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Sandia National Laboratories

IP Scanner Project Update

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U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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Summary

Current state of IP scanners at the HED facilities

Phase 1 contract and goals

Results from Phase 1 effort

Remaining tasks

Phase 2 and a prototype IP scanner

IP scanners at all HED facilities are outdated and unsupported by industry

- SNL's Z facility uses the DITABIS Super Micron scanner.
    - 3 units on-hand: One used for open side data; one for closed side data; one system.
    - Spare hard drive for 2 units (obsolete technology, not interchangeable).
- LLNL's NIF facility uses Fuji FLA 7000 scanners. Spare systems on hand but no longer supported by industry.
- LLE also uses Fuji FLA 7000 systems.
- NRL, AWE, LMJ – unknown status.

Project to develop a new IP scanner for the HED facilities is underway

Timeline

- Late 2019: drafted a requirements document collaboratively between several facilities (Z, NIF, LLE, AWE)
- March 2020 contract awarded to Southwest Design and Prototyping LLC
- August 2021 Phase 1 ended
- FY22 Q2 Proposal and RFQ for Phase 2 (expected)

Review of scanners in use at HED facilities informed desired capabilities of a new system

- Commercially available image plates from Fuji will continue to be used
  - (TR, MS, and SR with max sizes of 20 cm x 20 cm and 20 cm x 40 cm sizes)
- Use of templates to load IP into scanner is problematic
  - Constrains IP sizes to template dimension and limits maximum size
  - Templates do not always stay fixed to drum
- Drum scanning has the potential to provide highest image quality
  - Minimal moving parts contributing to noise
  - Precise light collection optics system
- Flying spot design using a light guide is fast but image quality degraded by complicated light collection optics design
- Raster scan system such as the Typhoon 9000 is slow
  - Scan head moves rapidly in scan direction and translates along length of scan – potential noise issues
  - Mechanical motion contributes to baseline system noise
  - Image quality potentially degraded from light collection optics (moving mirror & light guide)
- Scan speed is a priority – NIF scans ~6000 pieces of IP per year
  - Minimize rescans by increased dynamic range can reduce overall scan time
  - Rescans contributes to noise, decreases sensitivity, and adds uncertainty from post processing of multiple image files for a single dataset
- Ideal system uses a drum and avoids use of templates.

Key performance requirements in the statement of work

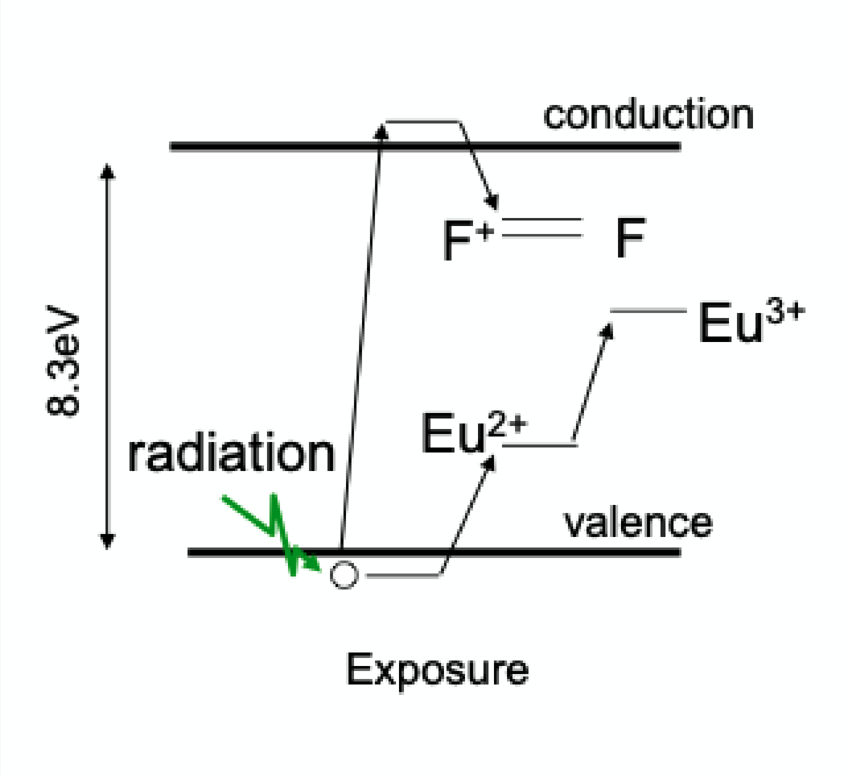
Attribute	Desired	Required	Comment
Resolution	≤ 50 µm	≤ 70 µm	As measured by an edge spread function on TR IP
Dynamic Range	$>10^7$	$>10^5$	Maximize dynamic range
IP size	20cm x 40 cm	20 cm x 25 cm	Standard size sheets
IP Type	Fuji TR, MS, SR	Fuji TR, MS, SR	COTS item
Scan speed	~20 µsec/mm	~20 µsec/mm	Comparable to speed of existing systems

Outline of the remainder of this talk

- IP scanner system architecture
- Noise source mapping
- First signal from photo stimulated luminescence
- Test patterns and images
- Lens adjustment and focusing
- Sensitivity and resolution testing
- Repeatability testing
- Laser power optimization
- Next steps

Images plates store x-ray signals which are released as light through the process of photo stimulated luminescence

Incident radiation excites Eu^{2+} to Eu^{3+} and e^- to the conduction band caught in F^+ centers to form F centers



Red laser excites the F-center to the conduction band causing a release of blue light or photo-stimulated luminescence.

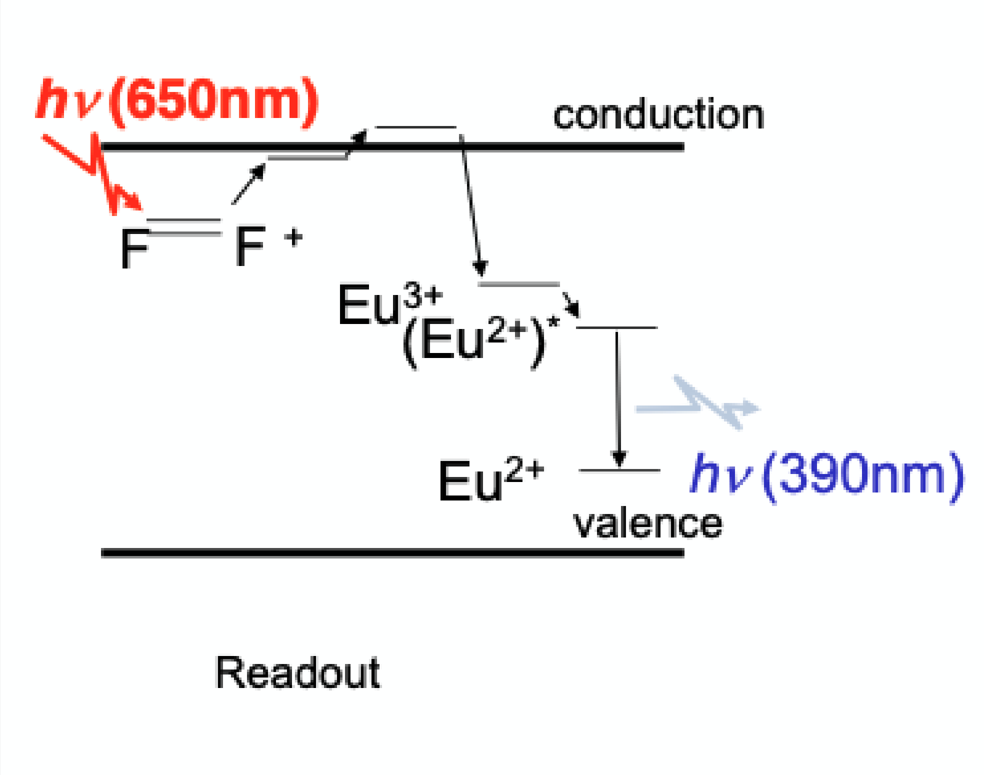
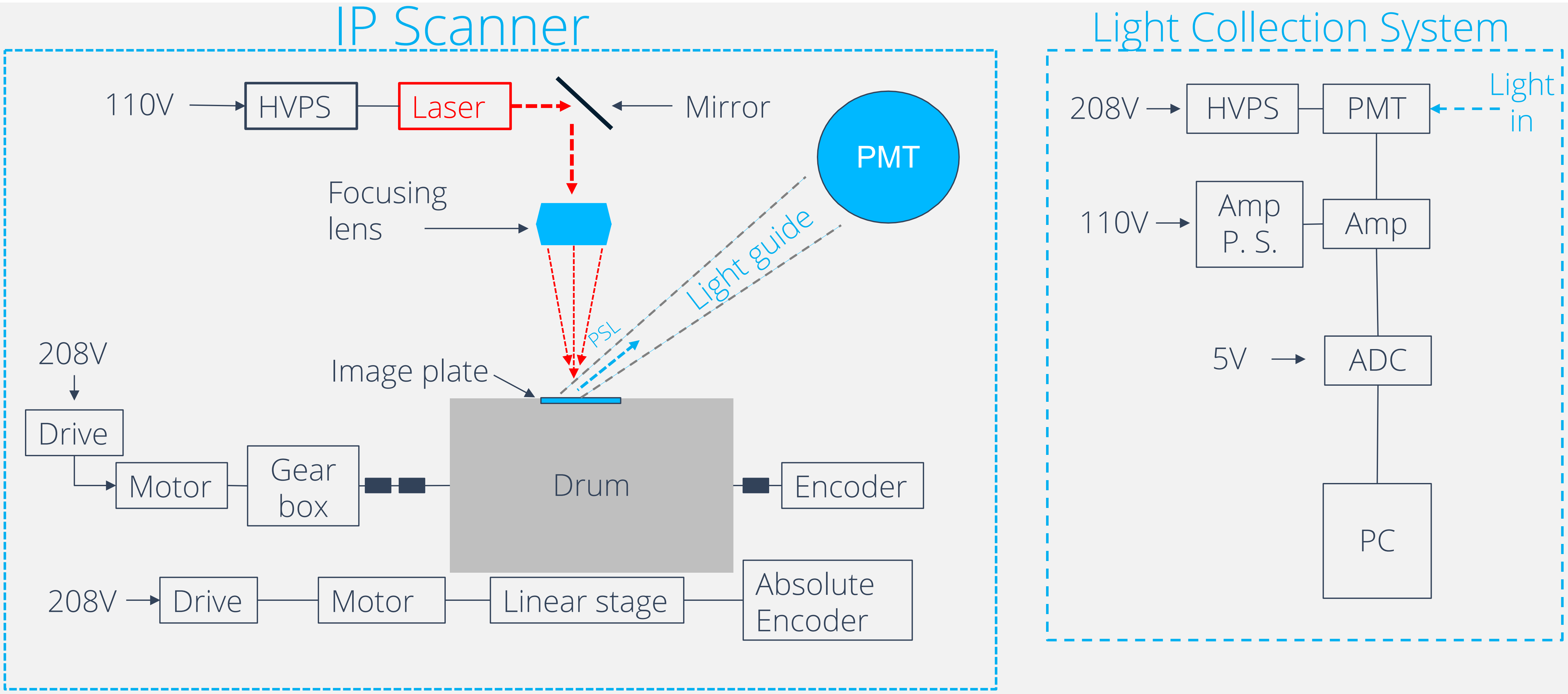


Image from N. Izumi et al., "Calibration of imaging plate scanners", Presentation given at NSTec, 01/17/2013. LLNL-PRES-413387

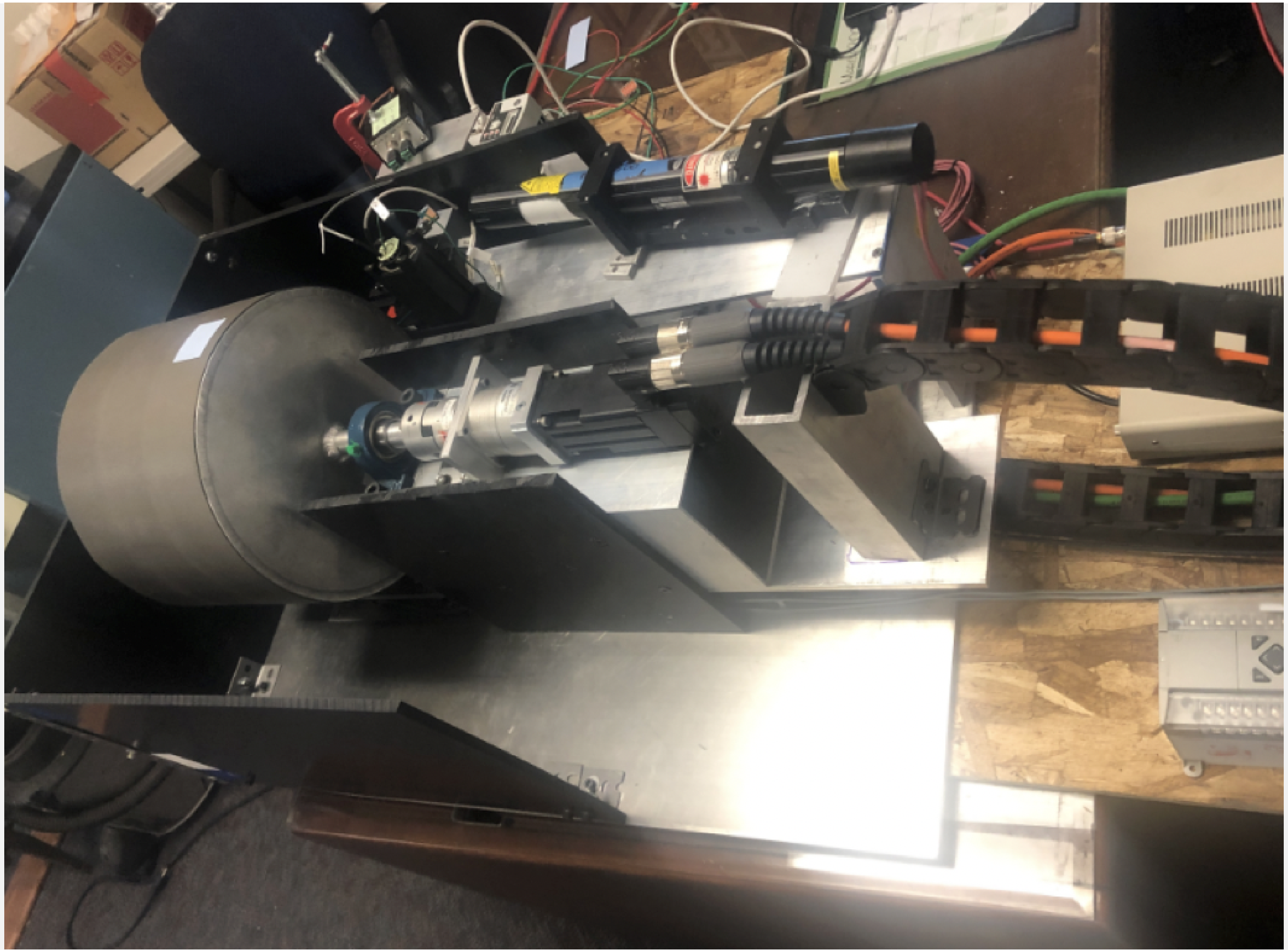
Y. Iwabuchi, et. al., Journal of Luminescence 48 and 49 (1991) 481-484

Layout of benchtop test system for component selection



Benchtop scanner built for testing

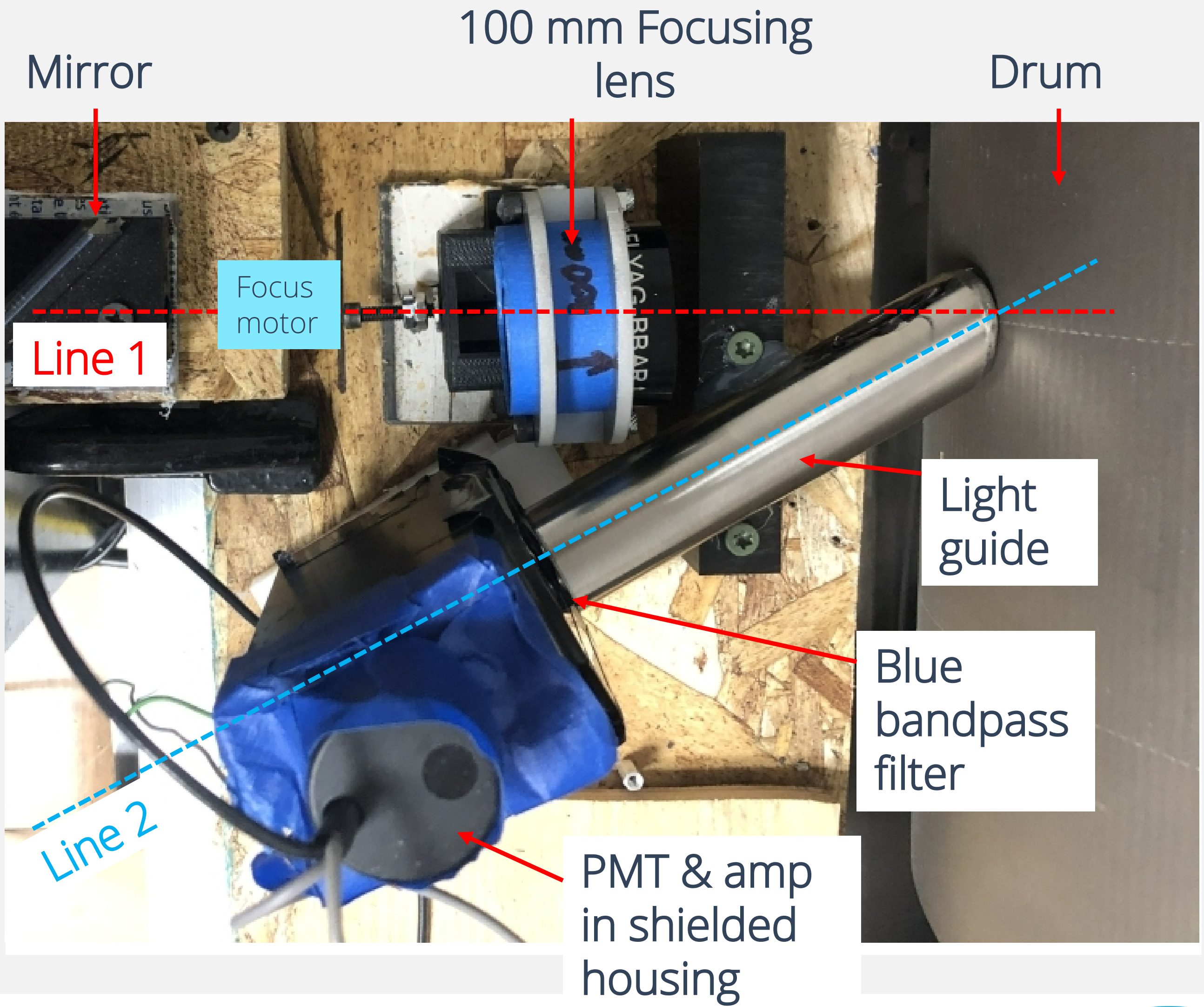
- 12" diameter magnetic backed drum was developed (8" bend radius too severe)
- IP attaches to outer drum surface and stays attached at 400 rpm
- 633 nm laser from Fuji BAS2500 reutilized
- Linear optics stage with > 9" of travel
- Absolute encoders for rotary stage and linear stage
- Linear stage increments with each drum rotation
- Drum speed tested up to 400 rpm



Light guide and focusing lens in benchtop system

Line 1: Red laser from the mirror interacts with the IP perpendicular to the image plate passing through a slot in the light guide.

Line 2: Light guide at a small angle to keep scatter from red laser to a minimum. As the red laser reflects off the IP, and off the inner surface of the light guide, it creates a halo on the IP which can cause further stimulation.



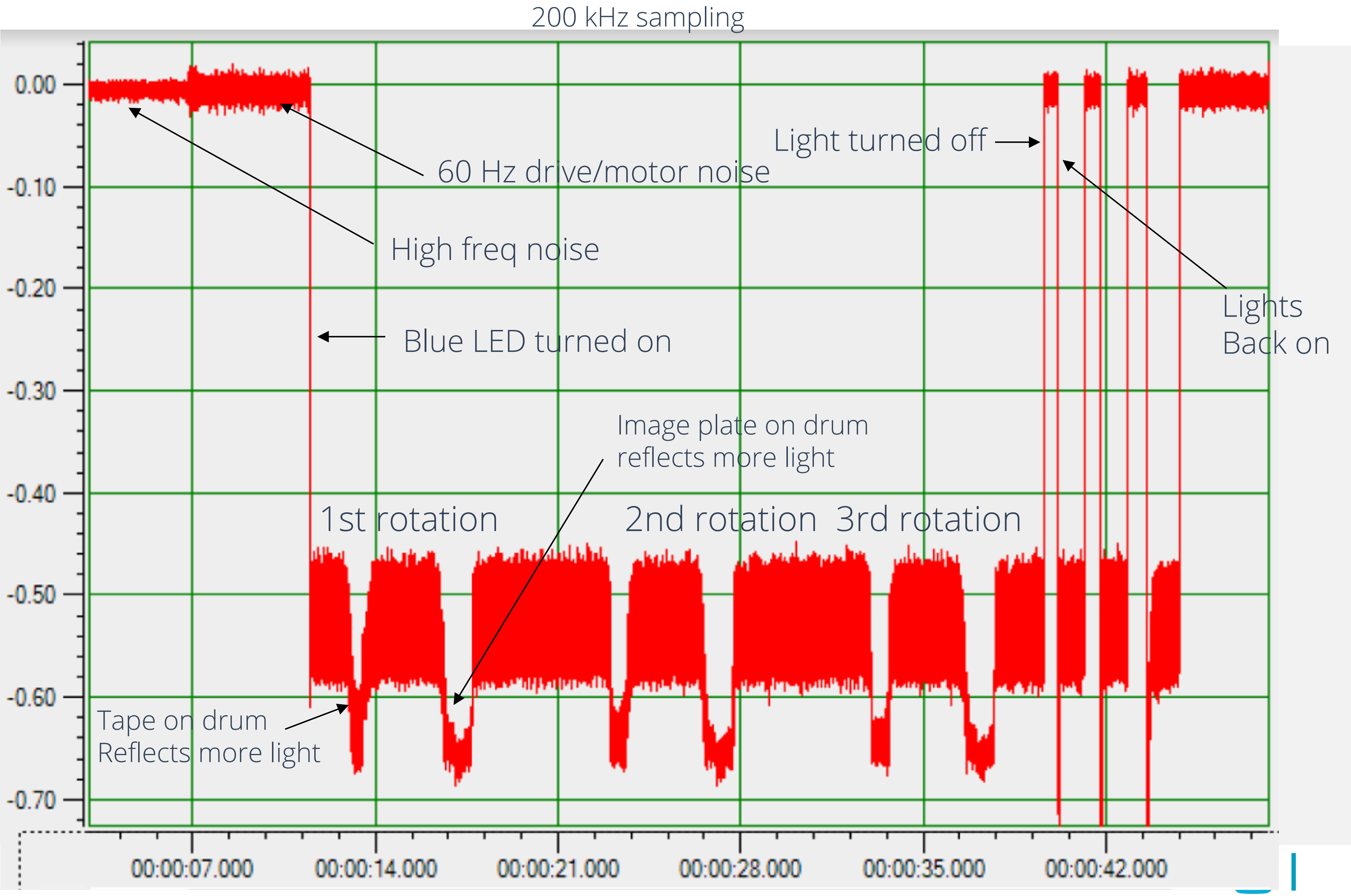
Benchtop test scanner at SWP

Darken the enclosure

- Fixed curtain around the sides and back with a hard top.
- Two sliding curtains to allow access
- Blue Interior light to aid handling operations

1st step: understand sources of noise

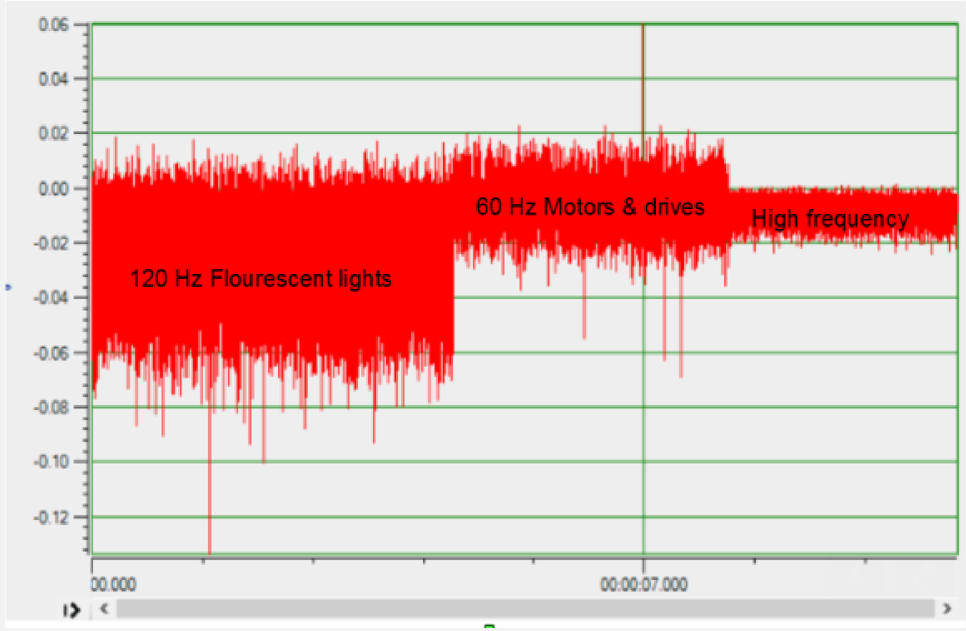
- IP and tape attached to drum surface
- Shine blue light onto drum to simulate photo stimulated luminescence
- Rotate drum and read voltage signal from PMT
- Plot signal as a function of time



Progress made to reduce noise

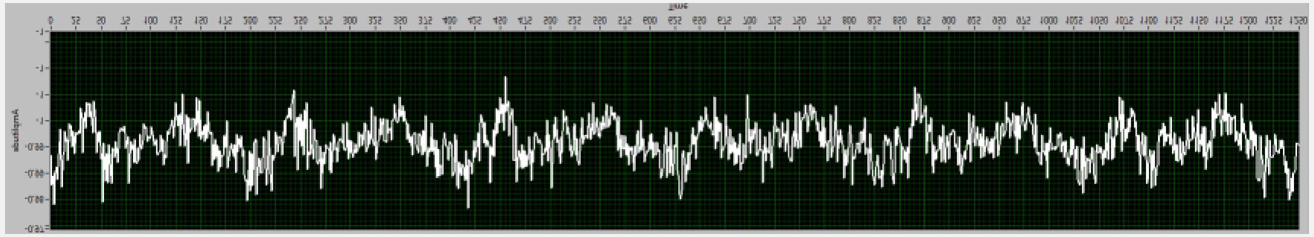
August, 2020

25 mv of noise with motors and drives on

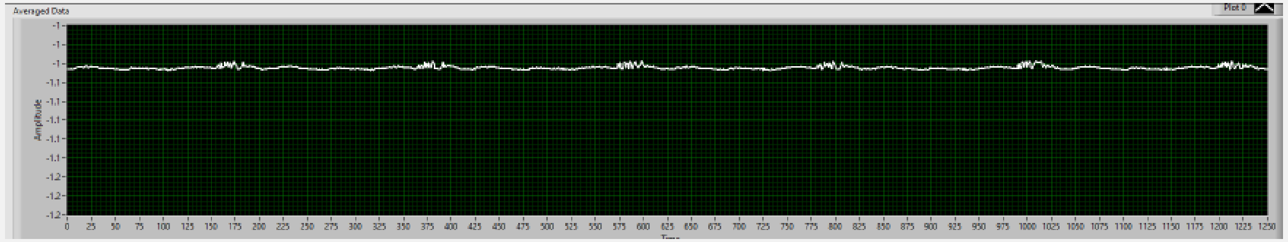


November, 2020

10 mv of noise - mostly from the PMT HVPS

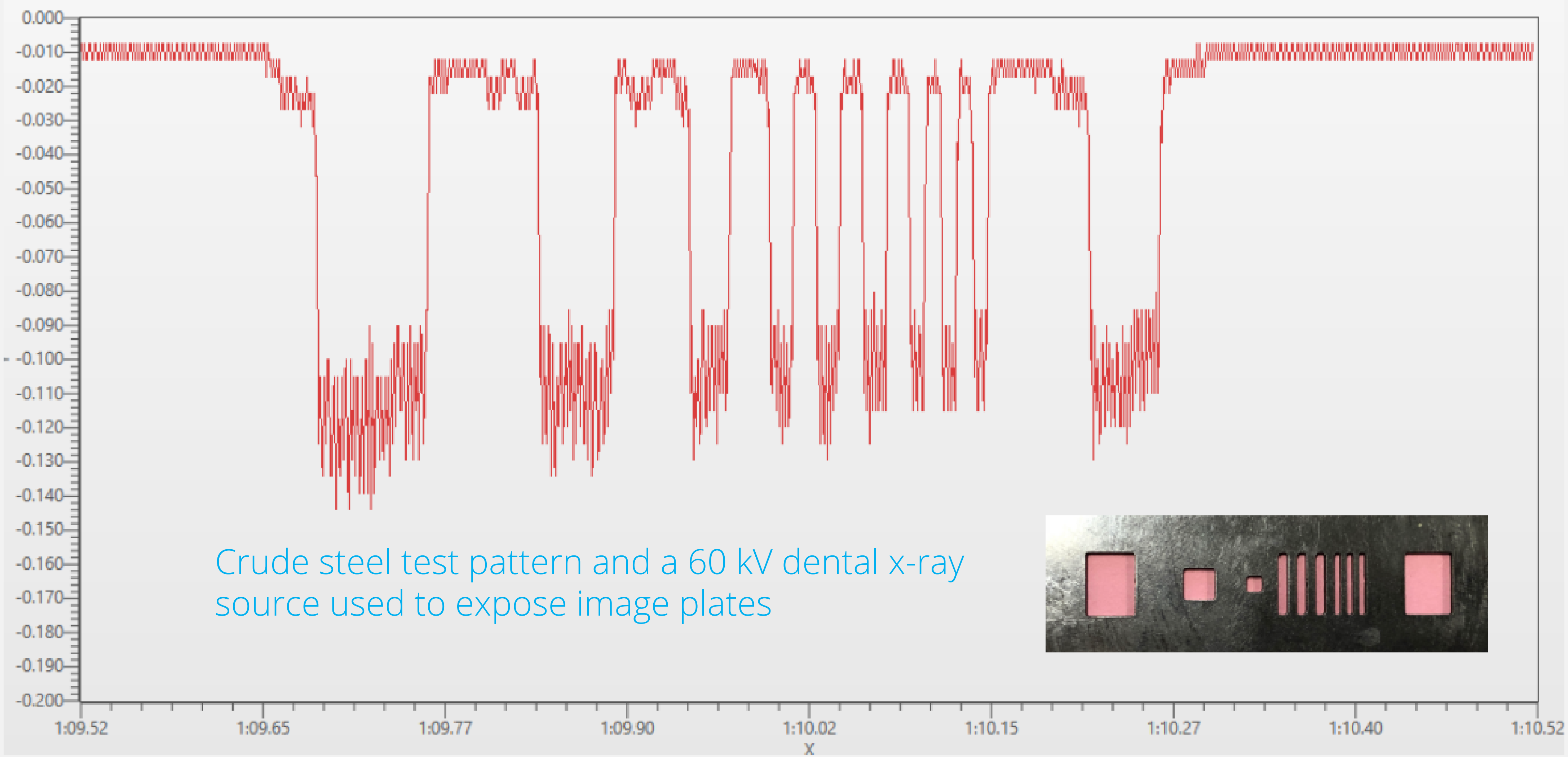


2 mv of 60Hz noise from the signal amplifier



- 120 Hz noise reduced through light tight enclosure
- 60 Hz noise eliminated by shielding motor drives, shielding signal and HV cabling, and improved grounding
- High frequency noise reduced by oversampling and averaging

Initial PSL data acquired as a continuous string from the rotating drum

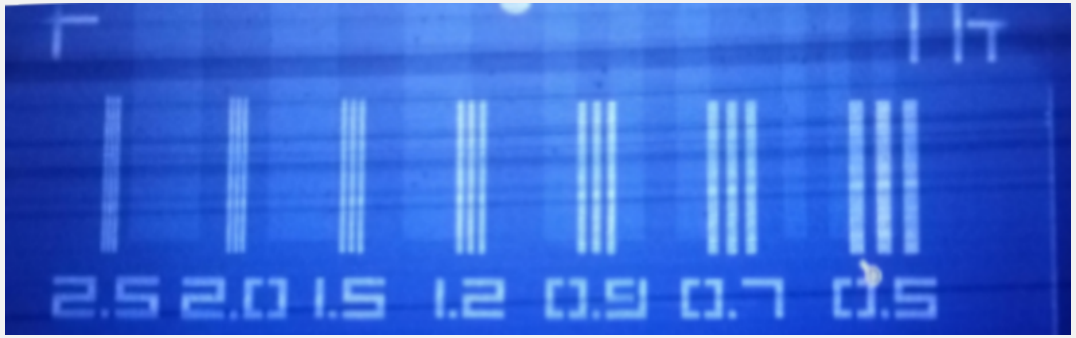


Crude steel test pattern and a 60 kV dental x-ray source used to expose image plates

A Tantalum test pattern was used to study scanner performance

Ta test pattern

Image created from data string

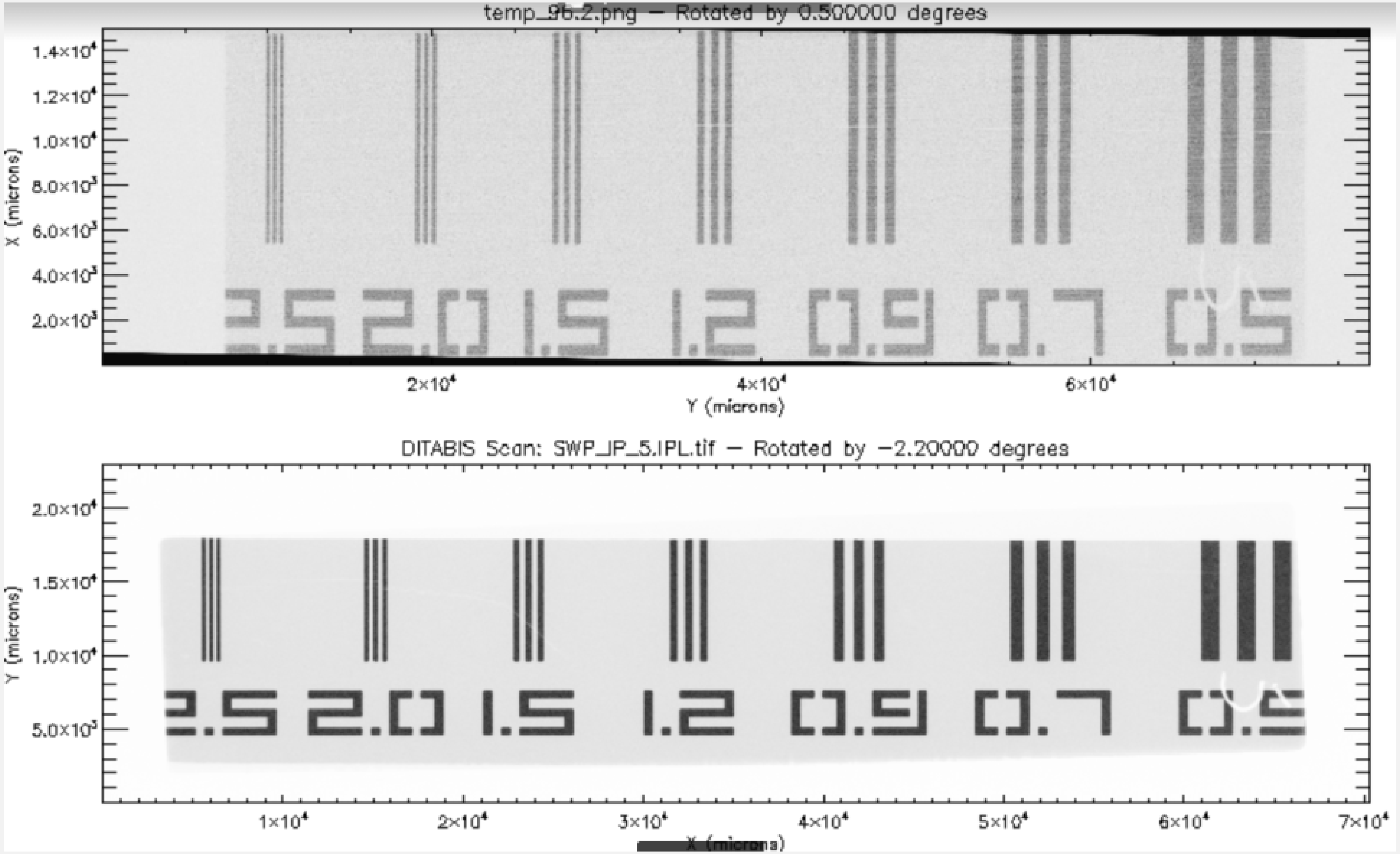


Data string from single rotation of drum

Improvements to image quality allowed us to study the effects on resolution from changing laser power and focus.

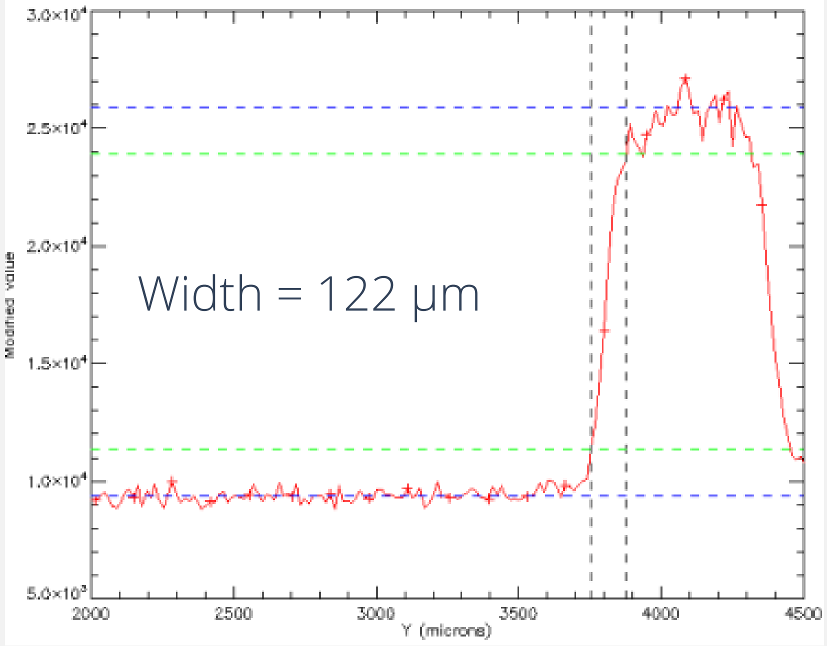
SWP scanner

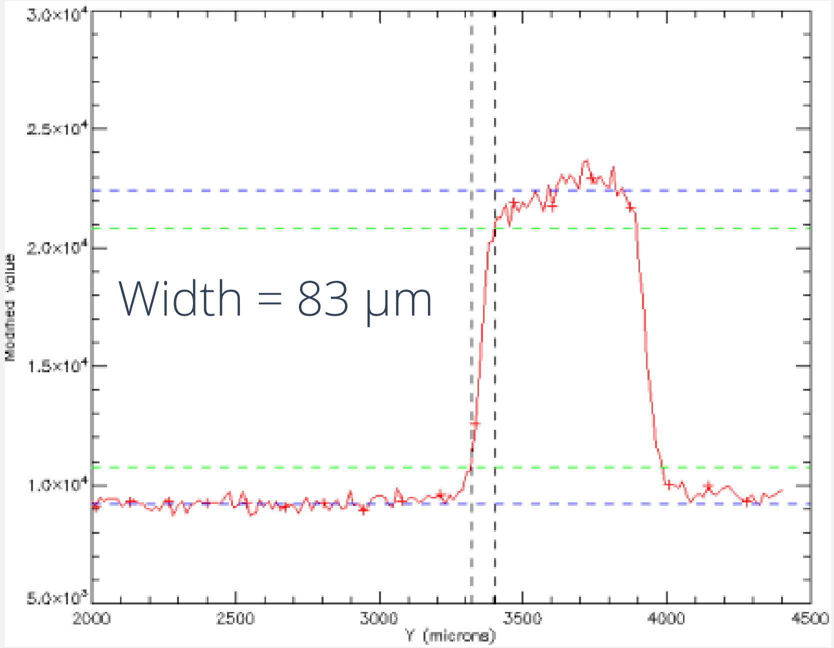
DITABIS scanner

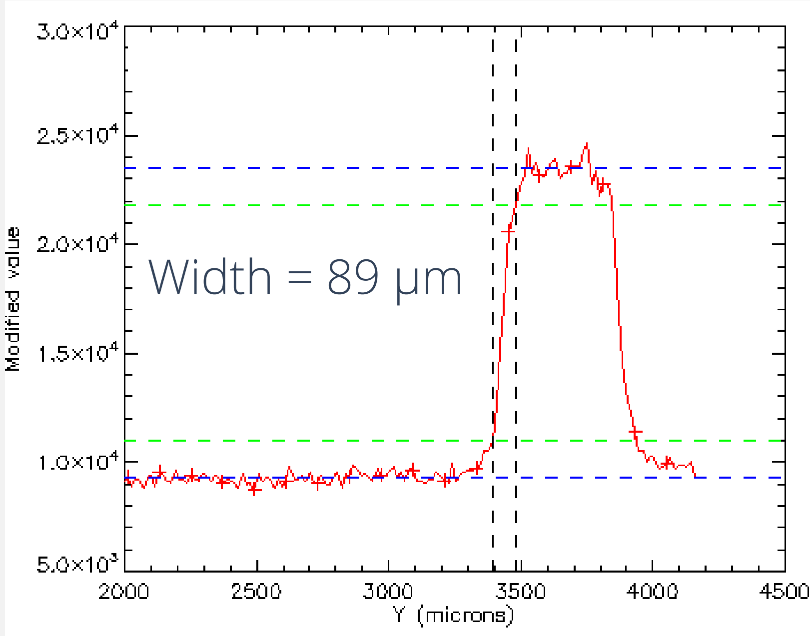


Lens focus adjusted in ±1 mm increments to find optimal focus

The middle position showed the best focus of the three distances.







We use the12%-88% edge width as a measure of resolution.
Measure baseline and peak region intensity, then find the 12% & 88% points betweem these values.
The difference in corresponding abscissa values is the resolution.

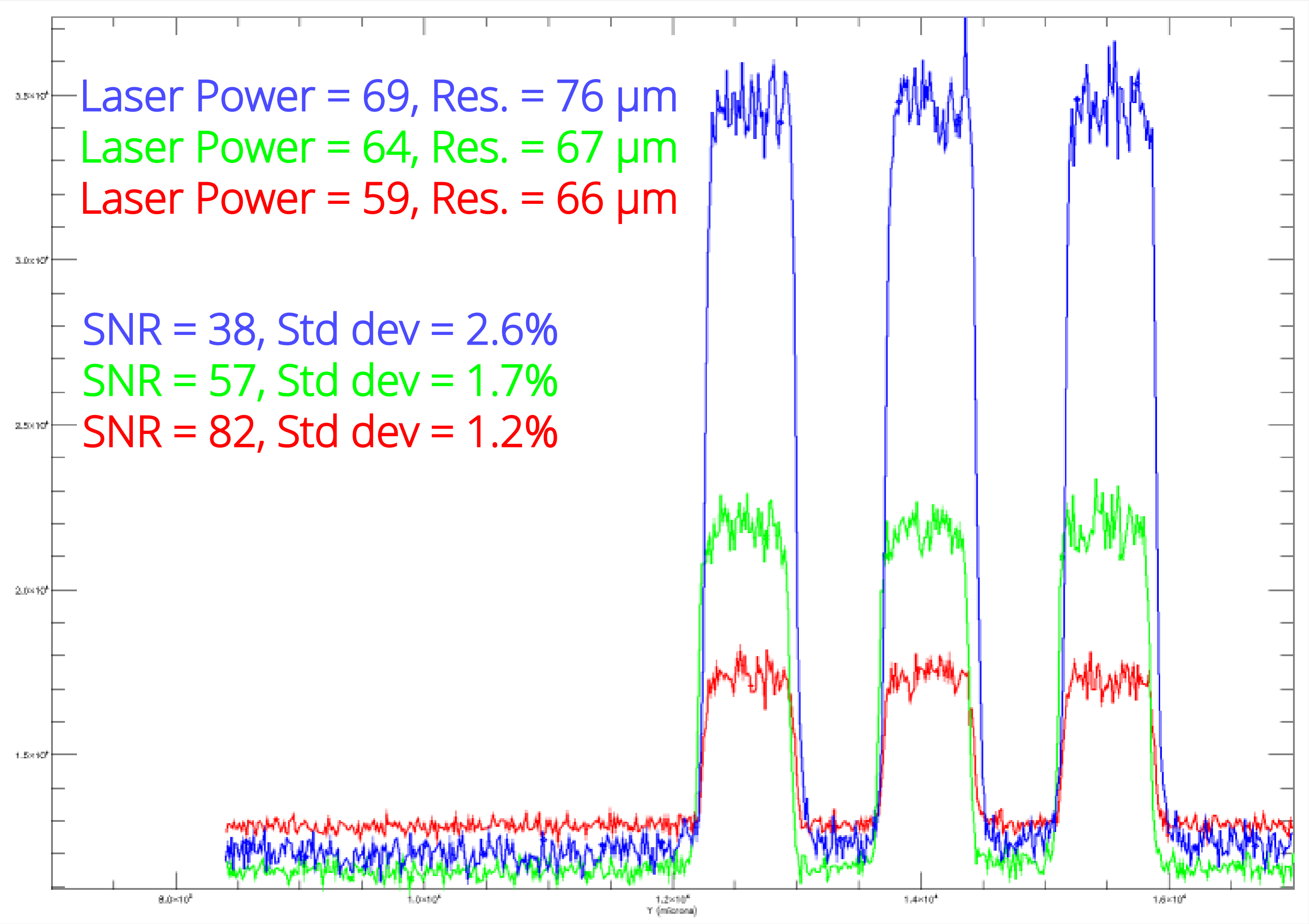
Laser power affects sensitivity and resolution

Sensitivity increases with laser power.

Lower laser power yields better resolution.

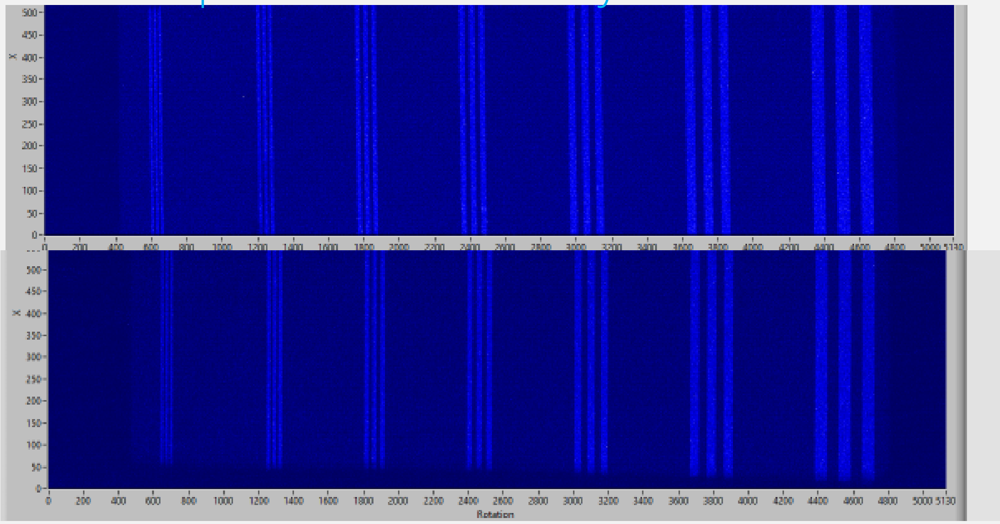
Higher laser power degrades SNR through increased light scatter.

*Laser power number is an arbitrary setting on the power supply between 0 and 179, not mW. Max power is 100 mW but response is not linear.



Repeatability was examined showing mixed results

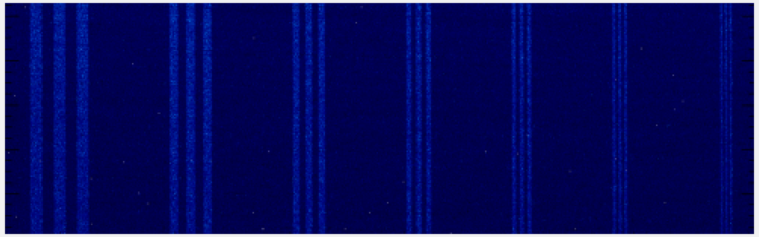
Images from two different exposures are visually similar



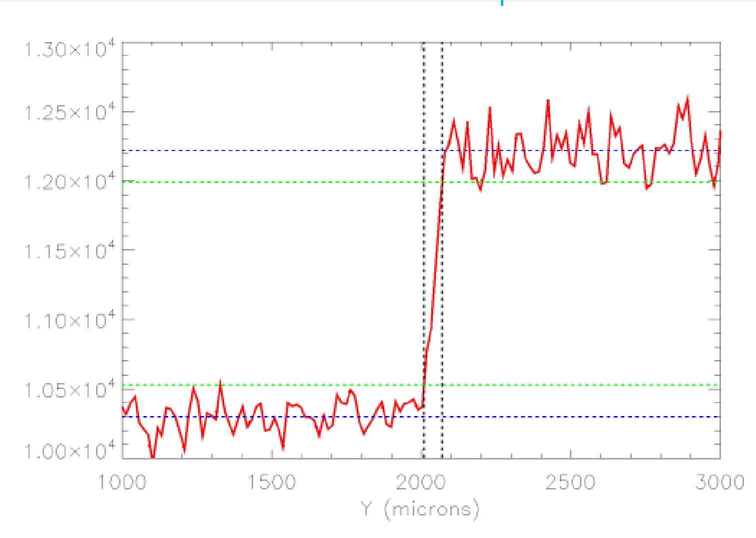
- 4 similar exposures were scanned in a row.
- Resolution values: 65, 70, 87, 108 μm.
- Absolute noise: 2-3% for all scans.
- Differences in baseline possibly due to ambient light conditions, IP handling, or PMT output variation.

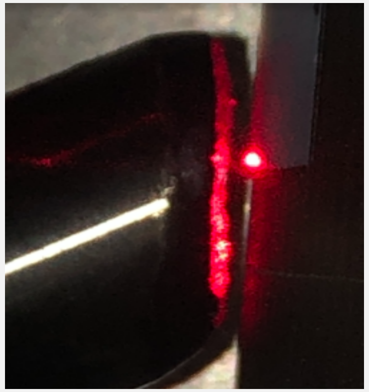
Too high a laser power increases red light scatter into light guide and scattering within the IP

Laser power = 50
Edge width = 60 µm
SNR = 79, Abs Std Dev = 1.3%

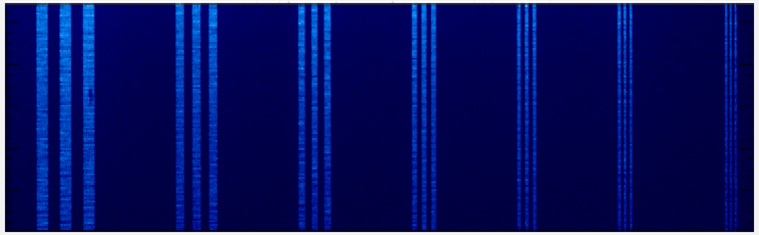


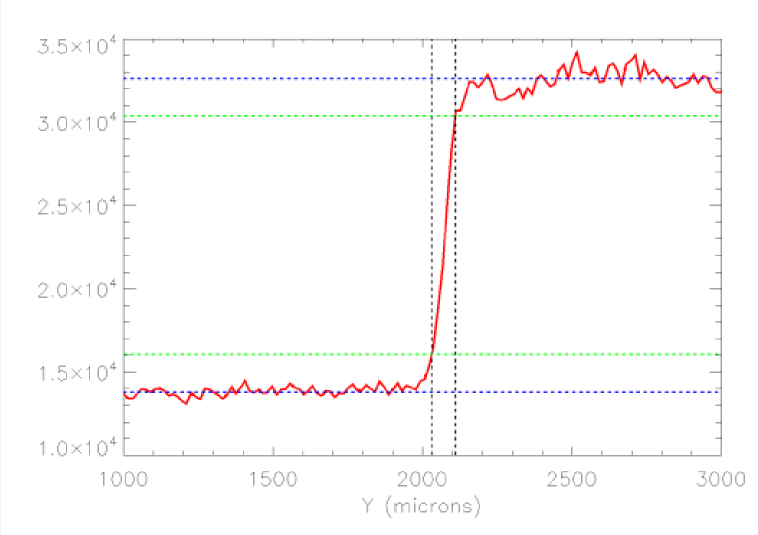
Res = 60 µm





Laser power = 90
Edge width = 78 µm
SNR = 41, Abs Std Dev = 2.4%





- If laser power is too low, photo stimulated luminescence is low and the signal is diminished.
- If laser power is too high, light scatter increases reflections in light guide and dispersion in IP degrading resolution

Ongoing efforts from Phase 1

- Further reduce noise and minimize the baseline signal level
  - Currently baseline is around 10,000 out of 65536 (15% of dynamic range)
  - Study oversampling to balance acquisition rate, noise, and scan speed
- Study sensitivity
  - Balance minimum signal level with required resolution
  - Quantify sensitivity and response using Izumi method
- Study and refine light guide
- Study methods of increasing dynamic range
  - Utilize multiple signal paths (multiple PMT's)
  - Investigate higher bit order image files (24-bit, 32-bit)

Schedule for future work

- Draft RFQ (proposal) and share with team members
- Submit to Small Business website for bidding
- Review and select
- Award contract

Q2 FY22

- Mitigate noise
- Study dynamic range

Q3 FY22

- Study sensitivity
- Complete prototype + develop user friendly GUI

Q4 FY22-Q1FY23

Summary

- We have a working benchtop scanner allowing component testing.
- A magnetic backed drum was designed, tested, and shown to securely hold IP while spinning faster than we can reasonably acquire data.
- Refinements to light collection system could increase image quality.
- More work is needed to reduce system noise and bring down baseline signal levels.
- More work is needed to study means of increasing the dynamic range in a single scan.
- Effort will continue in CY22.

Back up slides

Drum rotation speed may limit pixel size

Drum speed tested to be greater than 400 rpm (IP remains attached).

Can we meet the 20 µsec/mm requirement?

- ➢ Decay rate of PSL is 0.7 µsec → max data acquisition rate should be ~1 µsec/pixel
- ➢ 20 µsec/mm is 1 pixel per µsec for a 50 µm pixel
- ➢ 15 µm pixels require scan speed of 15 µm per µsec or 67 µsec per mm

- Drum speed of 400 rpm = 6.7 rps → 156 µsec/mm ⇢ oversample by 2.3x
- Testing conducted @ 2.5 rps → 417 µsec/mm ⇢ oversample by 6.3x
- 50 µm pixels require 976 rpm drum speed to get down to 1 µsec/pixel
- 15 µm pixels require only 292 rpm drum speed to get to 1 µsec/pixel

Concept for new light guide