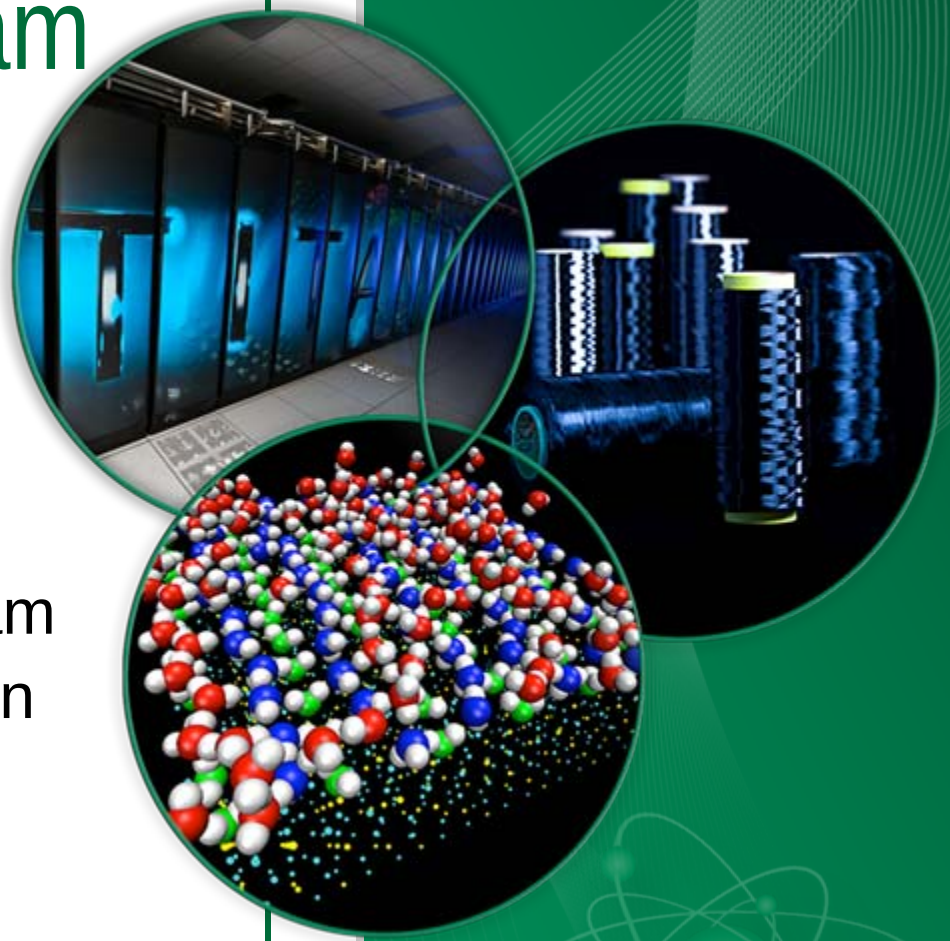
Laser Based H^- Beam Diagnostics



Yun Liu
for Beam Instrumentation Team
Research Accelerator Division
Spallation Neutron Source

Outline

- Overview of laser based H^- beam diagnostics
- SCL laser wire profile monitor
- HEBT laser emittance scanner
- MEBT laser bunch shape monitor
- Commissioning experience
- Conclusion

Laser Based Beam Instrumentation at the SNS Accelerator Complex

1. MEBT Laser Bunch Shape Monitor
2. SCL Laser Wire Profile Monitor
3. HEBT Laser Emittance Scanner
4. Laser Assisted H- Stripping

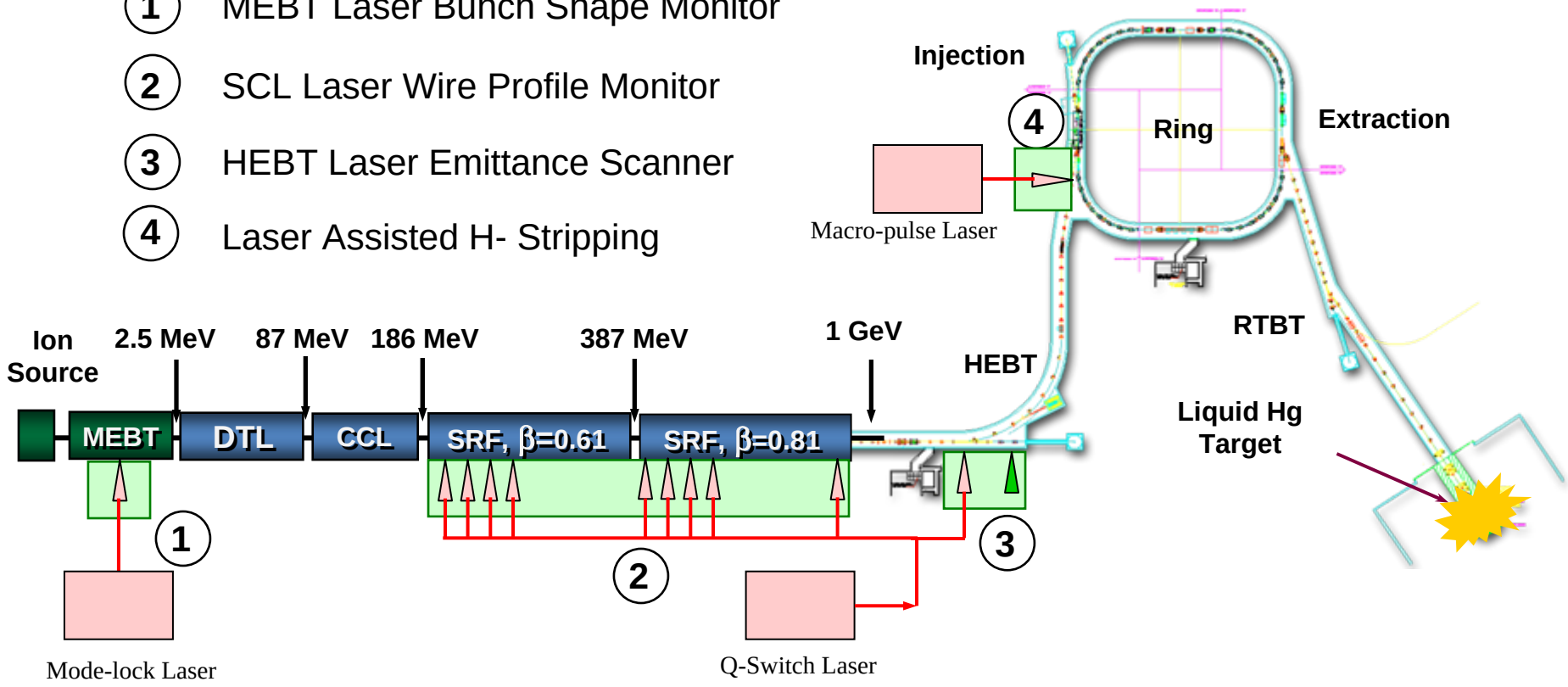
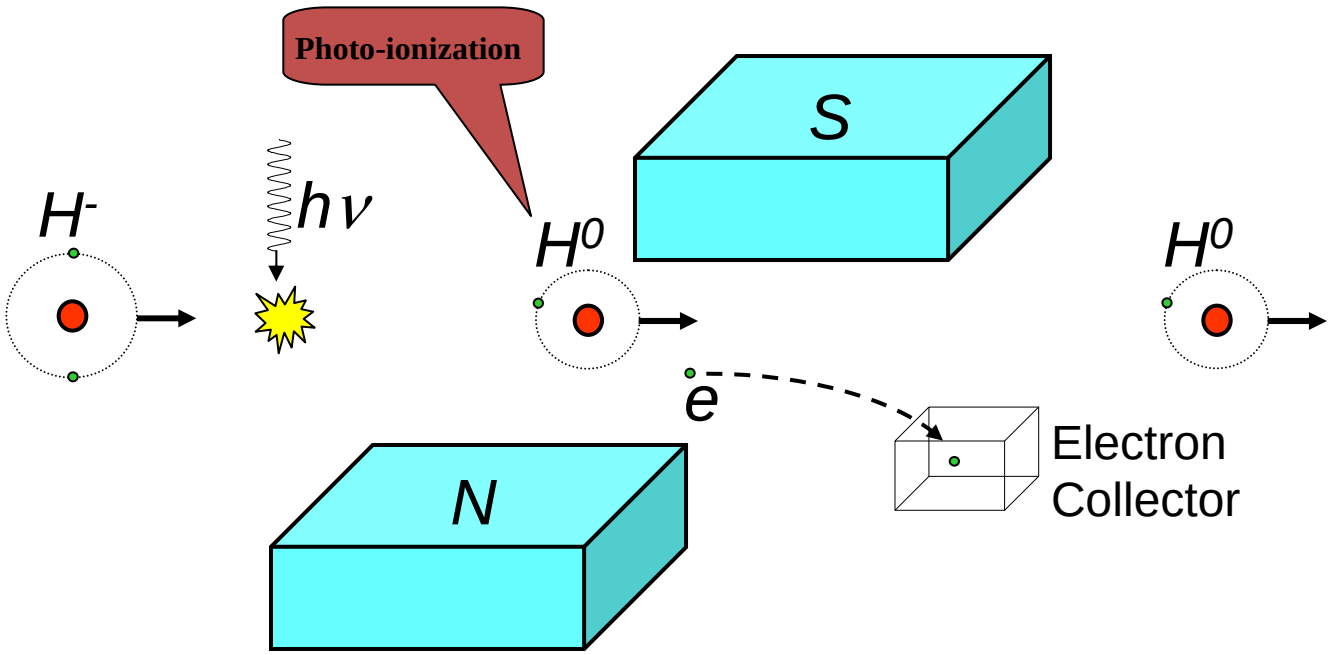
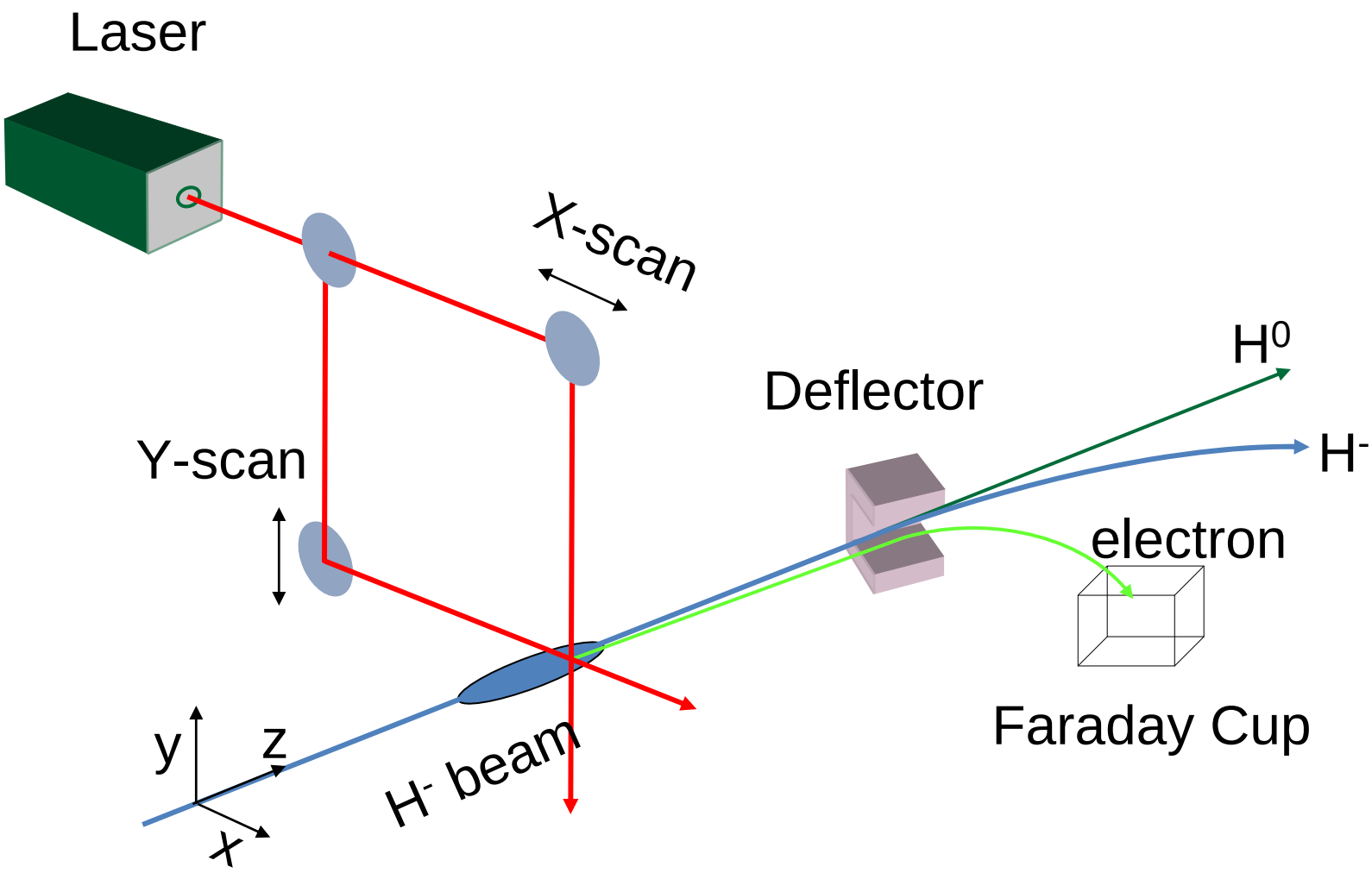


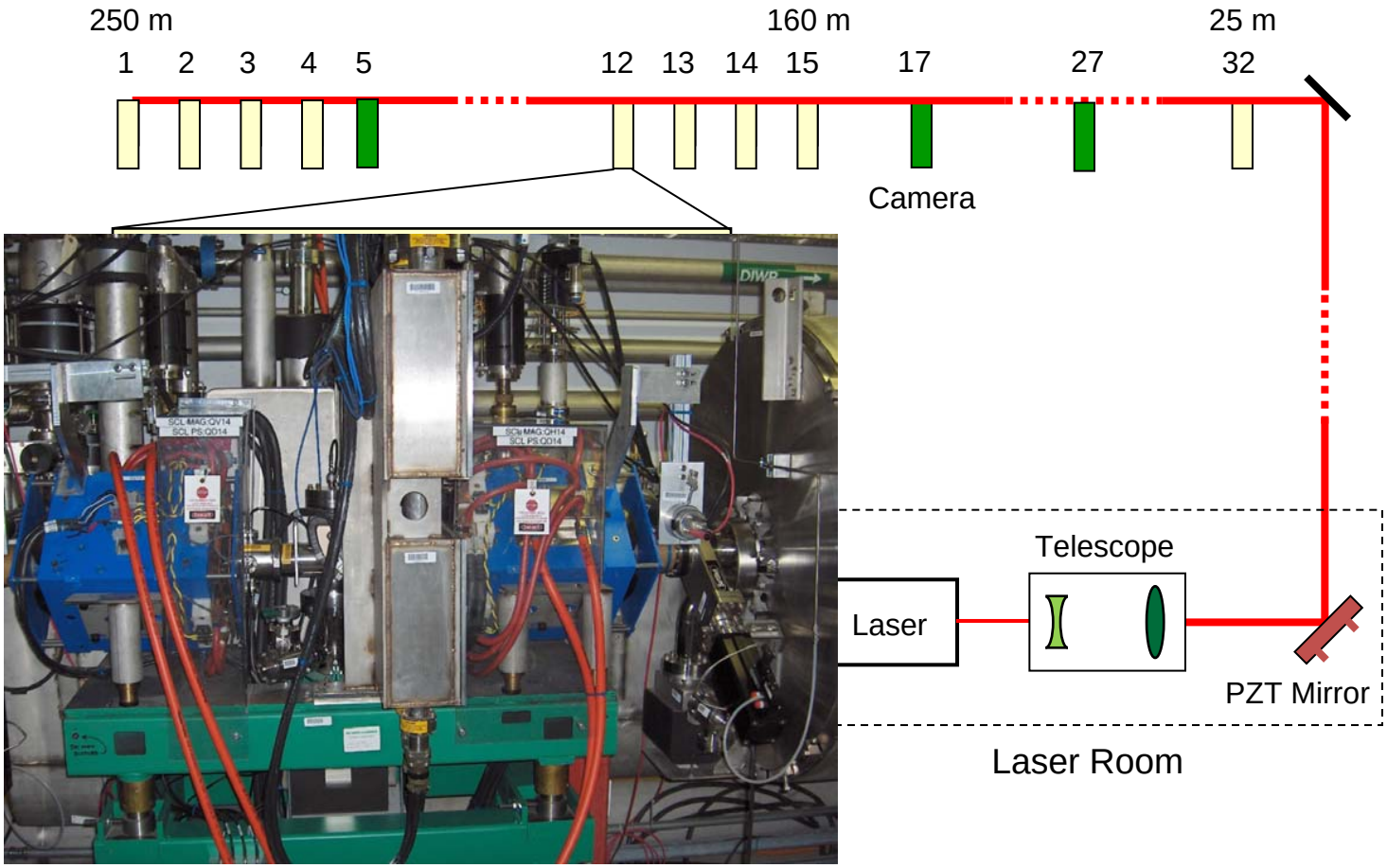
Photo-ionization – Physics behind Laser Based Ion Beam Diagnostics



Laser Wire Profile Monitor



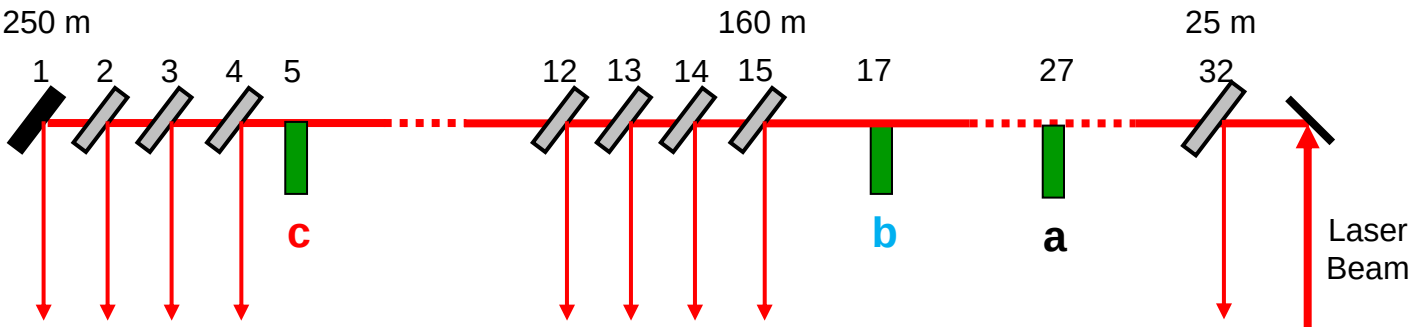
SCL Laser Wire Profile Measurement System

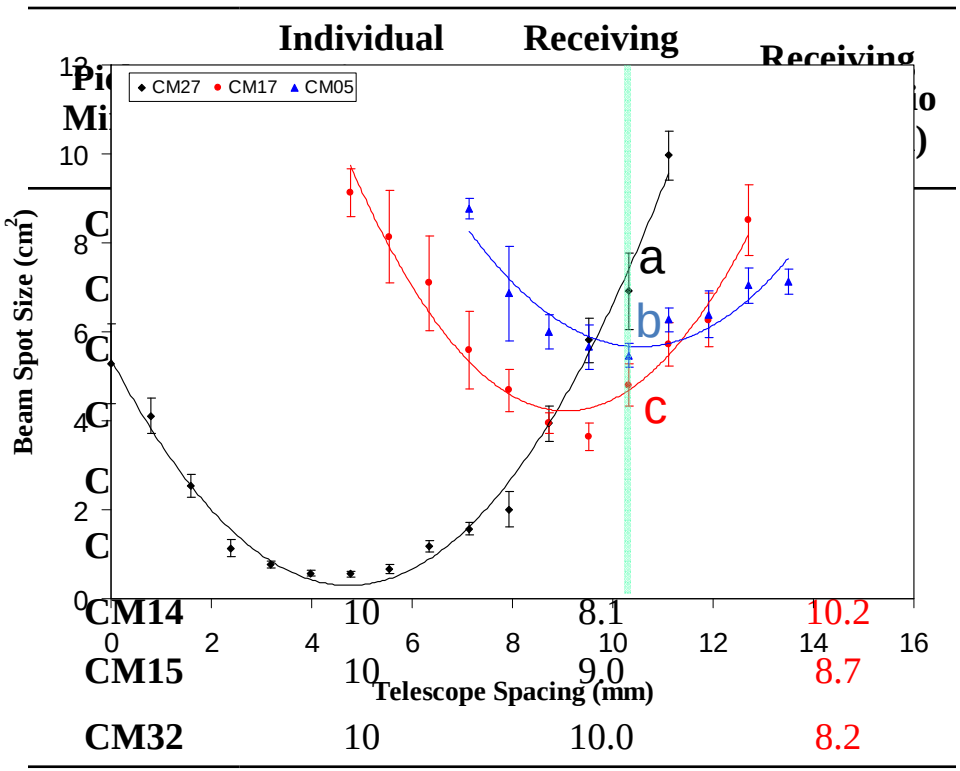


Liu et al, *NIMA* **612** (2010) 241–253;

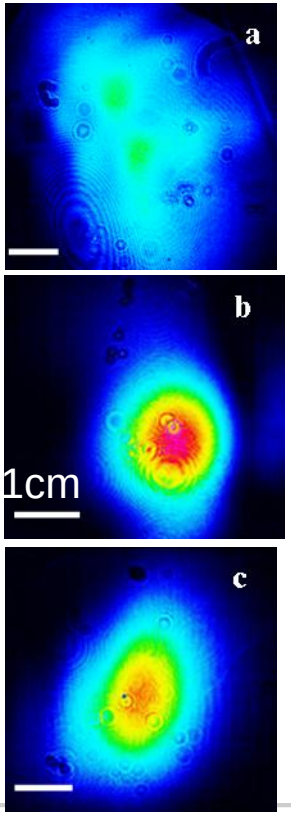
Appl. Opt. **49** (2011) 6816-6823.

Laser Transport Line

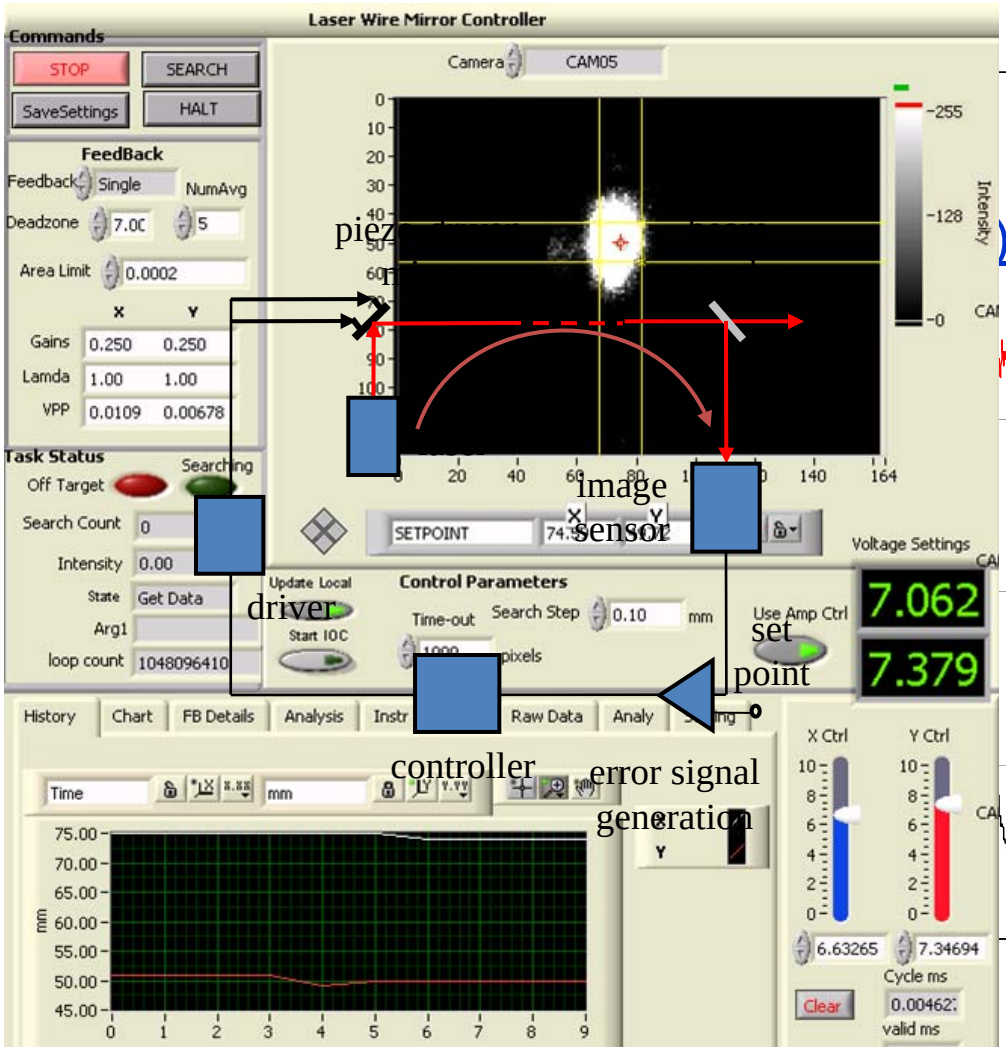


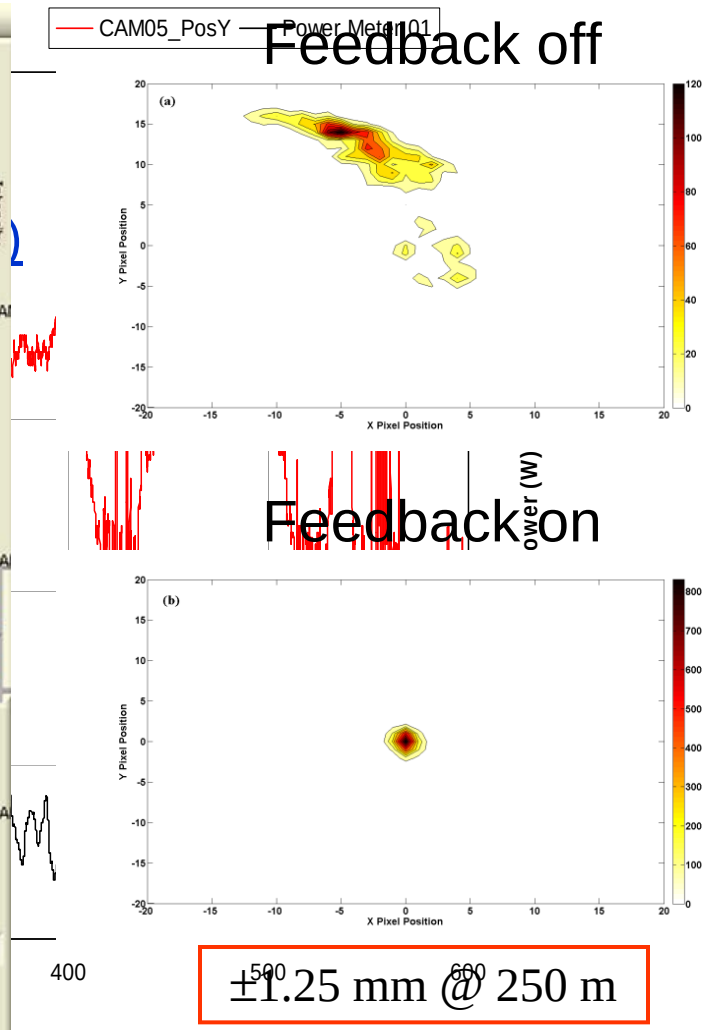


CM14	10	8.1	10.2
CM15	10	9.0	8.7
CM32	10	10.0	8.2



Laser Beam Pointing Stabilization

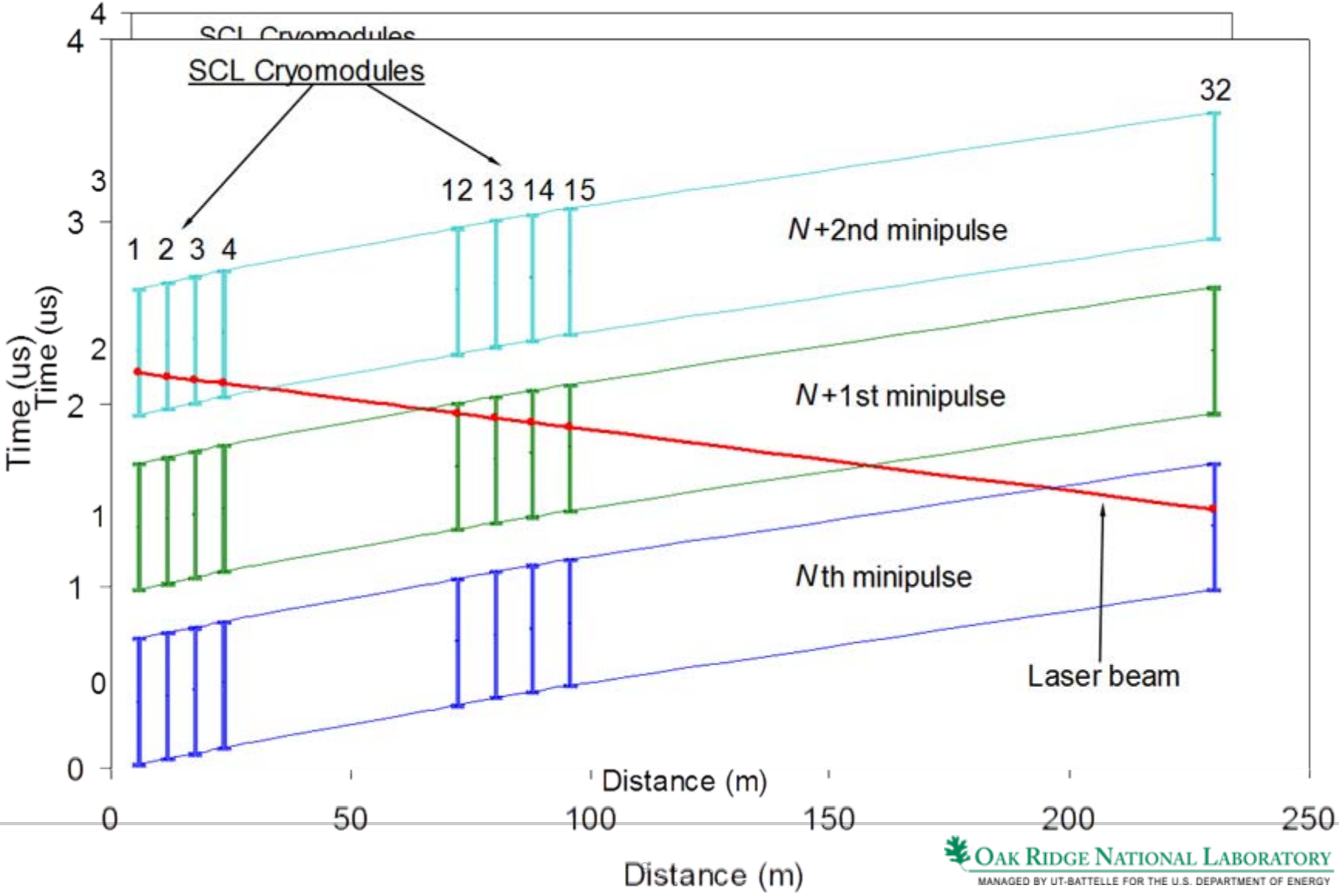




Hardin et al, *Opt. Express* **19** (2011) 2874-2885.

Phase Tuning between Laser and H- Pulses

Propagation of Ion Beam and Light Beam



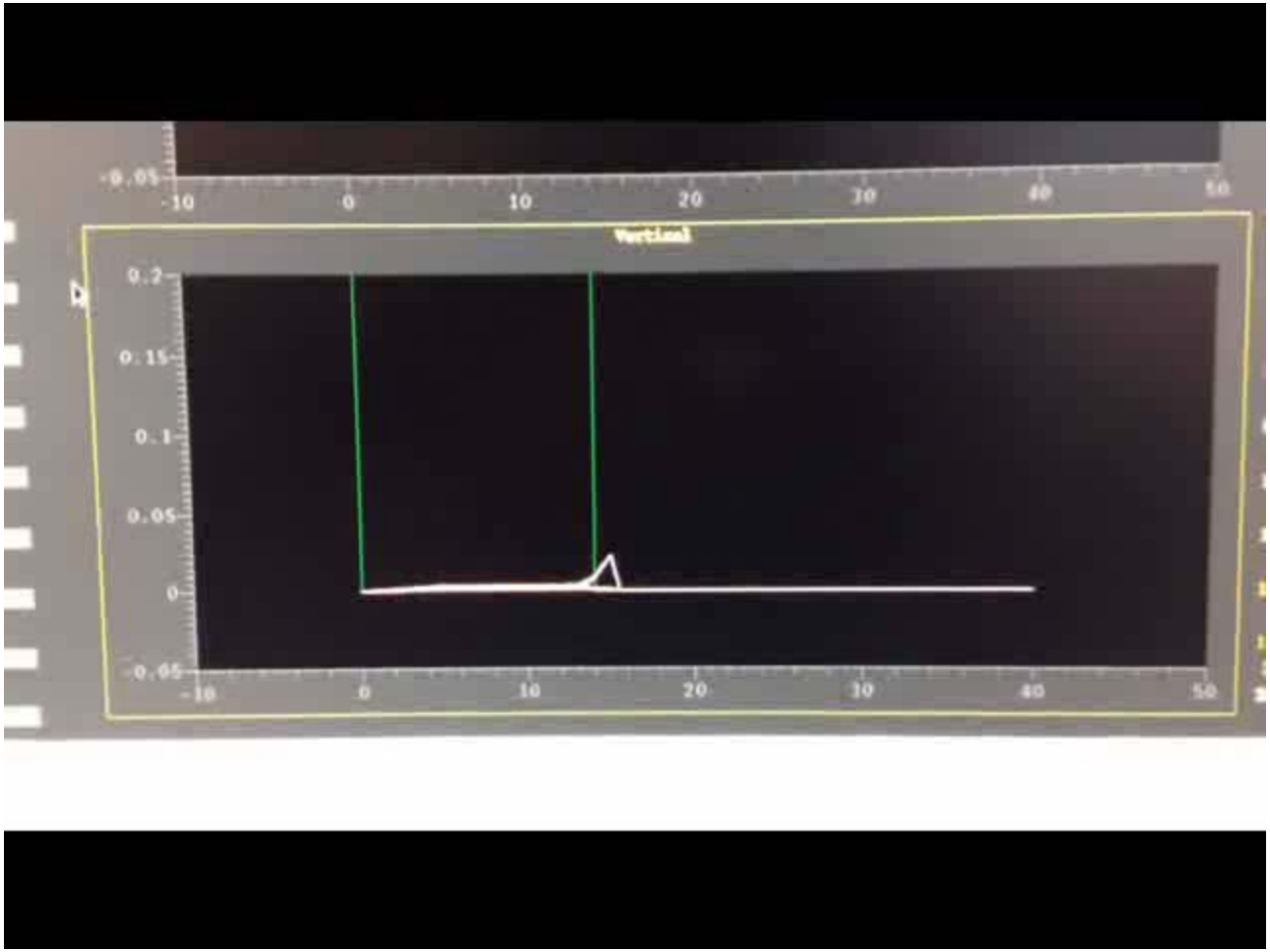
EDM Screens for Laser Wire System

From EPICS, user can select one, multiple, or all scanners

From EPICS, user can select scan range, step size, average number. Fitting is automatically conducted.

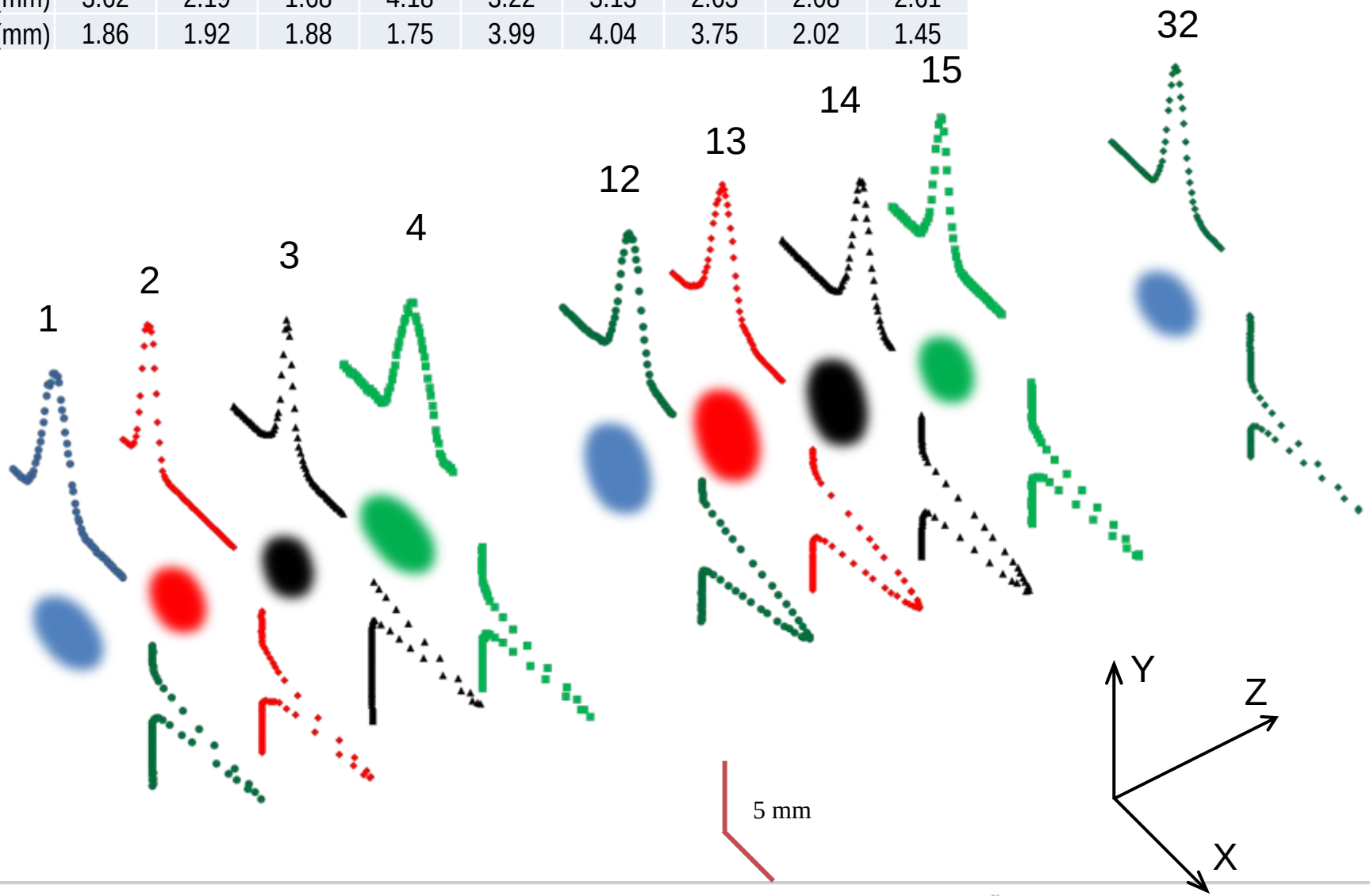
Simultaneous Profile Scan

Simultaneous Profile Scan



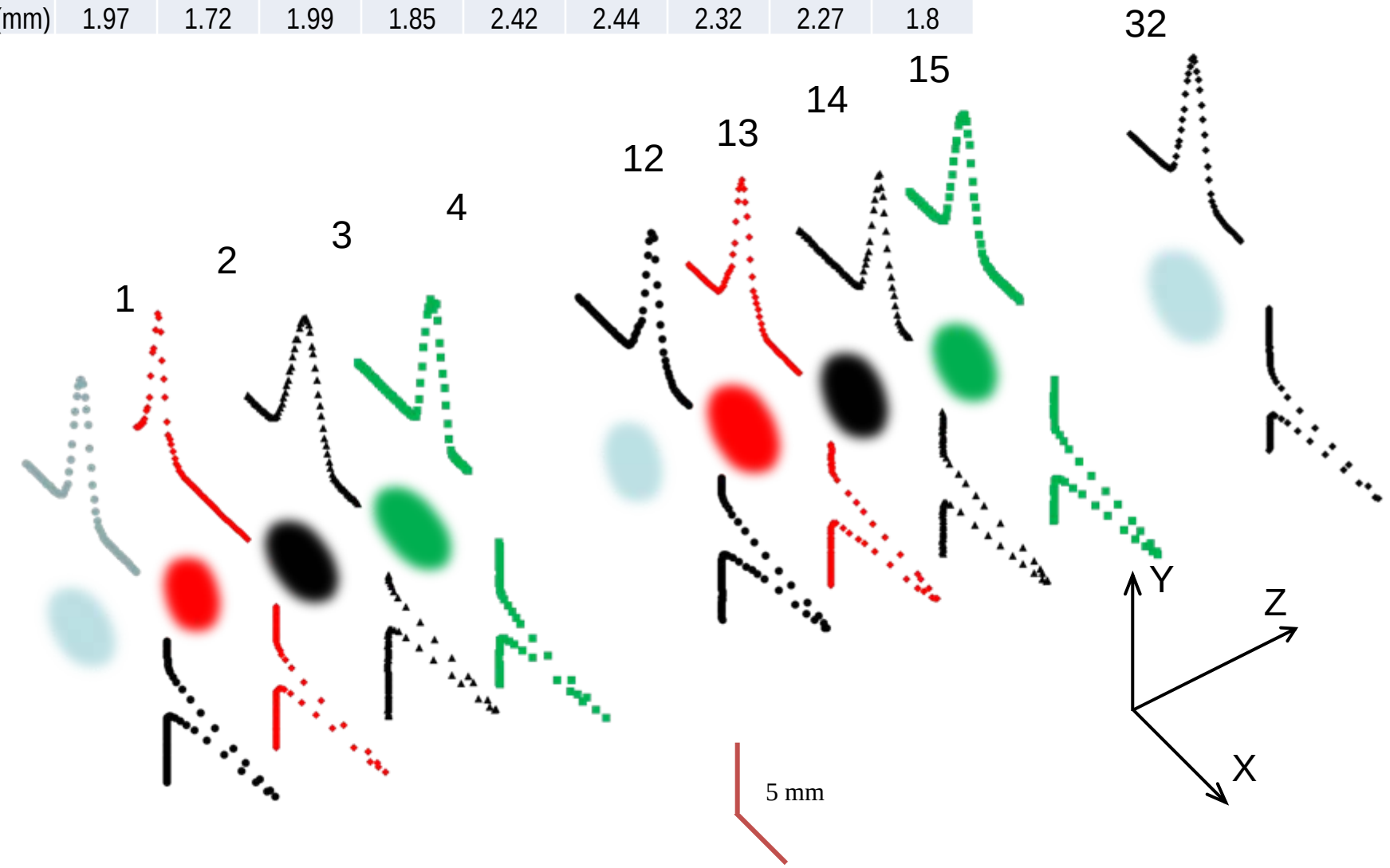
SCL H- Profiles (1150 KW, Sept. 20, 2013)

	1	2	3	4	12	13	14	15	32
σx (mm)	3.62	2.19	1.68	4.18	3.22	3.13	2.63	2.08	2.61
σy (mm)	1.86	1.92	1.88	1.75	3.99	4.04	3.75	2.02	1.45



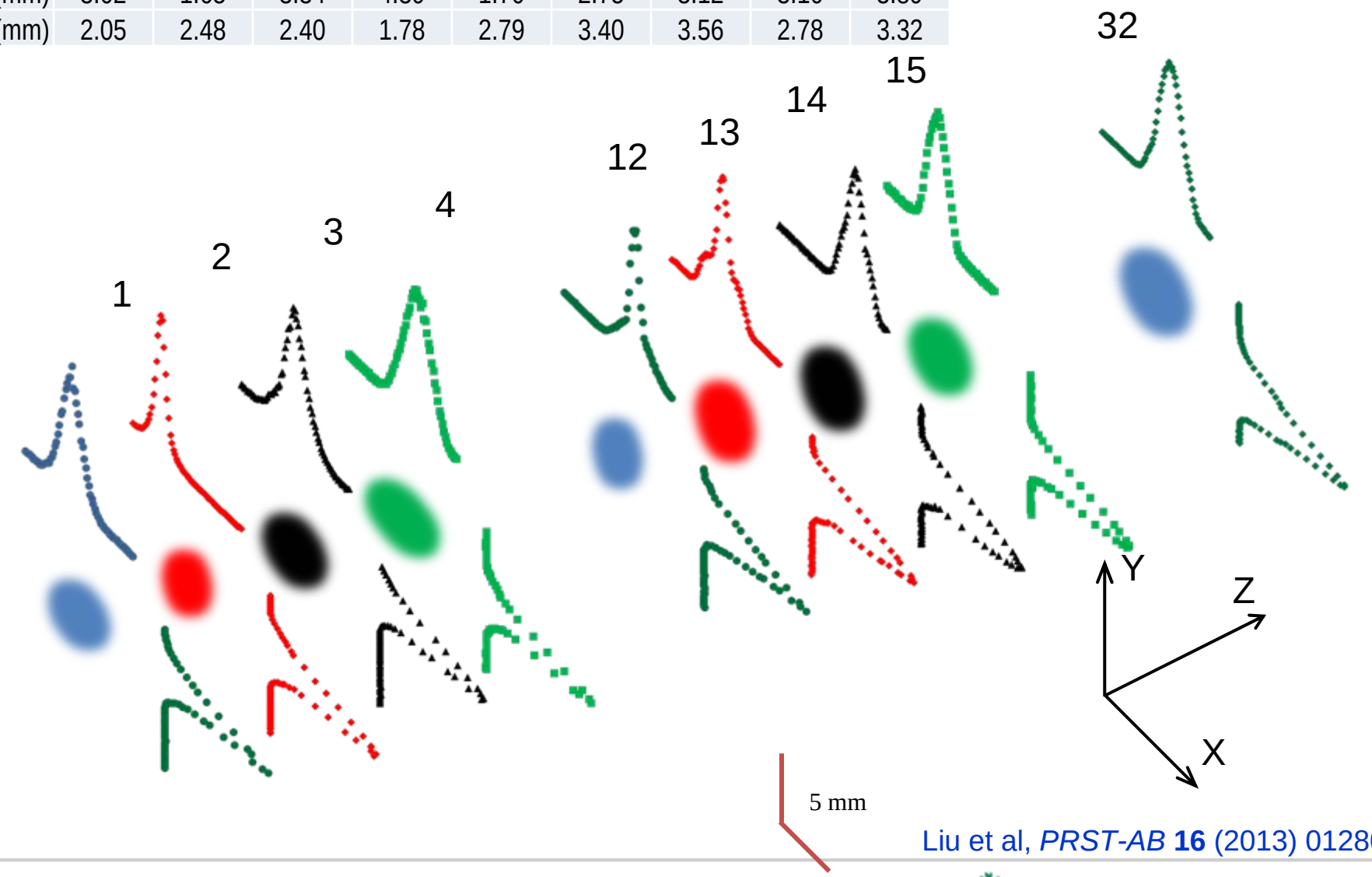
SCL H- Profiles (850 KW, April 15, 2013)

	1	2	3	4	12	13	14	15	32
σx (mm)	2.32	2.45	3.79	2.3	2.23	2.58	2.47	2.73	2.8
σy (mm)	1.97	1.72	1.99	1.85	2.42	2.44	2.32	2.27	1.8



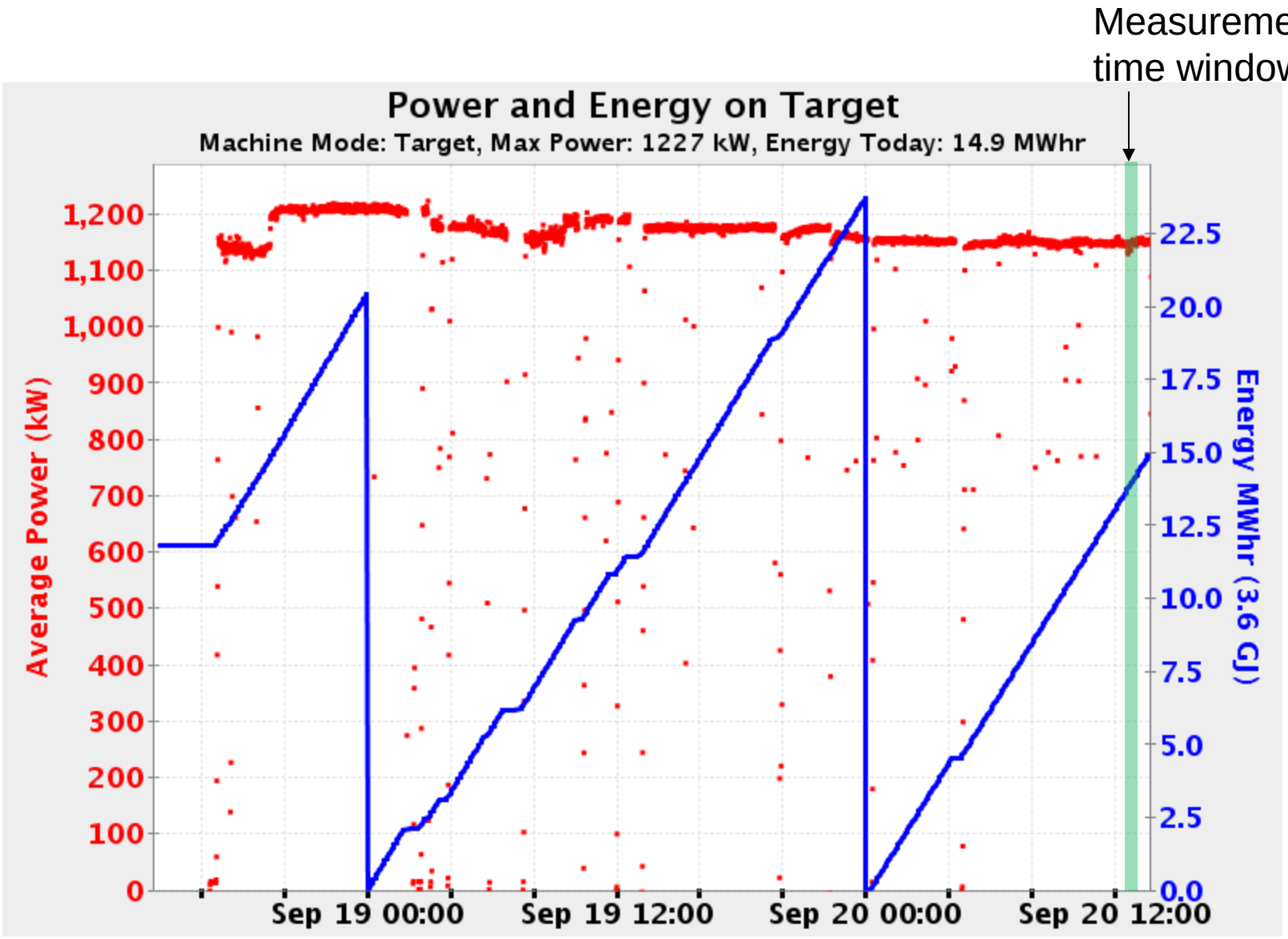
SCL H- Profiles (950 KW, Sept. 13, 2012)

	1	2	3	4	12	13	14	15	32
σx (mm)	3.02	1.65	3.34	4.39	1.70	2.75	3.12	3.10	3.89
σy (mm)	2.05	2.48	2.40	1.78	2.79	3.40	3.56	2.78	3.32



Liu et al, *PRST-AB* **16** (2013) 012801

Beam Status during LW Measurement



HEBT Laser Emittance Scanner

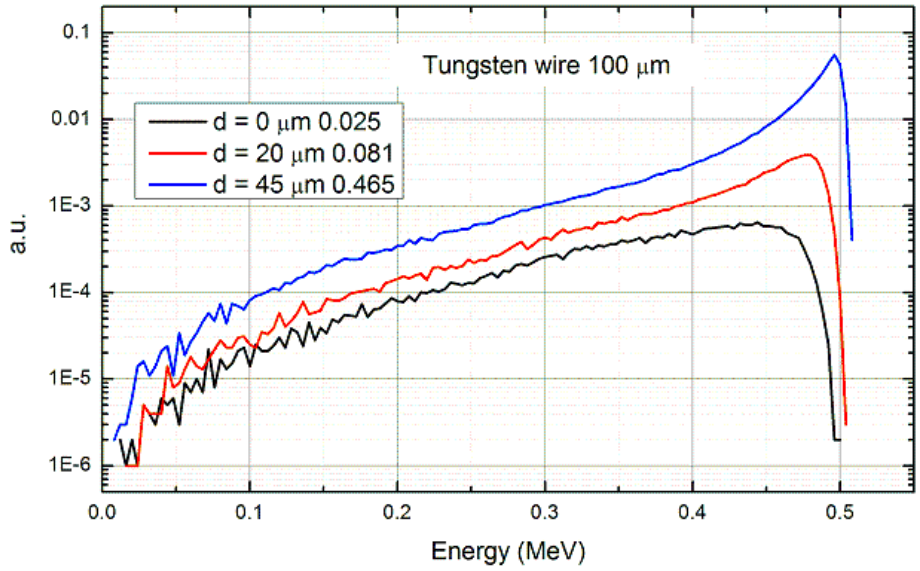
Wire Scanner

- **Laser wire scanner converts a narrow channel of H^- beam into H^0 beam**
- **Titanium wire scanner measures divergence of the H^0 beam released from laser slit**
- **Measurement is nonintrusive.**

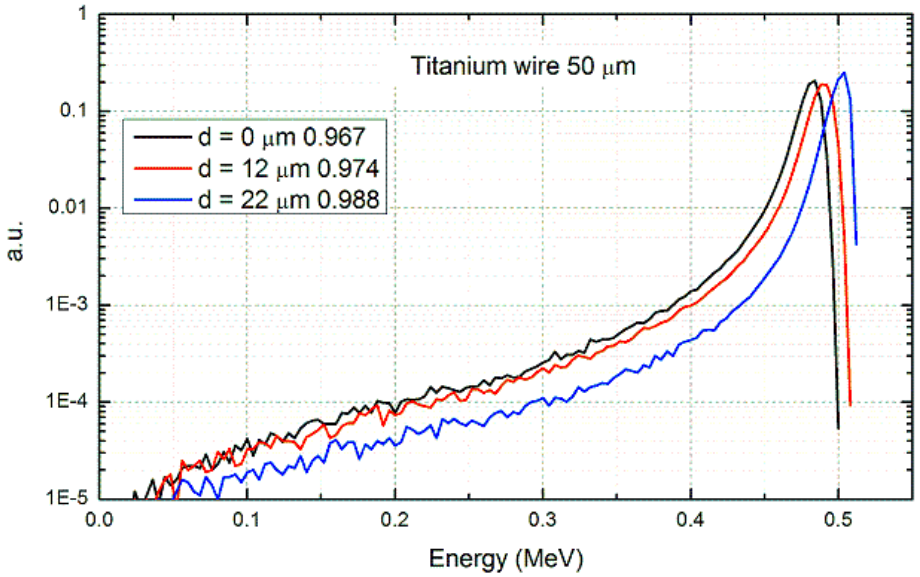
Performance Evaluation of Wires

Fraction of electrons passing through the wire

100-um Tungsten Wire



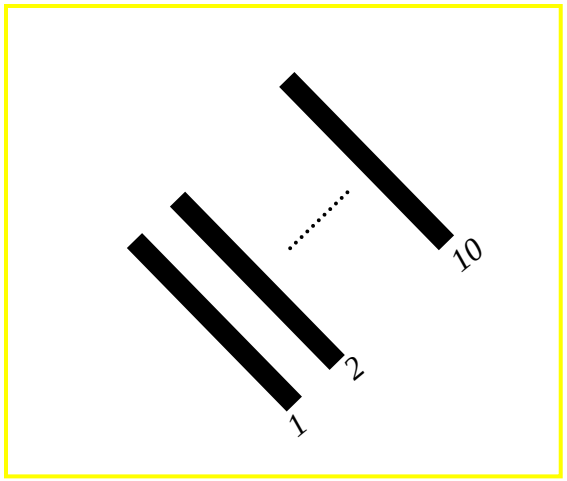
50-um Titanium Wire



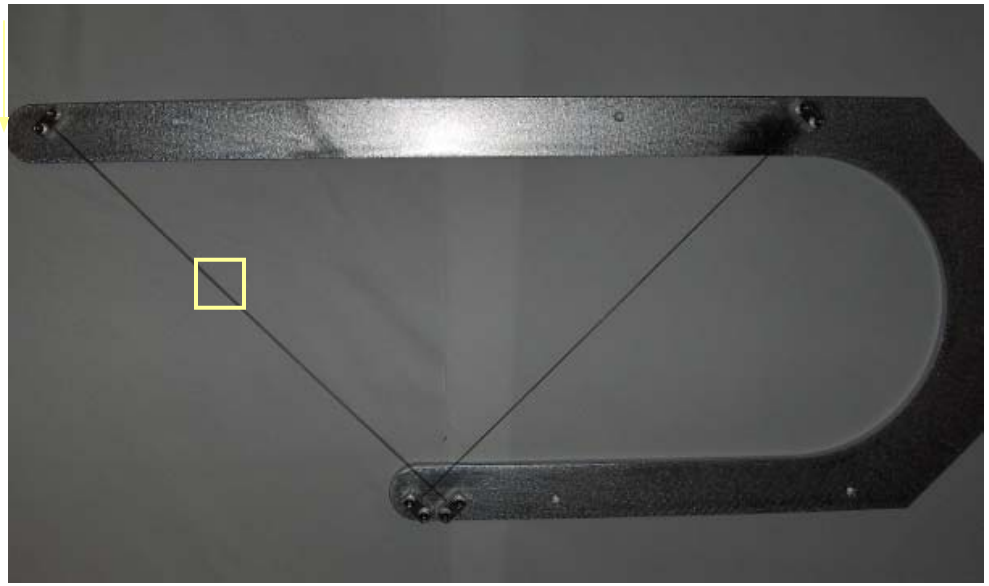
Multi-wire Ti Scanner

Wire thickness: 50 μm

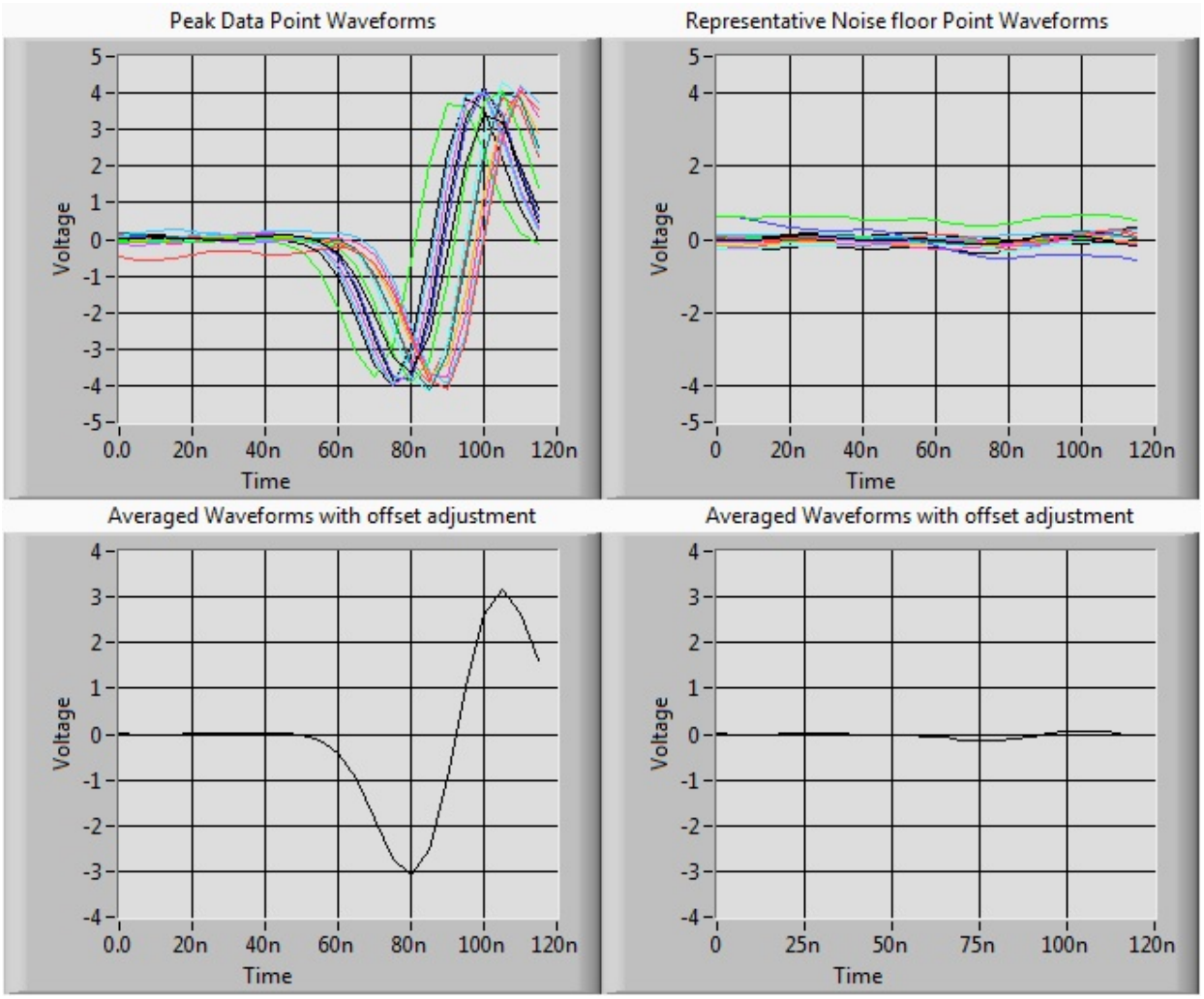
Wire spacing: 25 μm



Ti Wire Bundle

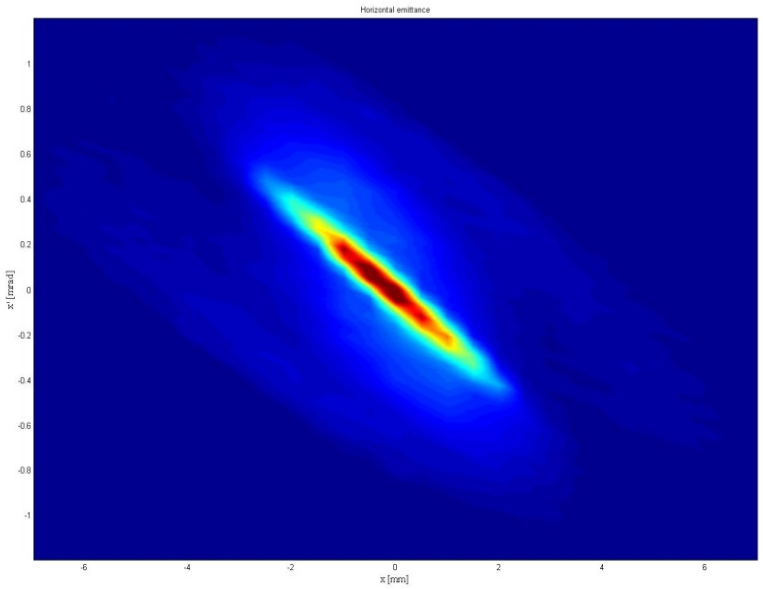


Raw Signal from Improved System

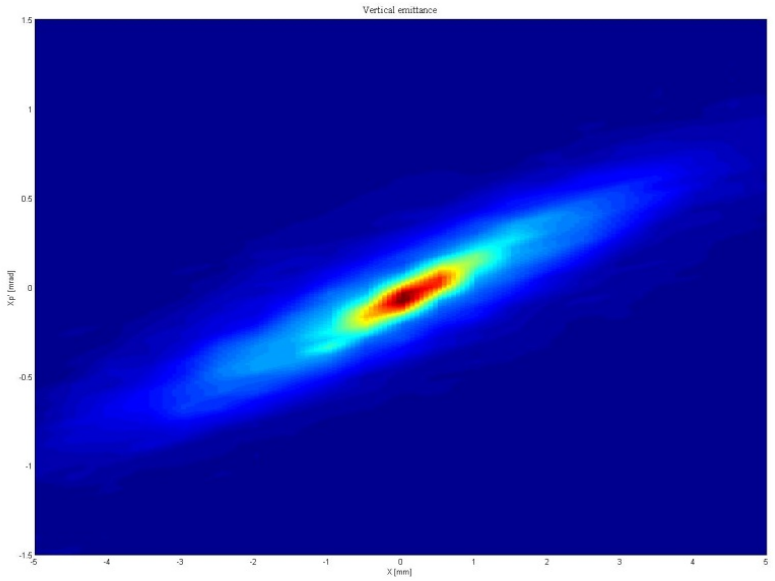


Emittance Measurement with Improved System

Horizontal



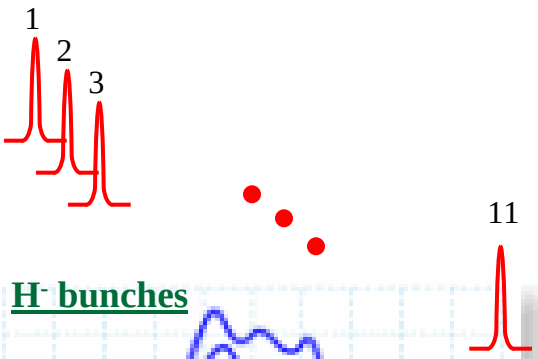
Vertical



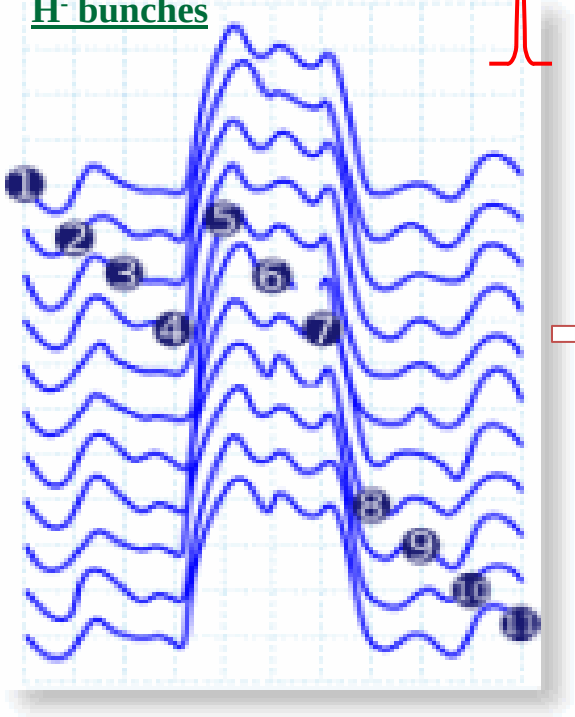
Liu et al, *NIMA* **675** (2012) 97–102

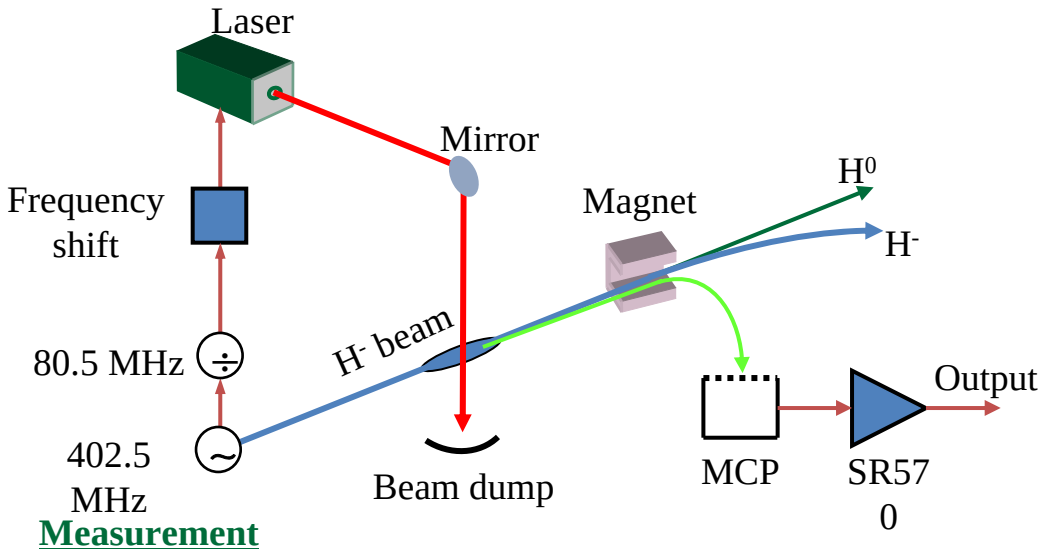
Laser Based Longitudinal Profile Measurement

Pico-second laser pulses

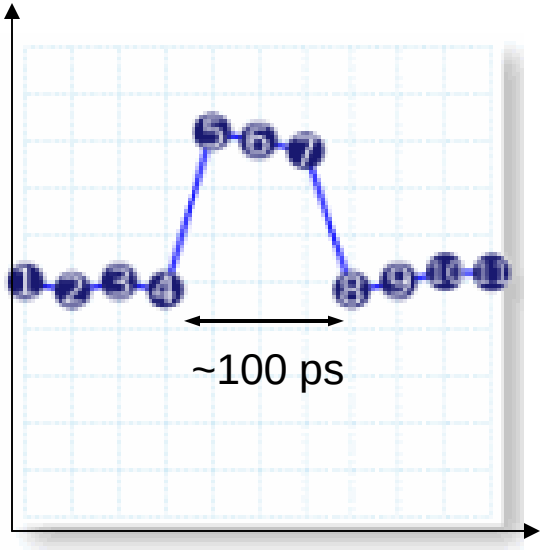


H⁻ bunches



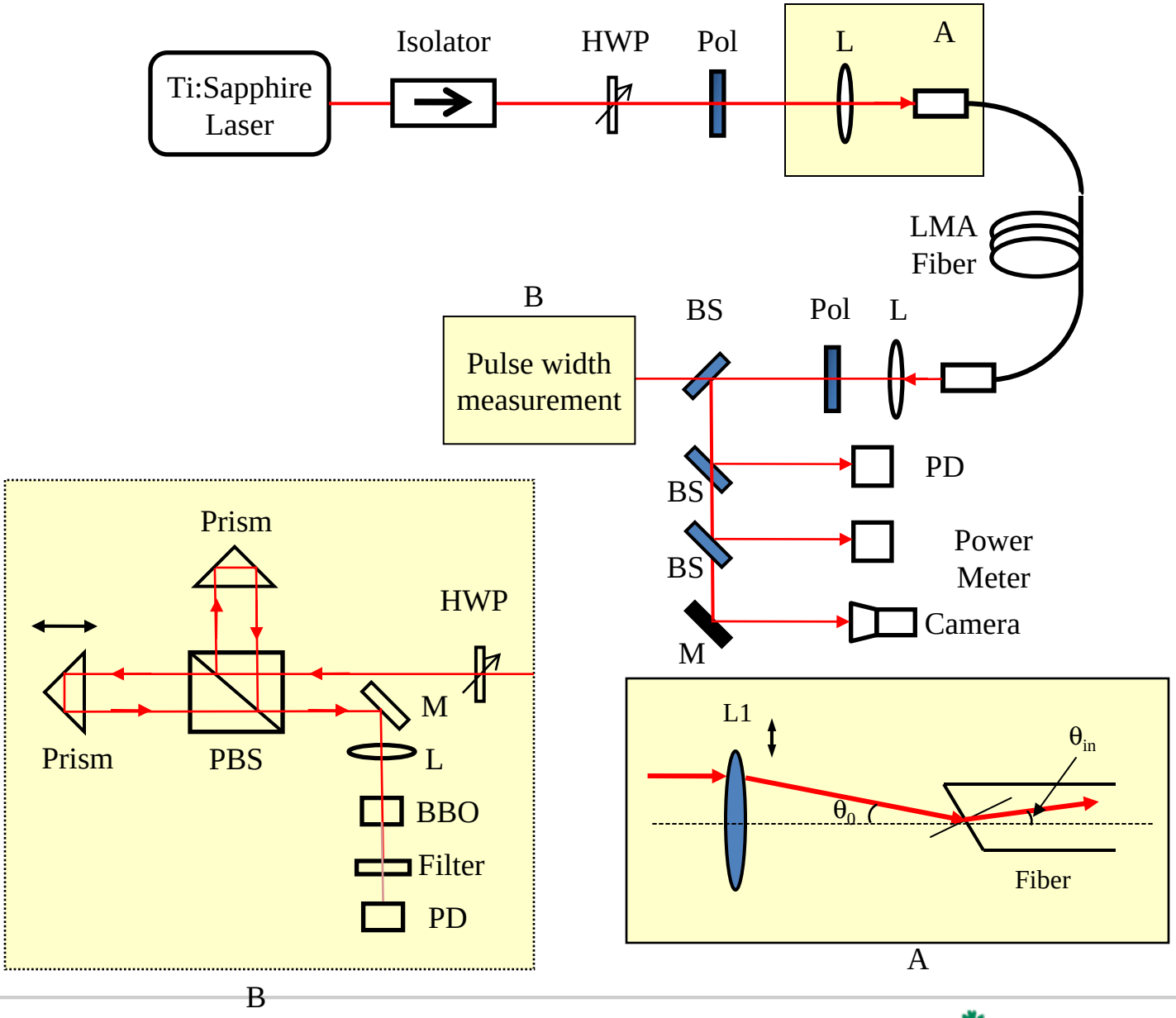


Measurement



- **Laser source: Ti:Sapphire mode-locked laser**
- **Externally locked to accelerator clock**
- **Pulse width: 2.5 ps**
- **Repetition rate: 80.5 MHz (5th subharmonic of RF frequency)**

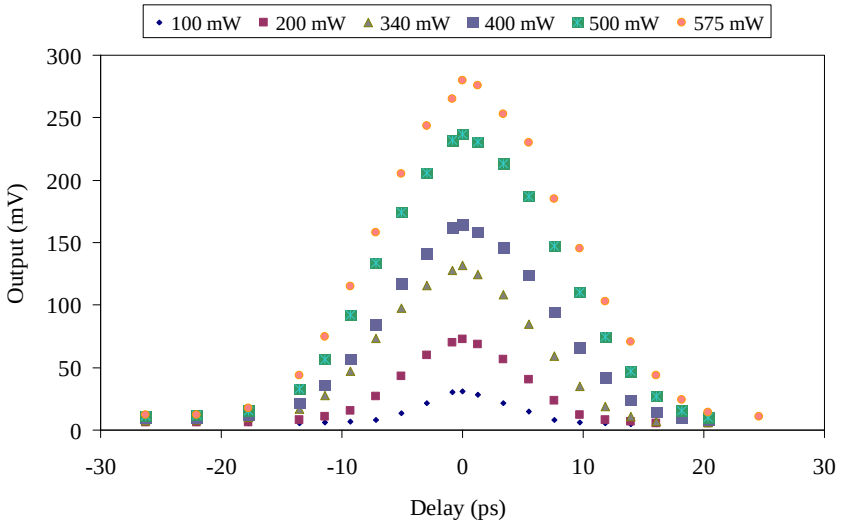
R&D: Fiber Transmission of ps Laser Pulses



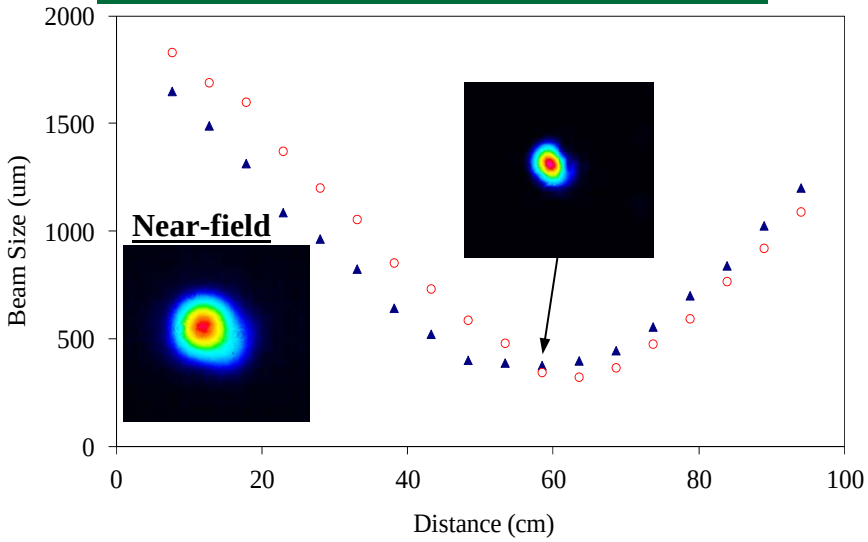
Transmission of ps Laser Pulses through LMA Fiber

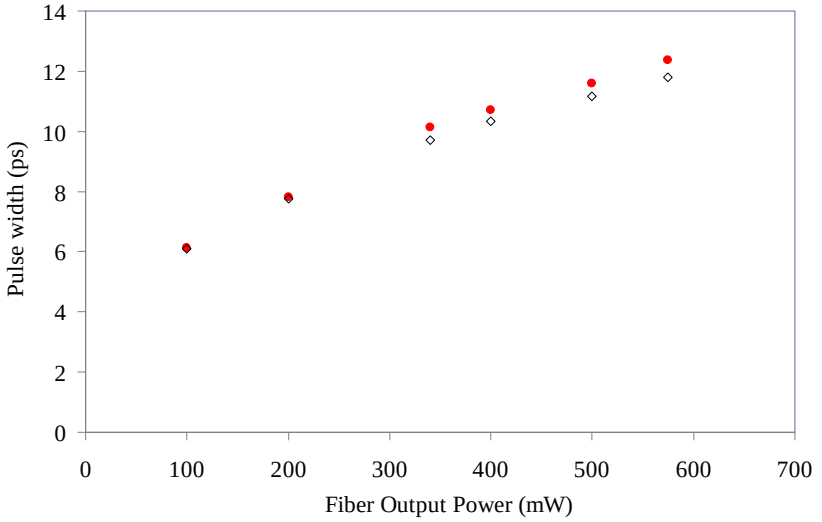
- **Over 85% of overall transmission efficiency through a 30 m fiber**
- **Nearly diffraction-limited output beam**
- **A beam diameter of less than 400 μm at a working distance of 600 mm**
- **At 3 KW transmitted (peak) power, pulse width broadens to 11.6 ps**

Pulse width broadening

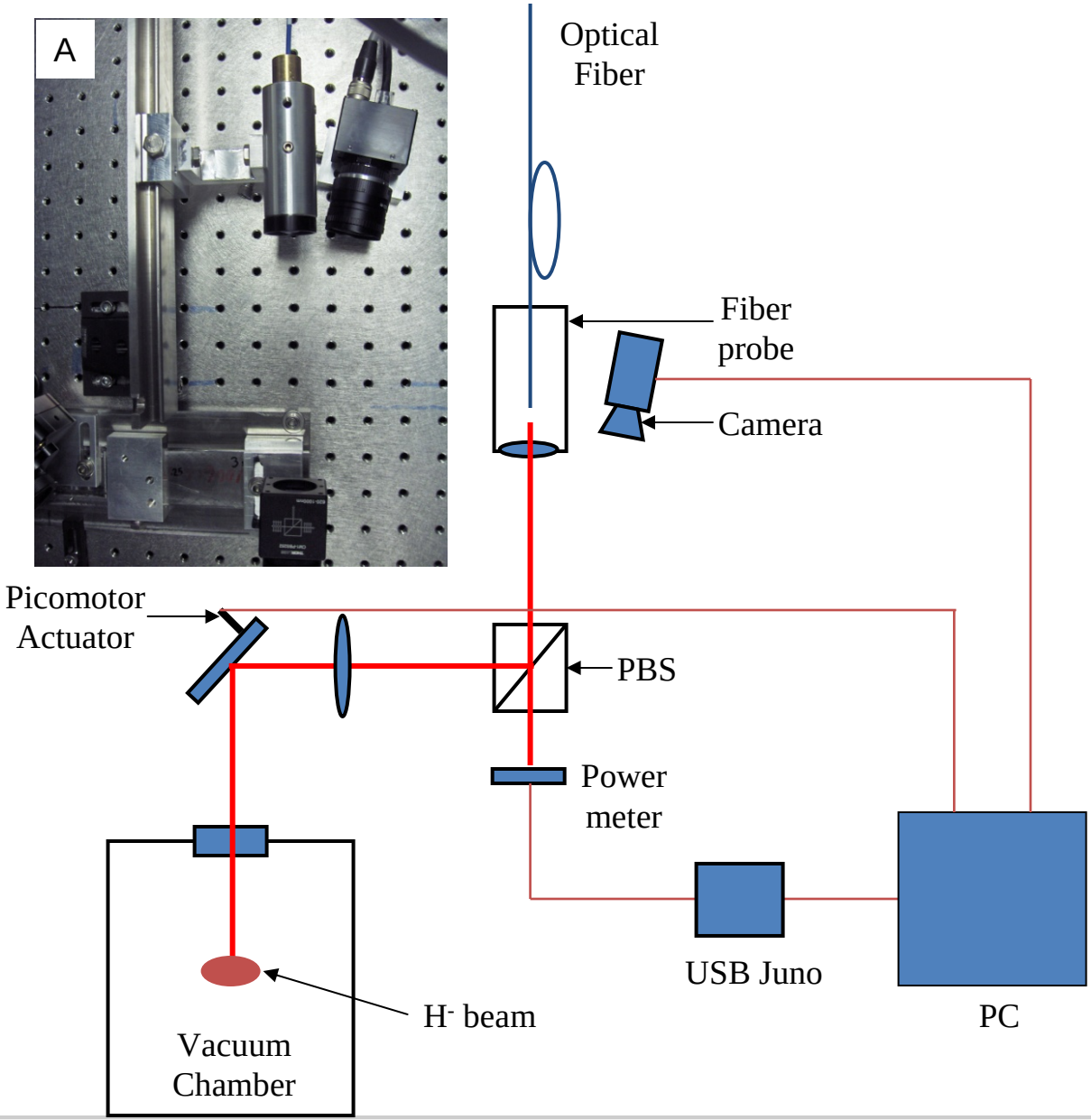


Beam profiles after fiber transmission



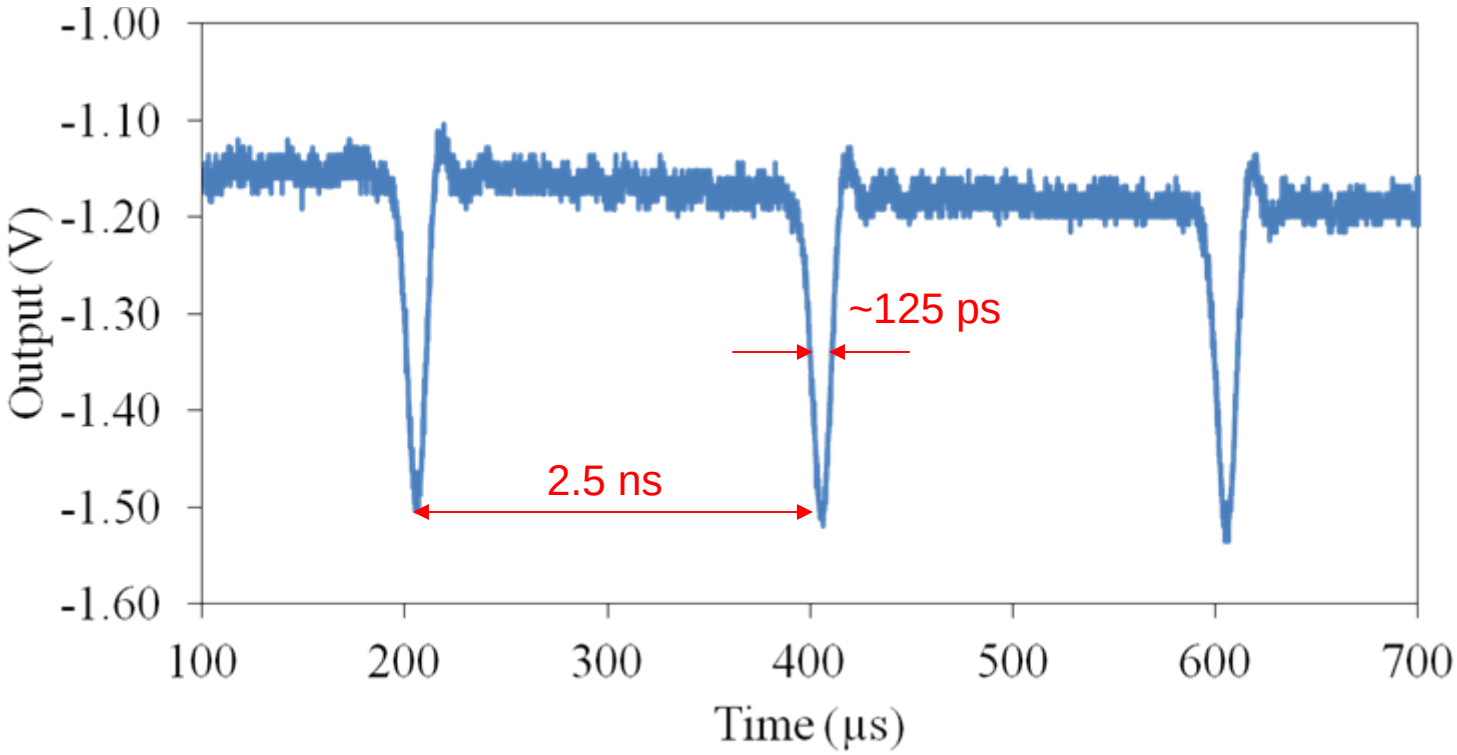


Setup Installed at SNS MEBT



Measurement Results – Frequency Offset Mode

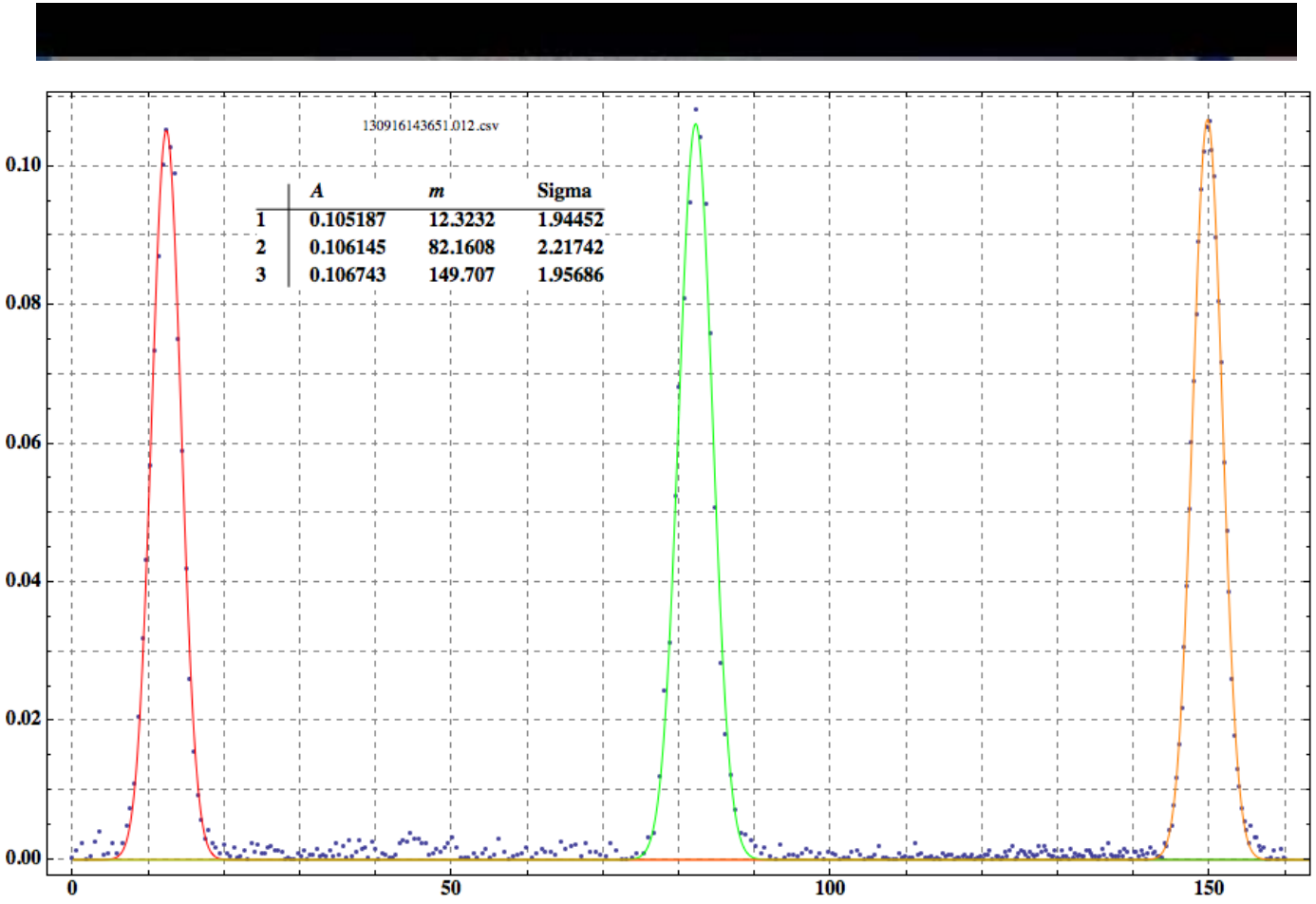
Instantaneous measurement
H- beam RF frequency: 402.5 MHz
Laser repetition rate: 80.501 MHz
Measured waveform is a magnified (in time domain) picture of the H- beam microbunch. The magnification factor is f_0/Df ~ 80,500.



Huang et al., Appl. Opt. (2013)

Measurement Results – Phase Scan Mode

Measurement time depends on H- beam frequency: 20 seconds for 60 Hz beam and 5 minutes for 1 Hz beam.



Commissioning Experience

Item	Findings	Solution
Laser Transport Line	Drift and vibration	Beam stabilization using active feedback Optical fiber based transport line (for low power)
Laser fluence	Over focusing of laser beam caused vacuum window breakdown	Avoid beam collimation optics close to measurement station. Ensure laser fluence below 1 J/cm^2.
Influence on beam	Electron collection magnets can cause tiny beam deflection	Correction magnet installed Orbit correction
Radiation hardness of laser	Laser driver (> 6 m from beam line) damaged in 1-2 days Unclear about laser head	Laser should be located outside the beamline for hadron machine
Image sensors	Gigabit Ethernet cameras (> 1.5 m from beamline)	Have to replace every 1-2 years
Motion control	Stepper motor (~ 30 cm from beam line); Picomotor actuators (1.5 m from beamline)	Stepper motors are very robust Open-loop picomotors have to be used

SUMMARY

- World-first demonstration of simultaneous H- beam profile scan using a single laser source. The system has been brought to operation level – a single push-button initiates profile scan at 9 locations of SCL (corresponding to energy levels of 200 MeV -1 GeV).
- Laser emittance scanner has been commissioned at SNS HEBT.
- Longitudinal profile measurement system has been developed using optical fiber transmission of picosecond laser pulses.
- Laser based beam diagnostics at accelerator facilities is reliable and realistic and provides a useful tool for beam tuning and physics study.