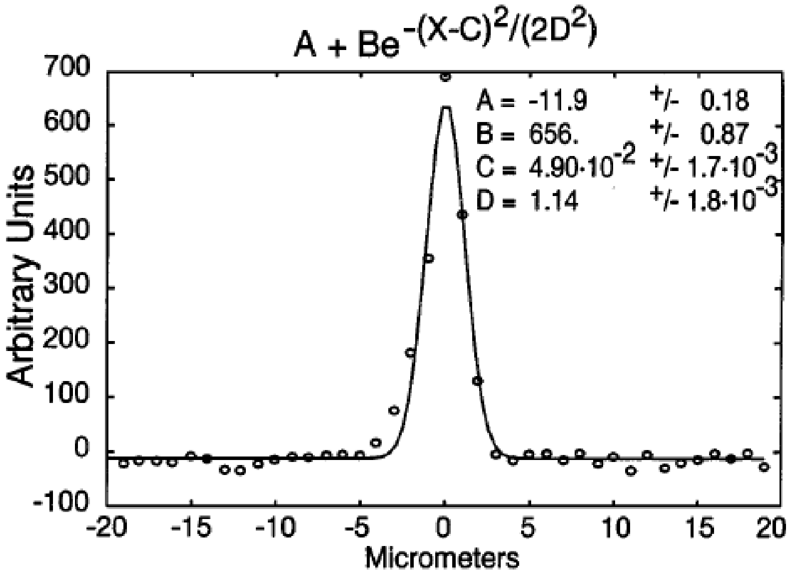

Beam profile in X-rays and OTR

W. Leemans *et al.*, *Phys. Rev. Lett.*, **77**(20), 4182 (1996)

# Application to Very Small Beams

- The laser wire scanner was originally developed for ultra-intense beam diagnostic on single-shot scales (FFTB @ SLAC, 1992)

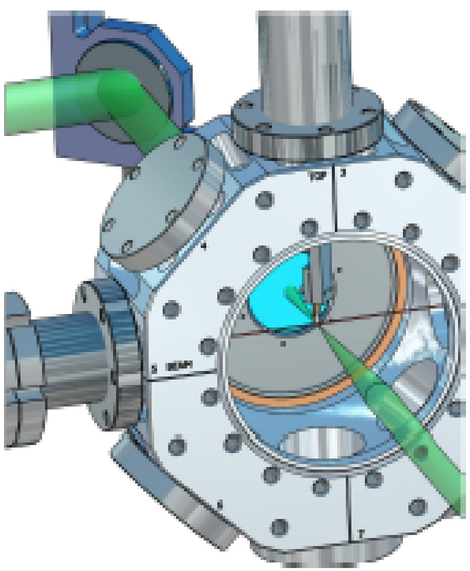


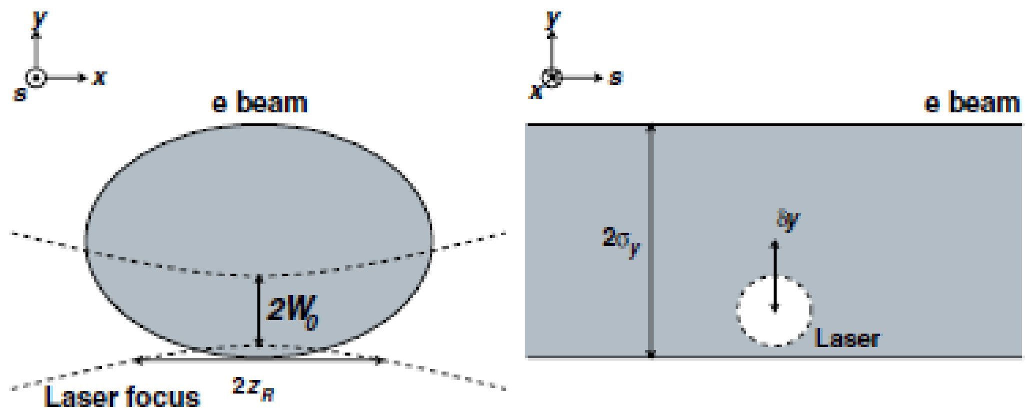




P. Tenenbaum and T. Shintake, *Annu. Rev. Nucl. Part. Sci* **49**, 125 (1999).

# Application to High Current Beams

- Diagnostic requirements for high average current beams, such as in energy recovery linacs (ERL) and other high-repetition rate superconducting drivers are much different than collider systems:
  - Larger beam sizes
  - Decreased resolution requirements
  - System is inherently multi-shot, running up to nearly CW
  - Time-averaged measurements OK






S.T. Boogert, *Phys Rev STAB* **13**, 122801 (2010)

# LWS Background Summary

- Laser wire is optimal for very high power scenario
  - Non-destructive
  - Needle-like precision
- Can provide robust alternative capable of full-duty cycle operations where conventional profiling cannot
- Extreme final focusing systems in colliders
  - Very small beams requiring exquisite resolution
  - Low repetition rate, high charge density
- High average power machines (ERL)
  - Larger beam size $\sigma_{x,y}$ ~ 1 mm @ injector, ~ 100 μm after acceleration
  - Modest charge $q_{bunch}$ ~ 50 – 100 pC
  - High repetition rate 50 MHz ~ 1.3 GHz

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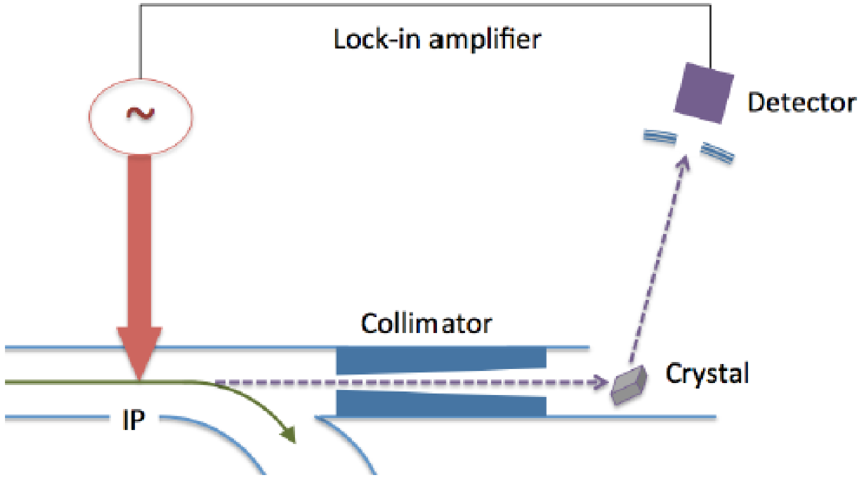
# Design and Test of LWS

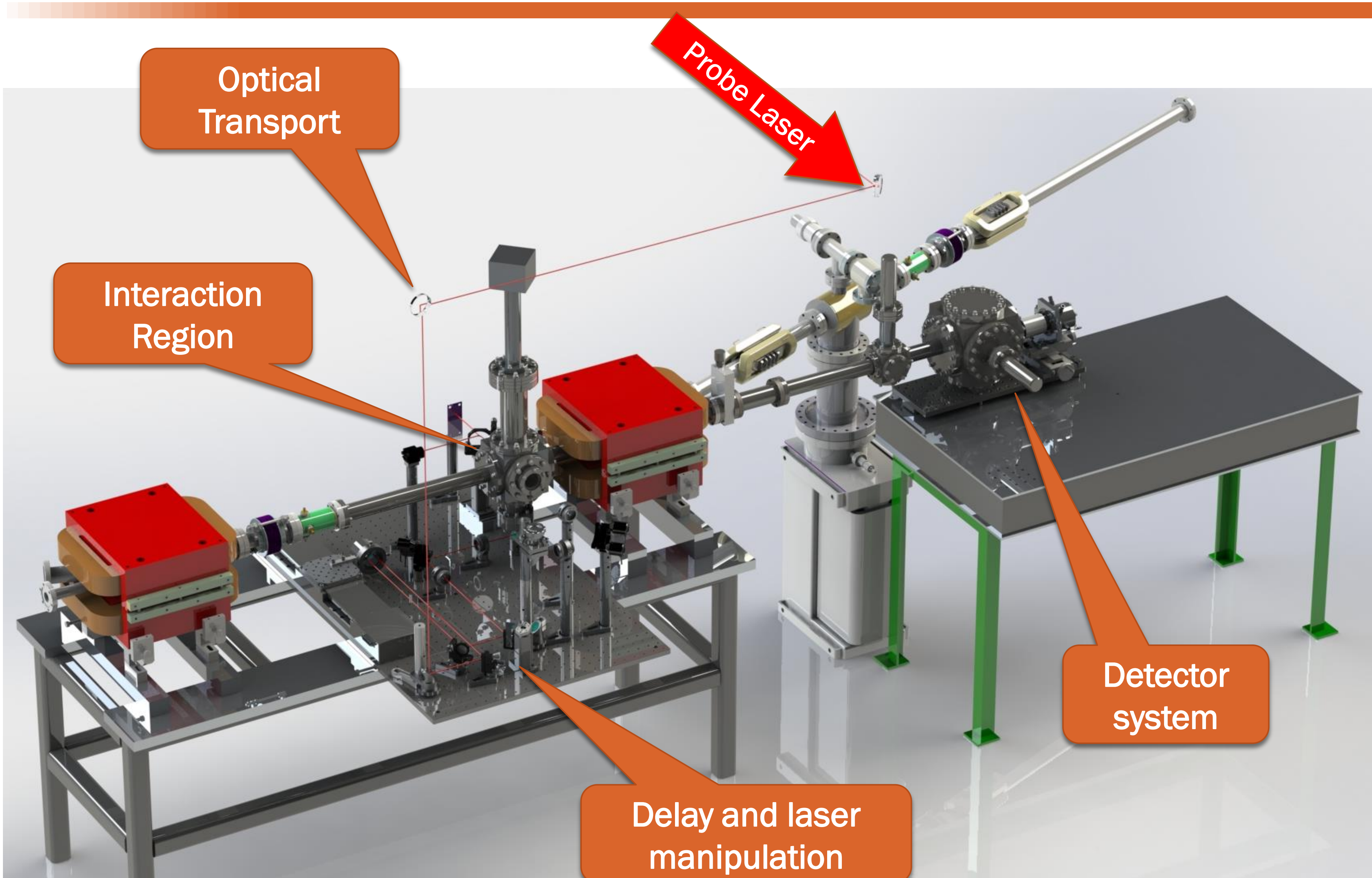
- Collaborate with the Energy Recovery Linac Group at Cornell University for beam test
- Operational SCRF injector system available (present)
  - 5 – 10 MeV, up to 80 pC per bunch, 50 MHz or 1.3 GHz
- Soon to have an additional linac providing up to ~ 40 MeV
- Leveraging high average power laser developments at Cornell
- In an ideal case, the maximum Compton photon yield can be estimated as:

$$\dot{N} \approx \frac{P_L}{h\omega}\frac{N_e\,\sigma_{th}}{\sigma_z\,\sigma_x} \propto 10^6 P_L\,[W]$$

- Seek to improve signal to noise through spatial, spectral, and temporal means

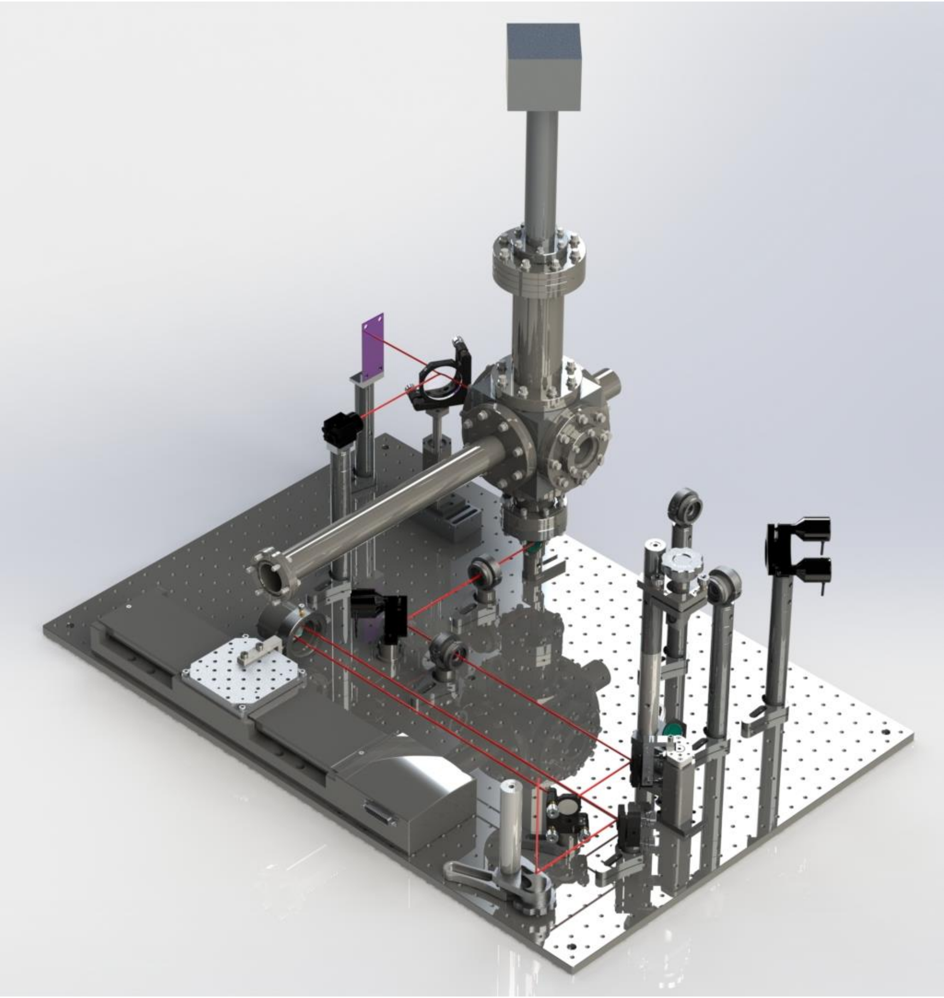


# LWS System Model

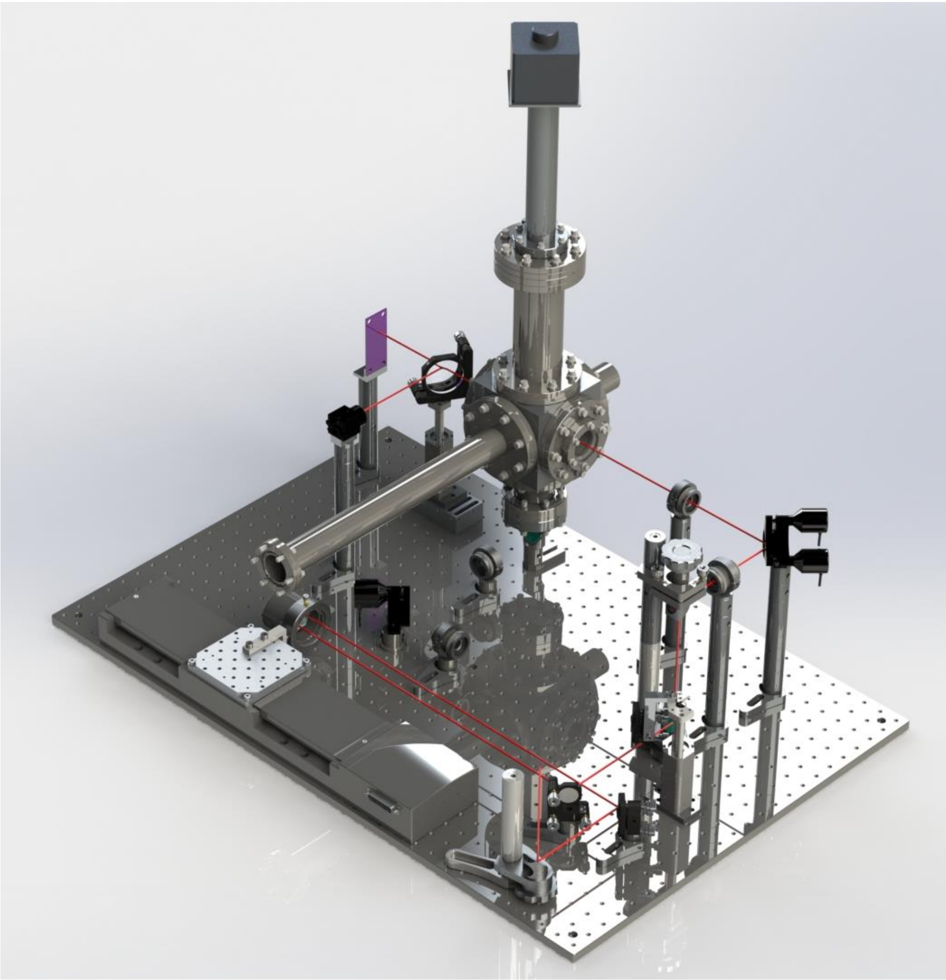


# Two Axis Scanning

## Scanning for Horizontal Profile

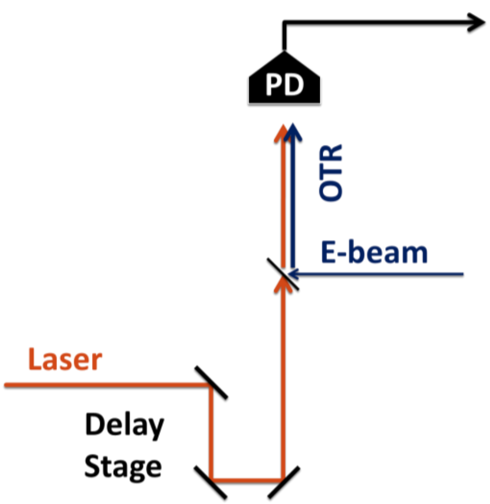


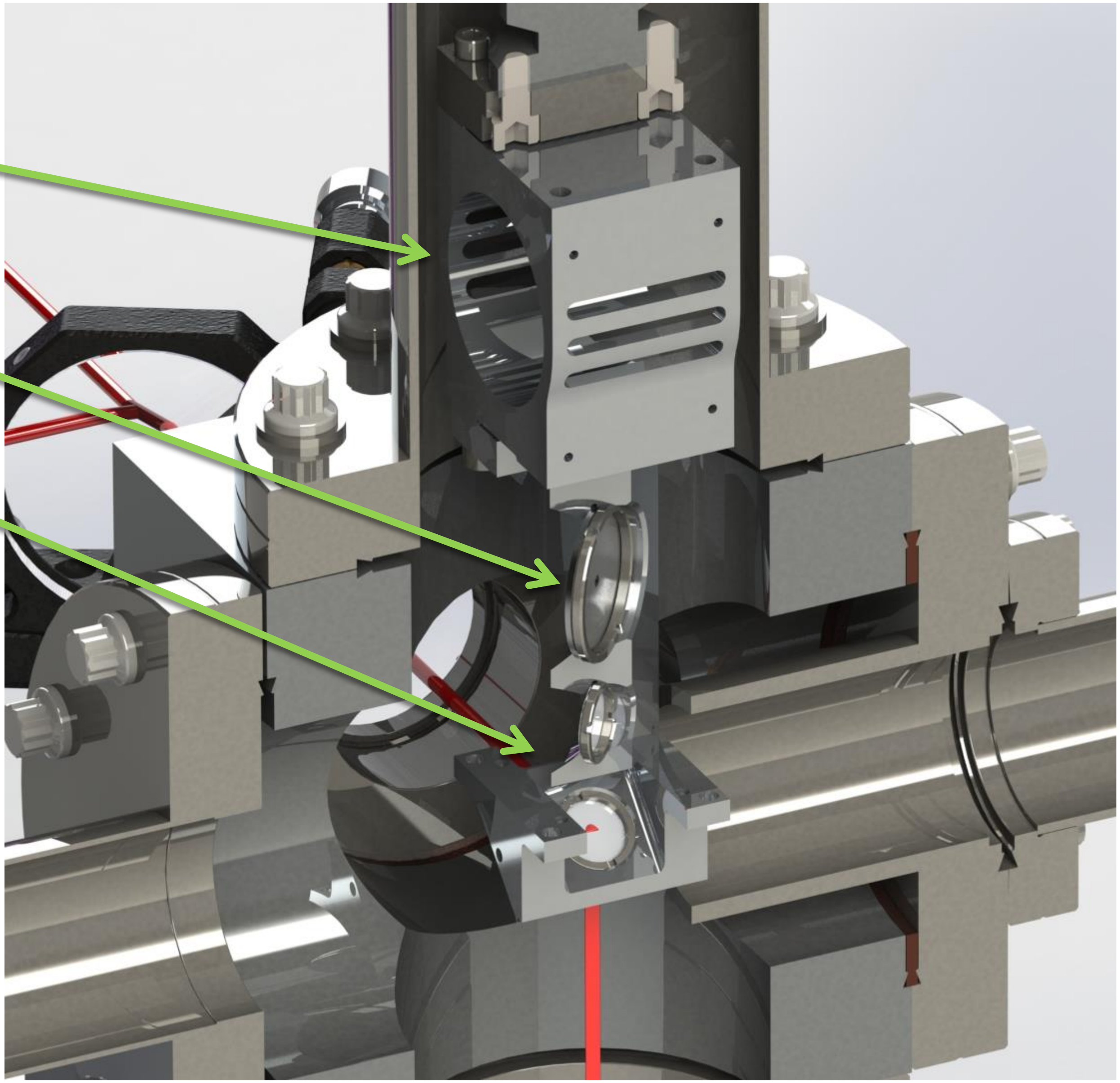
## Scanning for Vertical Profile



# Interaction Region

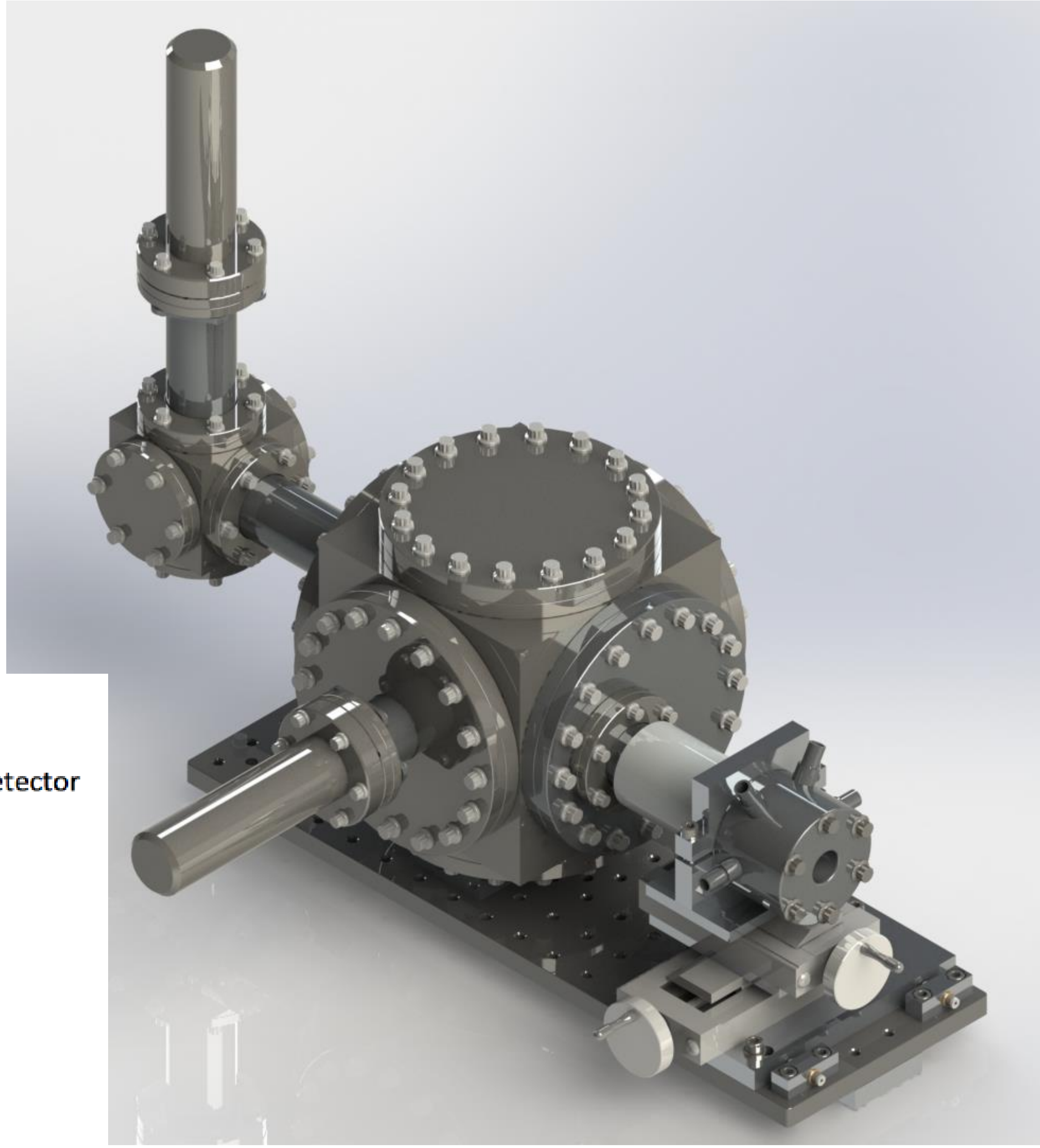
- Impedance matching cage for high average current beams
- BeO screen for e-beam imaging w/ pinhole for laser positioning
- Foils for OTR and laser timing
- Nearby electronic BPM for stability monitoring

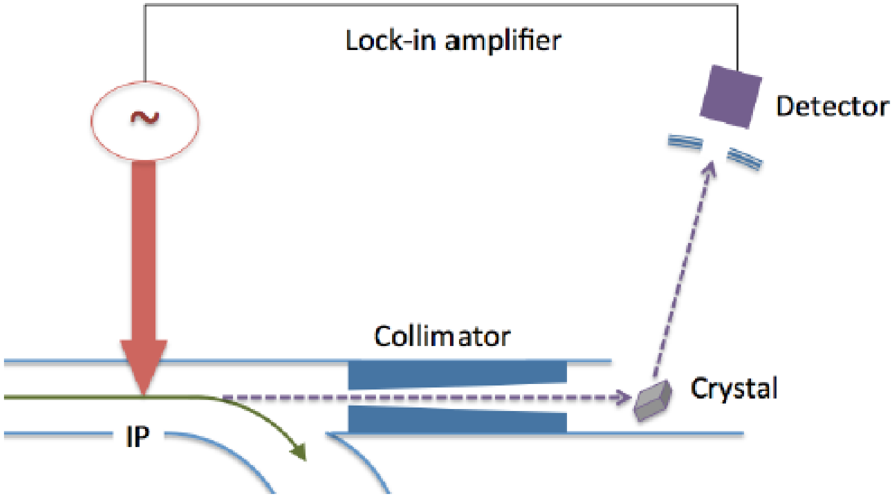


# Spectrally Resolved Detection

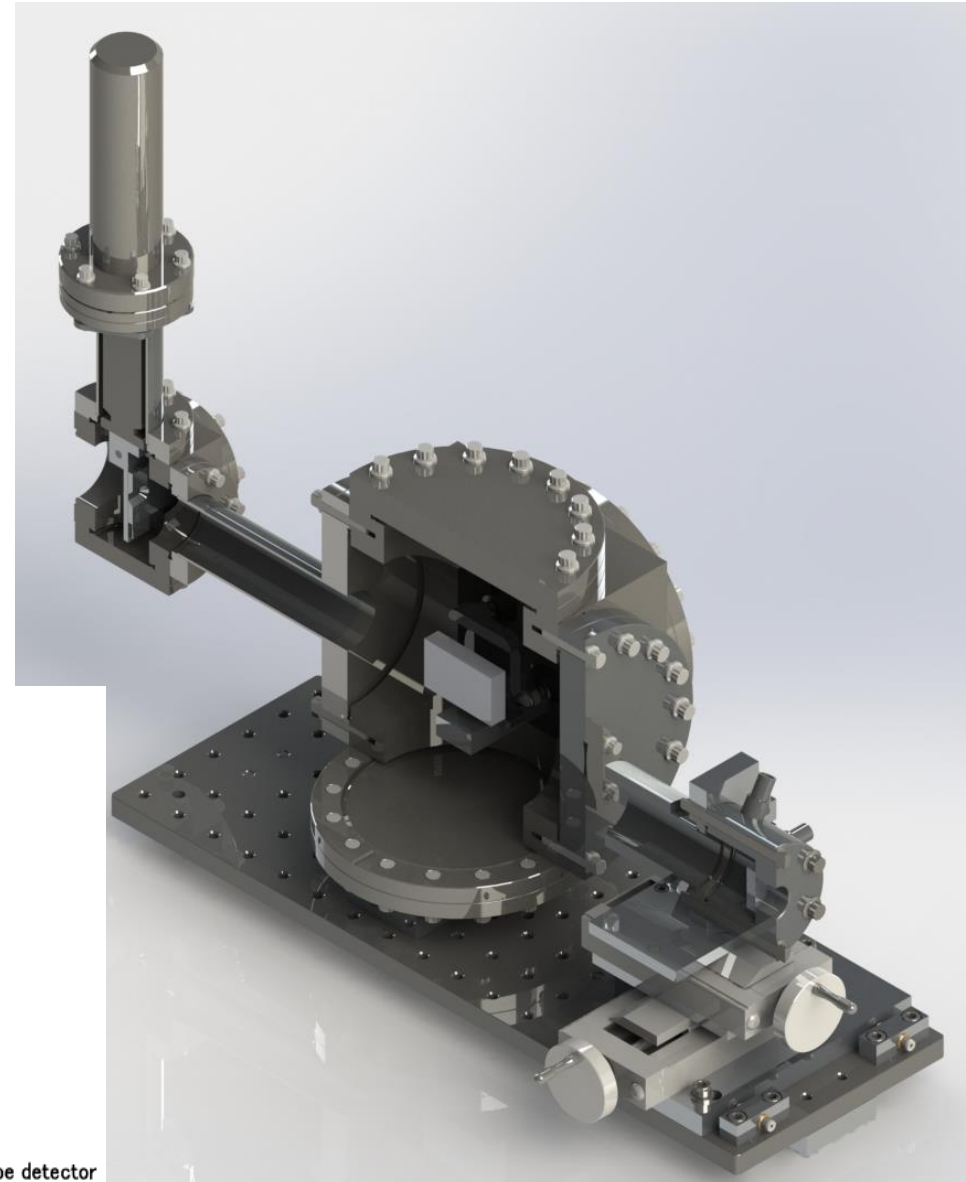
- Develop EUV/soft X-ray spectrometer system
- Reduce background from high-energy halo bremsstrahlung
- MCP detector for imaging or electronic readout

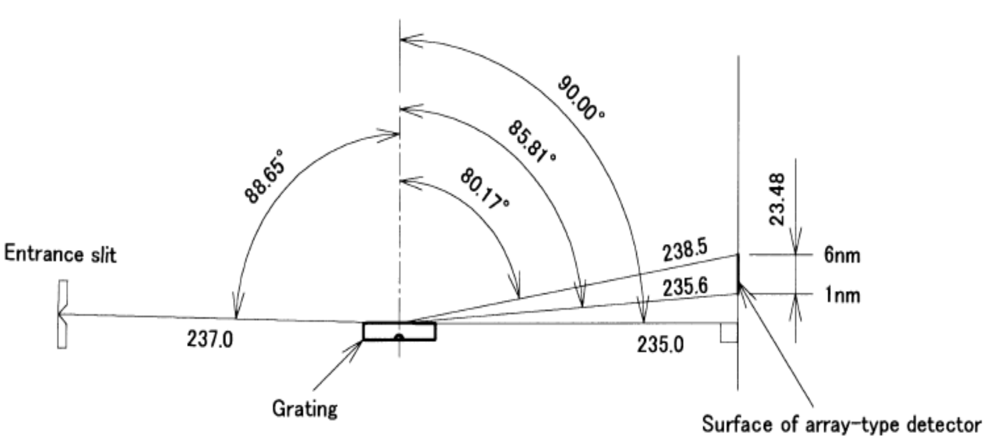




# Spectrometer Details

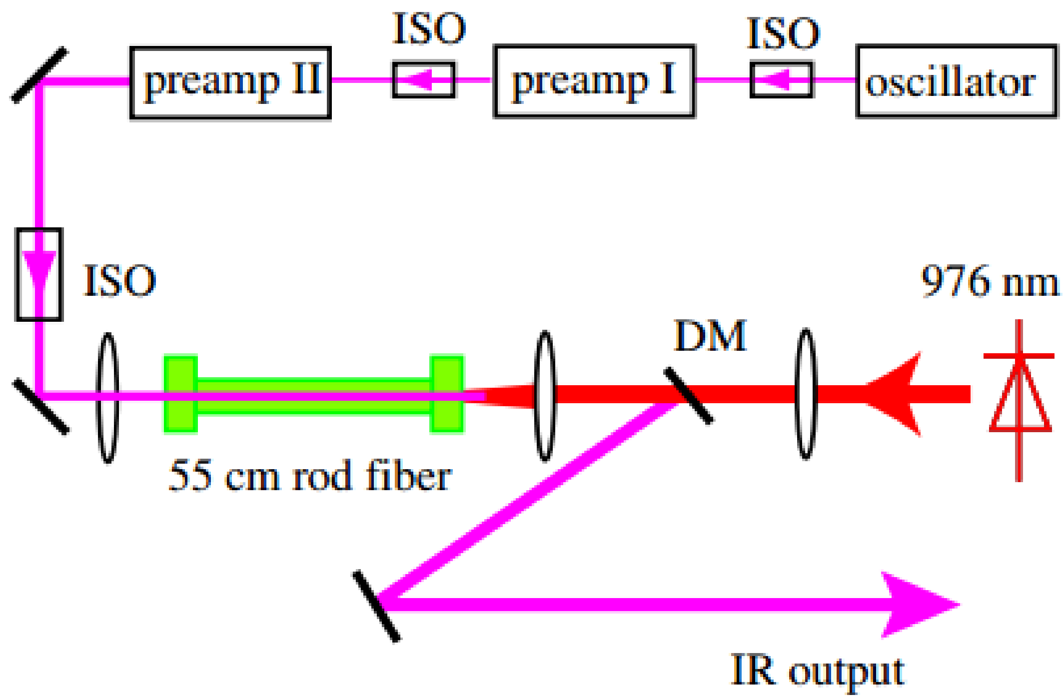
- Flat-field spectrometer design
- Unequally spaced curved-groove grating
  - 2400 groves/mm
- Adjustable stage mounted MCP readout covers 1 – 6 nm (1.2 keV ~ 200 eV) spectral range



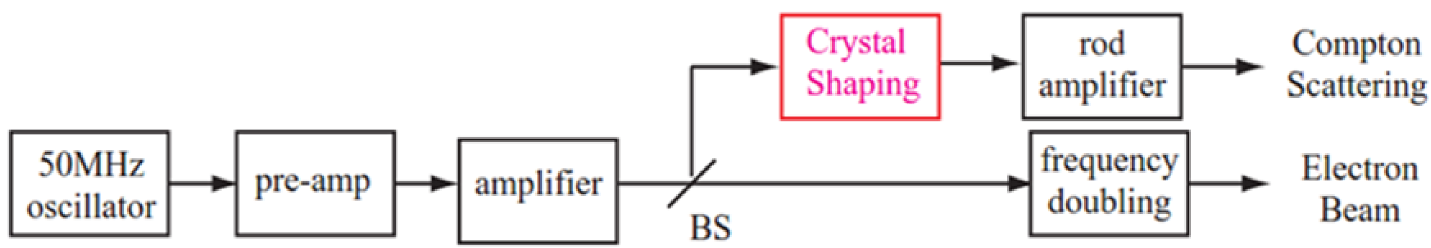


# Cornell High Power Fiber Laser

- Cornell group has developed 50 MHz and 1.3 GHz high average power lasers
- Up to 160 W IR power!
- Use crystal shaping to temporally alter probe laser pulse

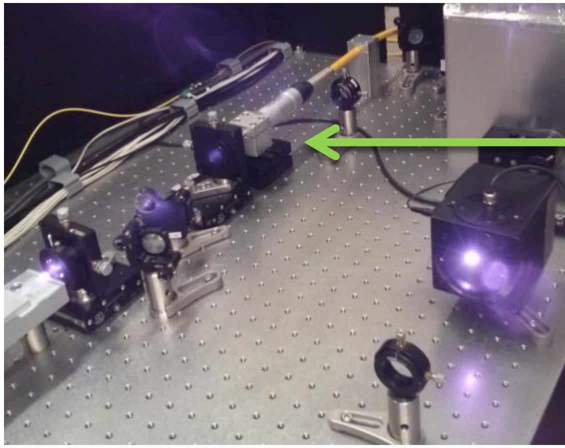



Z. Zhao, *et al.*, PRSTAB **17**, 053501 (2014)

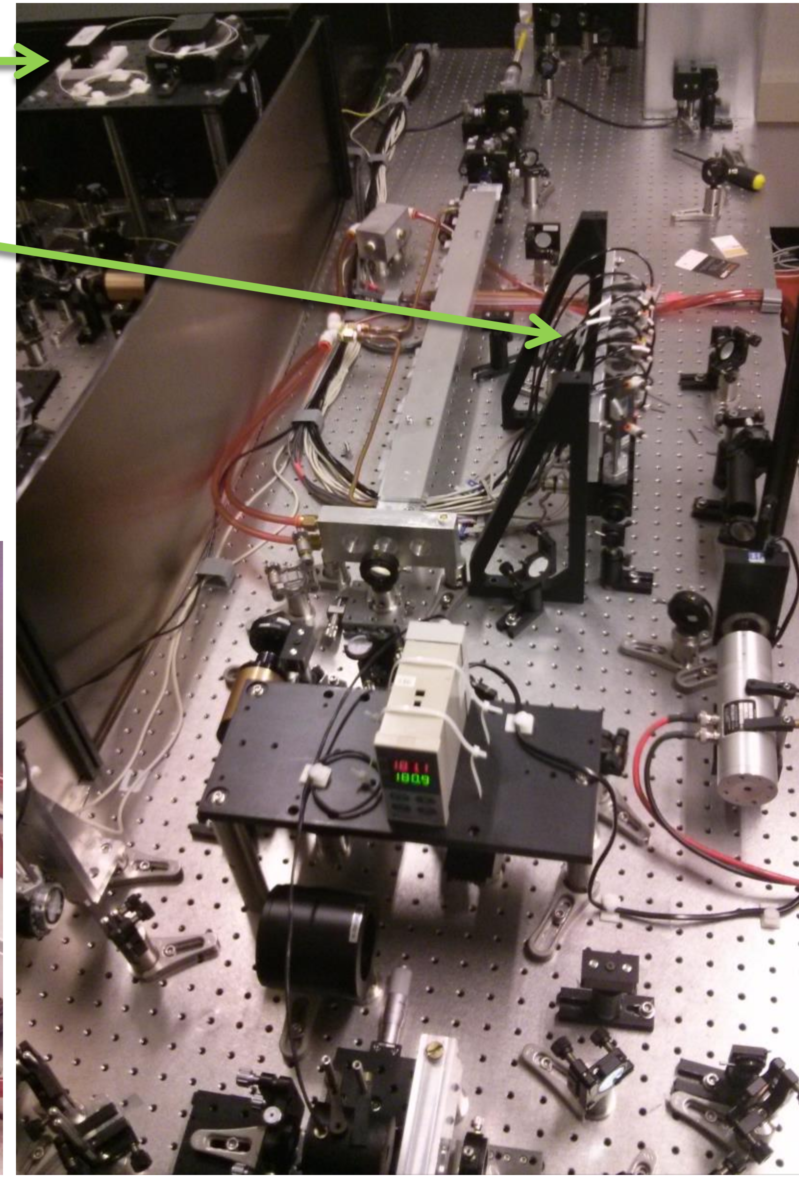


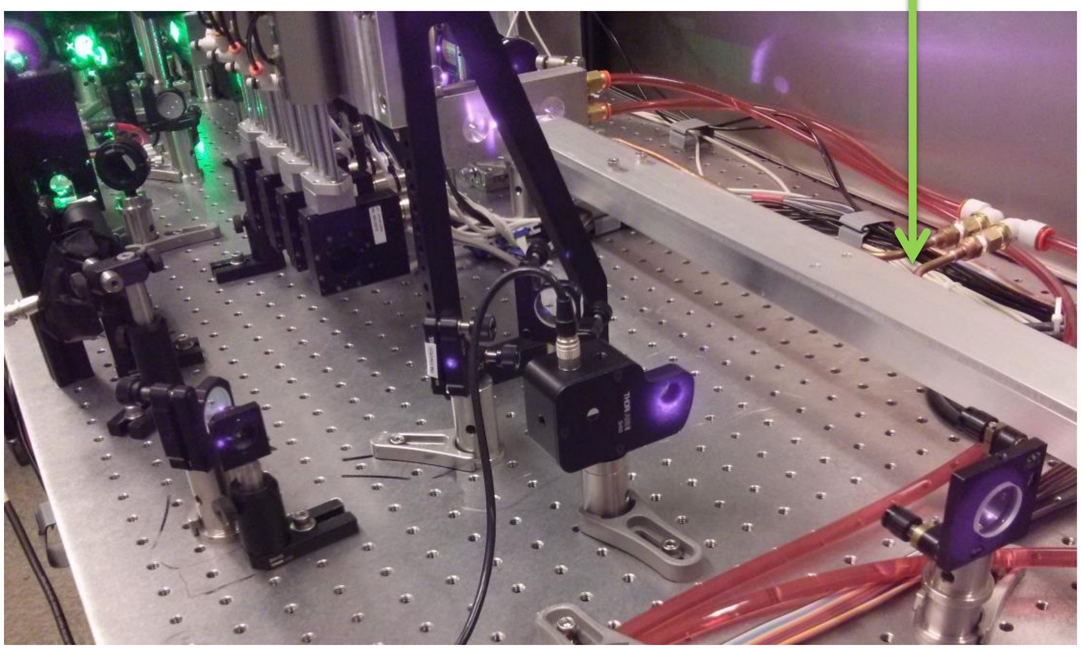

Crystal shaping is used to produce 5-10 ps pulses and amplified in the rod fiber.

# High Power Rod Fiber



- Oscillator
- Pump laser
- Crystal shaping
- Fiber rod amplifier





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# Development and Test Plans

- Collaboration with Cornell ERL Group
  - Some tests already complete
  - Low energy 5 – 12 MeV
  - Very low photon energy detection problem
- Engineering and component manufacturing complete
- Finalize tests of X-ray/EUV spectrometer @ RadiaBeam (next months)
- Integrate with new Cornell beamline installation (Summer 2015)
- Experimental verification and demonstration using Cornell ERL high average power laser (Fall 2015)

# Conclusions

- LWS can be a solution for non-invasive 3D profile measurements for high-repetition rate high average current beams
- Relaxed resolution requirements (mm to sub-mm) for ERL-type beams vs. those used in final focusing systems (micron or sub-micron!)
- Detector challenges
  - signal-to-noise issues in accelerator environments
  - low scattered photon energy  when used in injector systems
- Ongoing experiment with Cornell ERL group
  - Upgrading to higher energy (hopefully in time!)
- Many thanks to you all!

# Acknowledgement

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This material is based upon work supported by the Department of Energy under Award Number DE-SC0009598.