Material Damages and Burn-Through Detection for FEL Beams at LCLS

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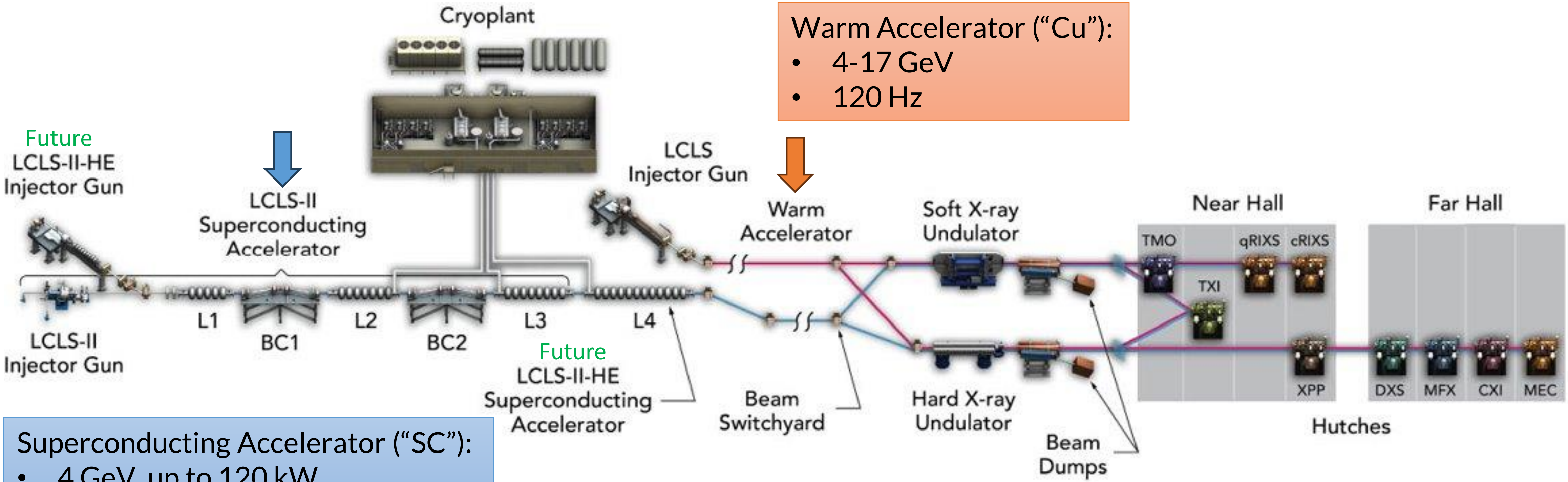
Outline

1. Introduction of LCLS Complex
2. Material damage by FEL beams
3. Burn-through detection for high repetition rate FEL beams
4. Summary

Introduction of LCLS Complex



Warm Accelerator ("Cu"):
- 4-17 GeV
- 120 Hz

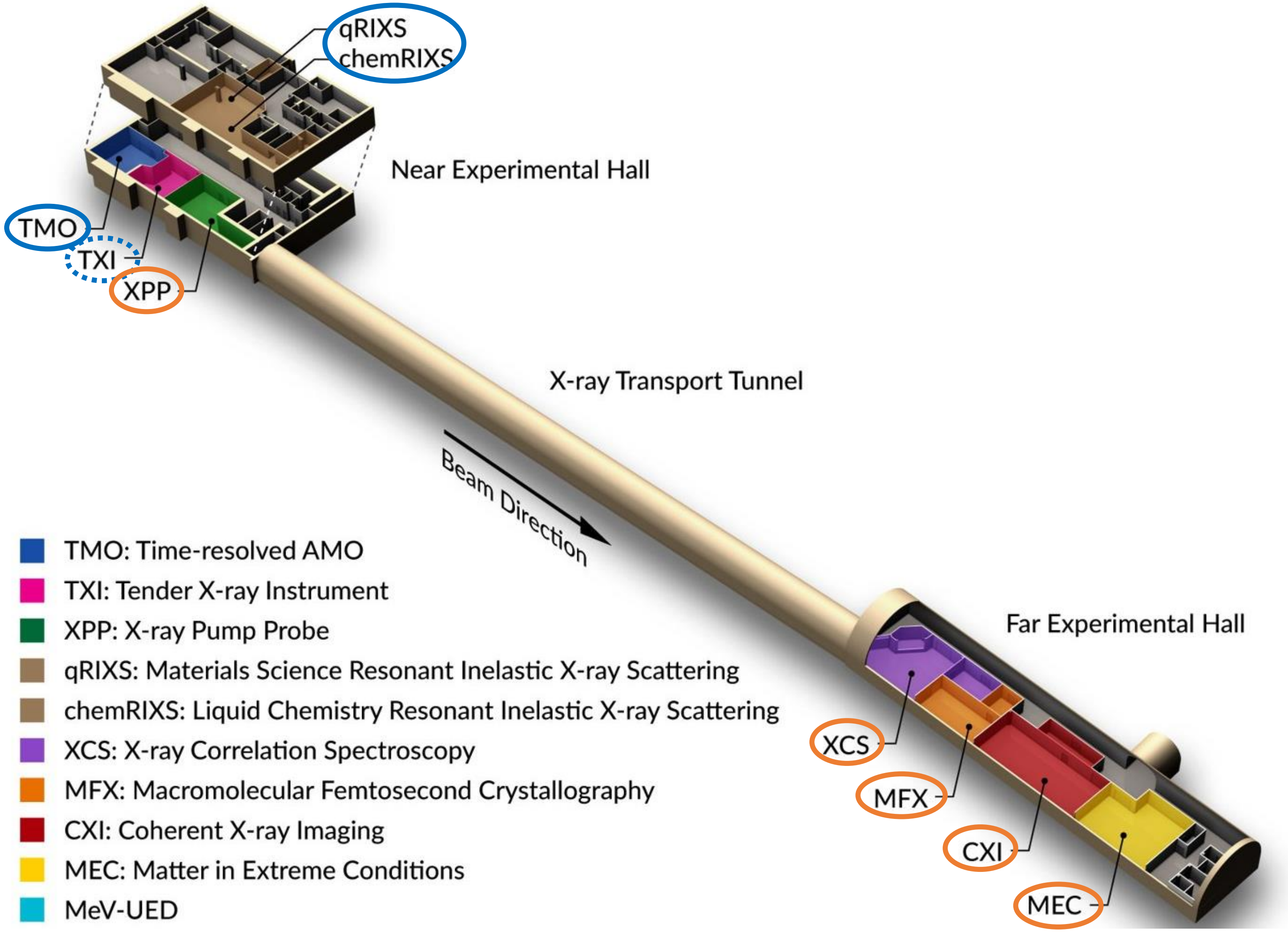
Superconducting Accelerator ("SC"):
- 4 GeV, up to 120 kW
- Up to MHz

Undulator	SXR	HXR	Unit
Period length	39	26	mm
Number of periods	87	130	
Segment length	3.4	3.4	m
Number of segments	21	32	
K_{eff} at min. gap	>5.48	>2.44	

LCLS Photon Instruments

SC & Cu FEL

Cu FEL

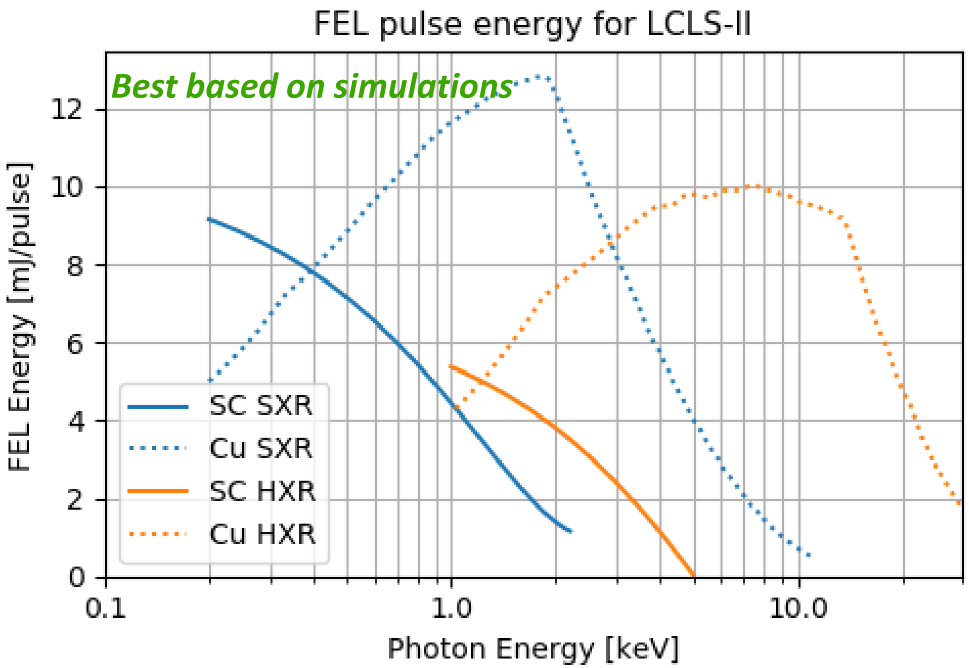


- 🟦 TMO: Time-resolved AMO
- 🟪 TXI: Tender X-ray Instrument
- 🟩 XPP: X-ray Pump Probe
- 🟫 qRIXS: Materials Science Resonant Inelastic X-ray Scattering
- 🟫 chemRIXS: Liquid Chemistry Resonant Inelastic X-ray Scattering
- 🟪 XCS: X-ray Correlation Spectroscopy
- 🟧 MFX: Macromolecular Femtosecond Crystallography
- 🟥 CXI: Coherent X-ray Imaging
- 🟨 MEC: Matter in Extreme Conditions
- 🟦 MeV-UED

FEL Beam Parameters and Material Damages

LCLS can generate strong Free Electron Laser (FEL) beams

→ can damage materials, especially when focused



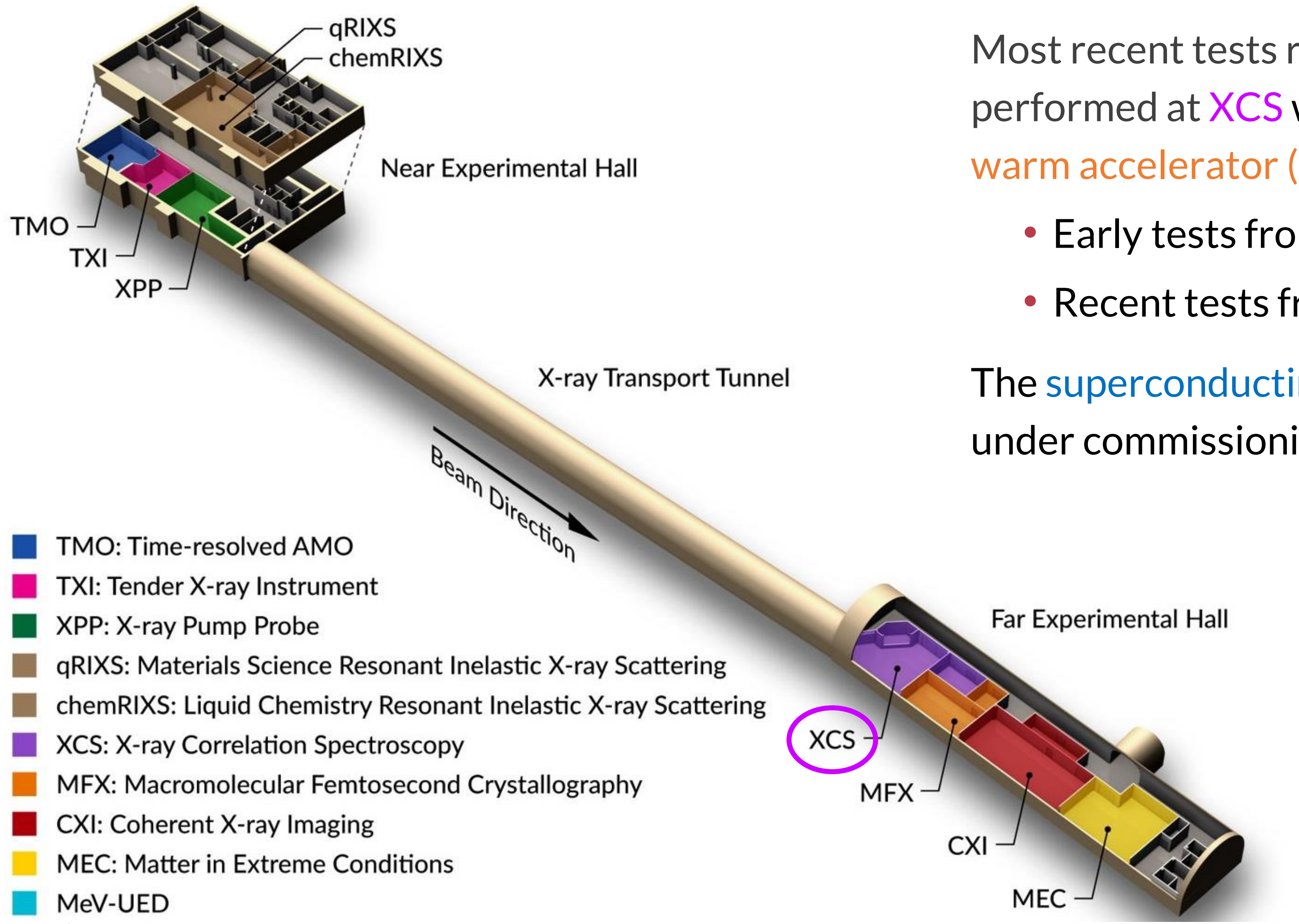
Cu FEL:

- Large pulse energy →
  - *Achieved 5 mJ SXR and 3 mJ HXR*
- Single pulse ablation, or
- Multi pulse fatigue

SC FEL

- Smaller pulse energy, but much higher repetition rate *(120 Hz vs. 100 kHz)*
- Melting, multi pulse fatigue, sublimation, …

Instruments for Tests

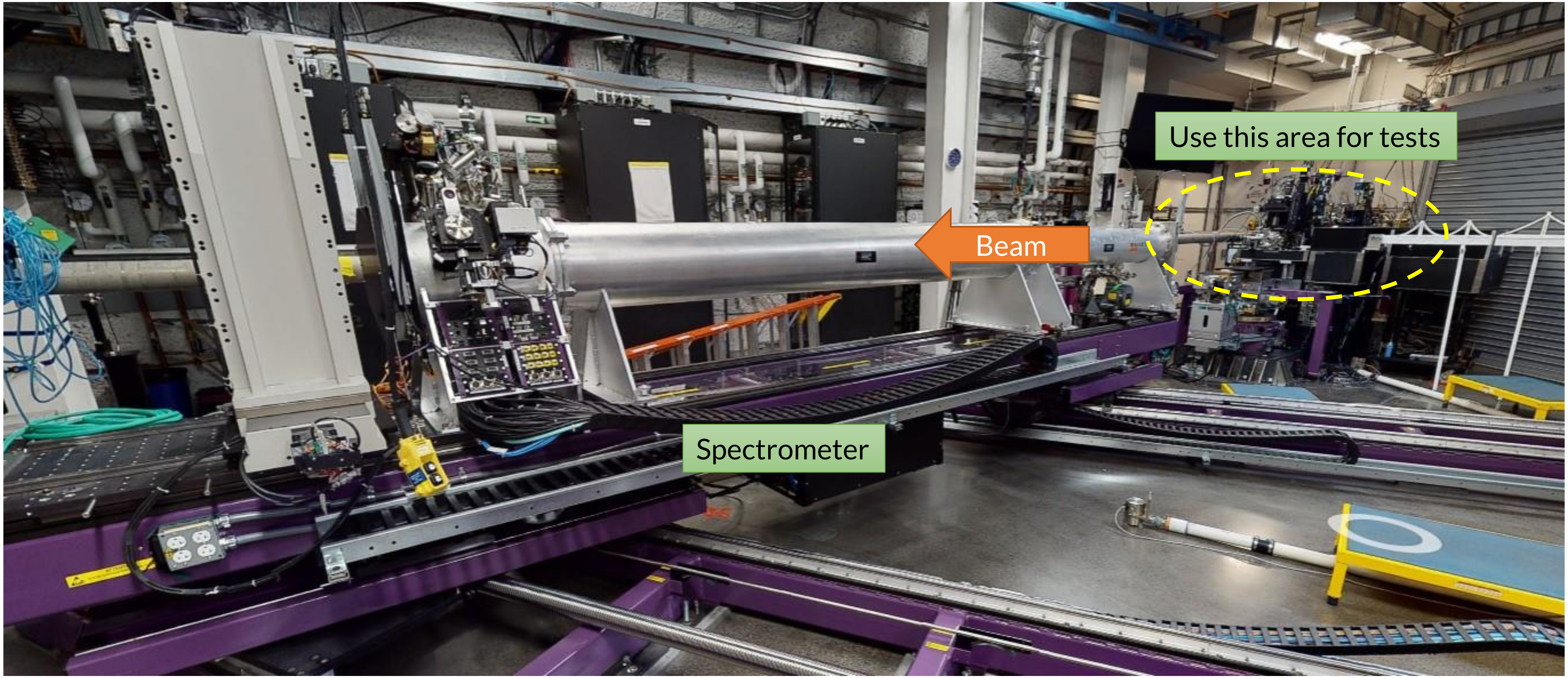


Most recent tests referred in this talk were performed at XCS with FEL beams from the warm accelerator (Cu)

- Early tests from 2009 to 2013
- Recent tests from 2020 to 2024

The superconducting accelerator (SC) is still under commissioning

Overview of XCS Instrument



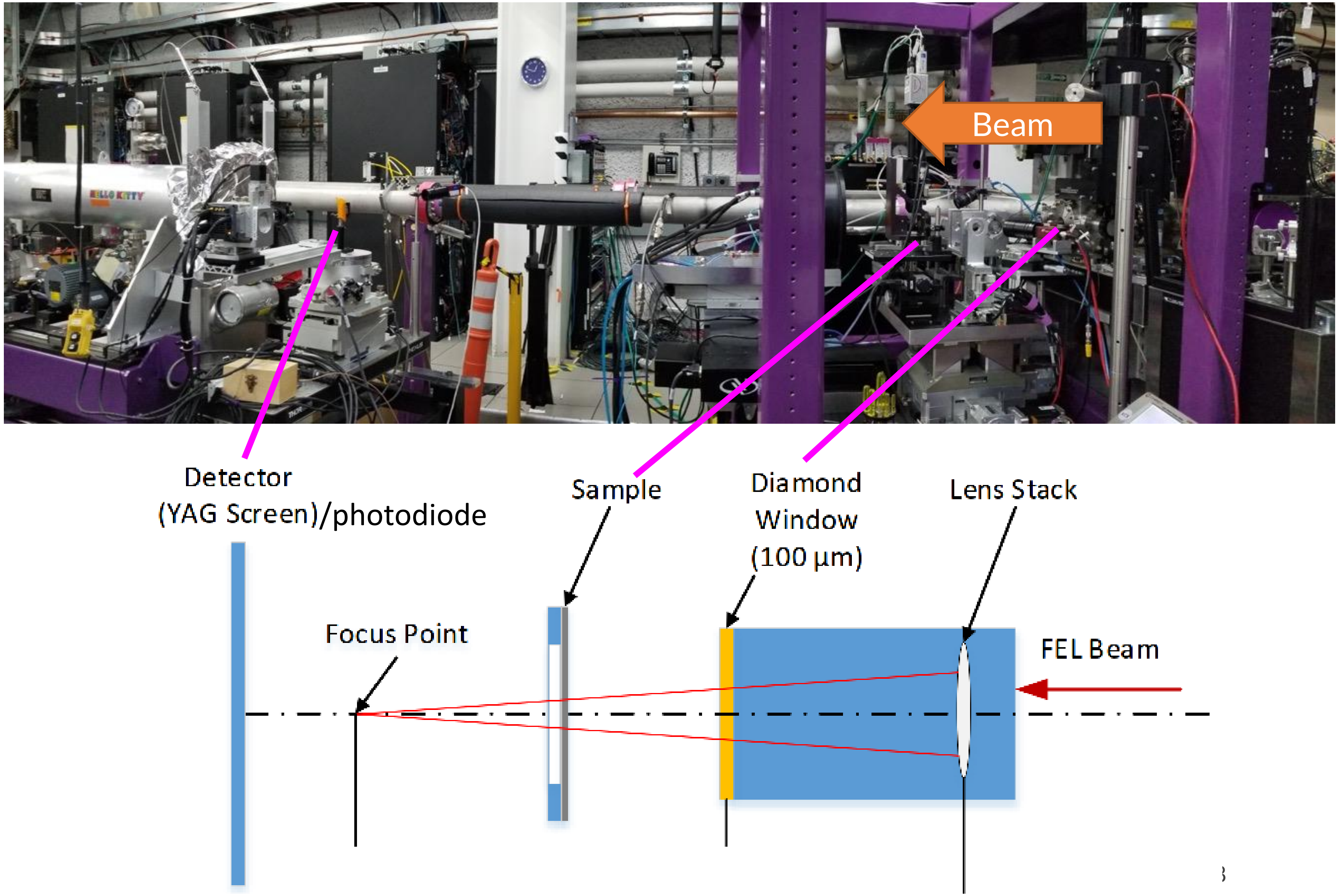
Test Setting for Material Damage

Adjust beam sizes at the sample location to get different beam intensity

120 Hz, 9.1-9.3 keV beam

Test Purposes:

- Damage threshold
- Damage speed
- Hole size

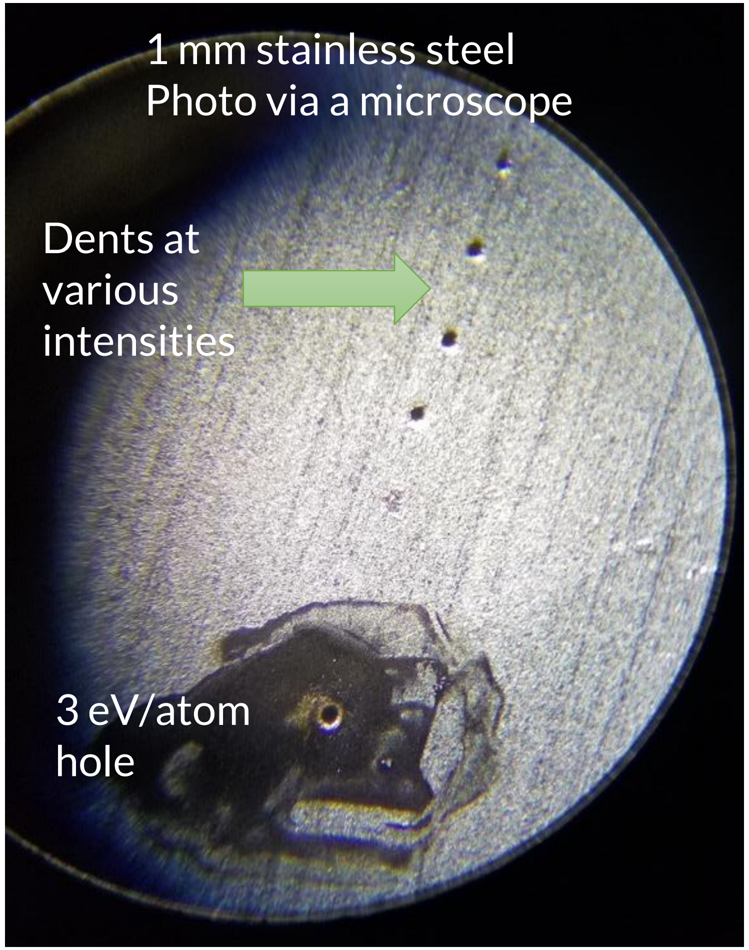


Material Damage Test

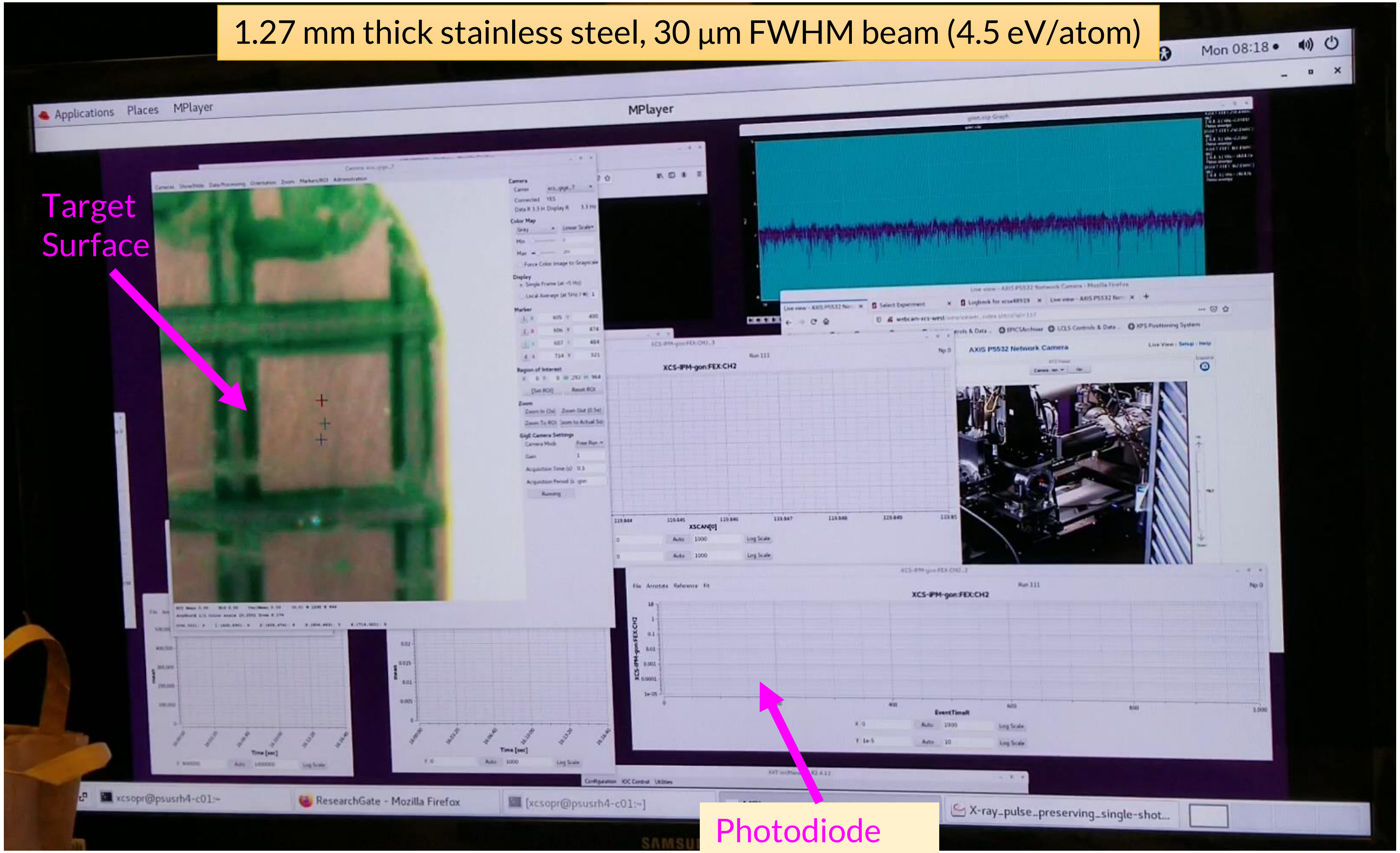
Stainless steel

- Early test established a multi-short safey level at 0.28 eV/atom
- Burn through 1 mm thick stainless steel immediately at 8 eV/atom *(high level)*
- Visible damages from 0.7-4.2 eV/atom *(intermediate levels)*, but much slower damage speed:
  - 70 minutes (~500,000 pulses) to burn-through 1mm thick stainless steel at 3.0 eV/atom *(melt threshold is only 0.45 eV/atom)*

No obvious surface change on **SiC** under 1.1 eV/atom for 500,000 pulses



Material Damage Test: Drill Time



1.27 mm thick stainless steel, 30 µm FWHM beam (4.5 eV/atom)

Target Surface

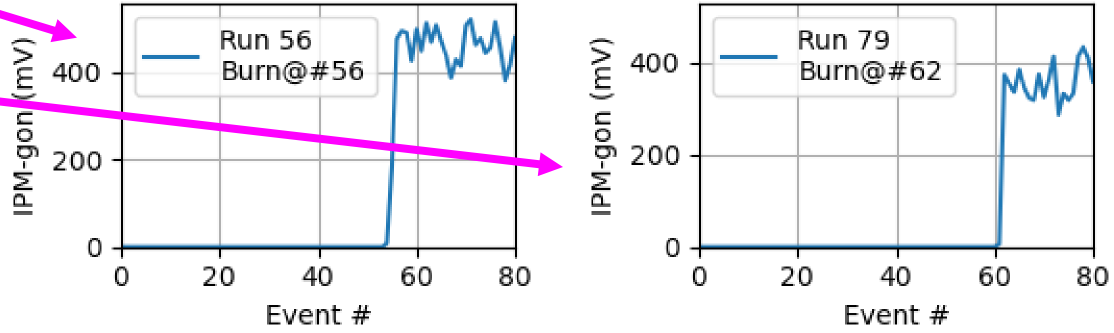
Photodiode behind target

Material Damage Test: Drill Time

	Spot Size (FWHM µm)	eV/atom	Burn In	
			Pulses*	Second
1.27 mm Stainless Steel	2.25	800	57±2.2	0.5
	5	160	58±1.2	0.5
	10	40	60±0.4	0.5
	20	10	76±1.3	0.6
	30	4.5	117±2.4	1
	40	2.5	Not in ~1,000 pulses	
12.5 mm Stainless Steel	2.25	800	Not in ~65,000 pulses (9 min)	
	10	40		
	5	160	622	5
14 mm Al	2.25	60	83±1.0	0.7
7 mm SiC	5	10	150	1.2
50% trans.	5	5	600	5
25% trans.	5	2.5	Not for 1 hour	

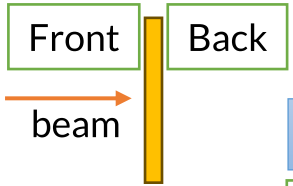
9.09 keV, 0.36 mJ (on target), 120 Hz, 0.043 W

** Repeat 10 times for each beam size on steel (raster the sample), but only twice on aluminum*

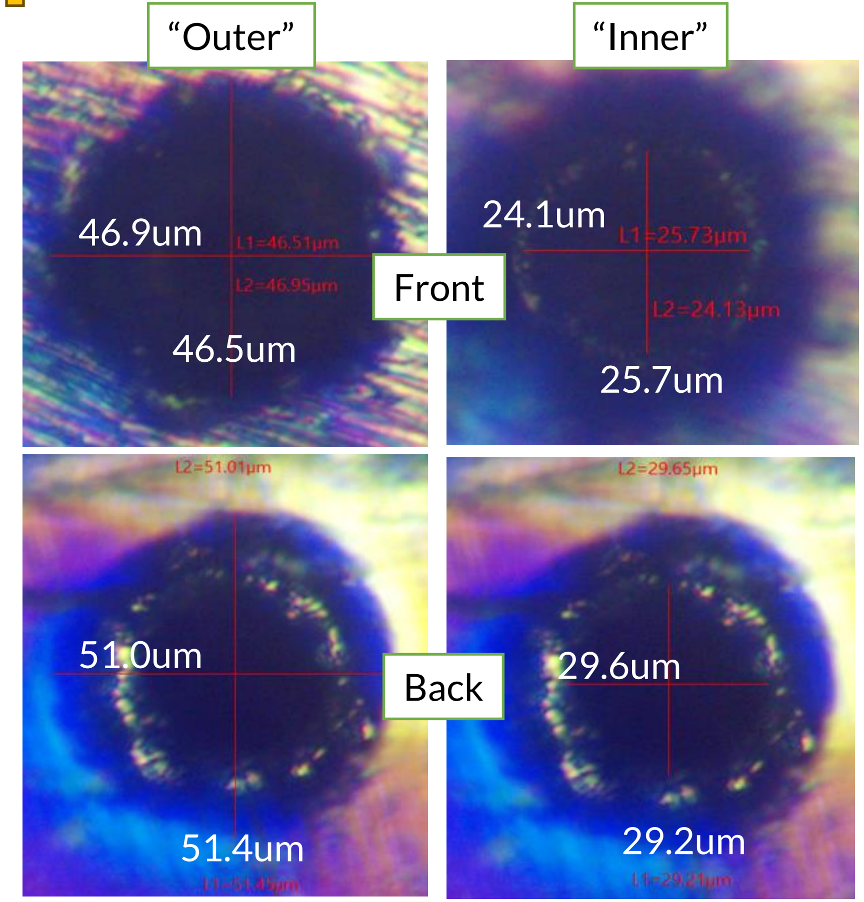


- 12.5 mm thick steel was burned by 5 µm beams in 5 s, but not drilled through by 2.25 or 10 µm beams
- 7 mm thick SiC was burned quickly at ≥5 eV/atom, but not drilled through at 2.5 eV/atom for 1 hour

Material Damage Test: Hole Size

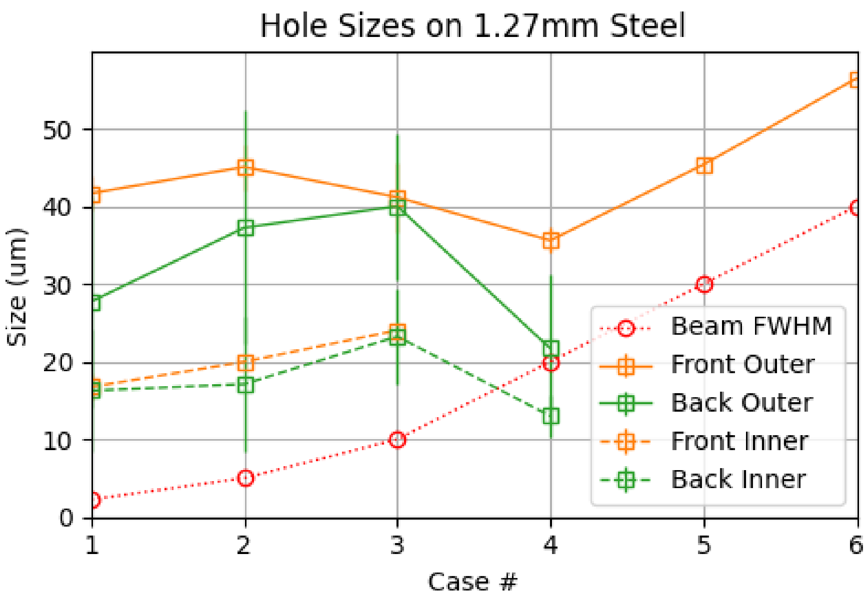


1.27mm steel, 10 um FWHM



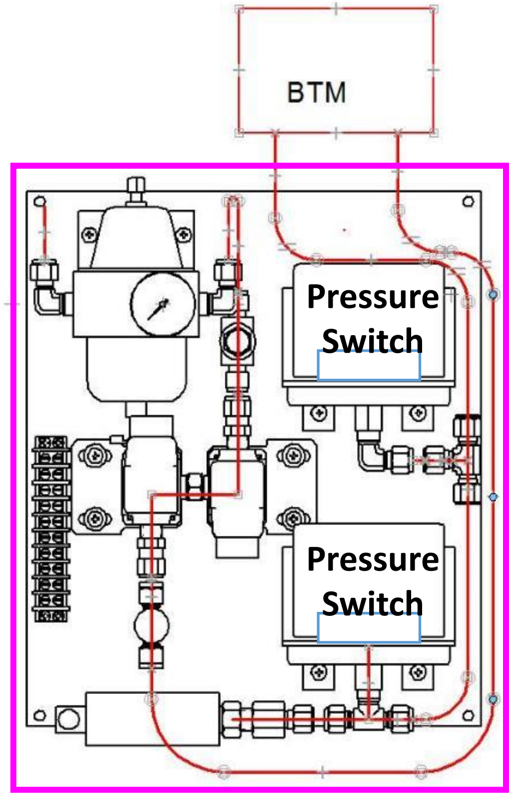
Assume hole diameter = beam FWHM in radiation safety analyses

- Assumption is conservative in most cases but not conclusive
- No "Inners" and no Back holes for 30 and 40 um beams
- More tests with SC beam are planned



Burn-Through Monitor (BTM): Traditional Design

A **traditional BTM** consists of a pressured gas chamber connected to a control box

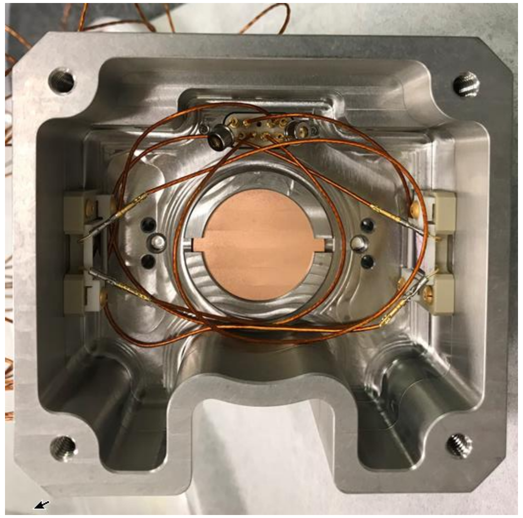


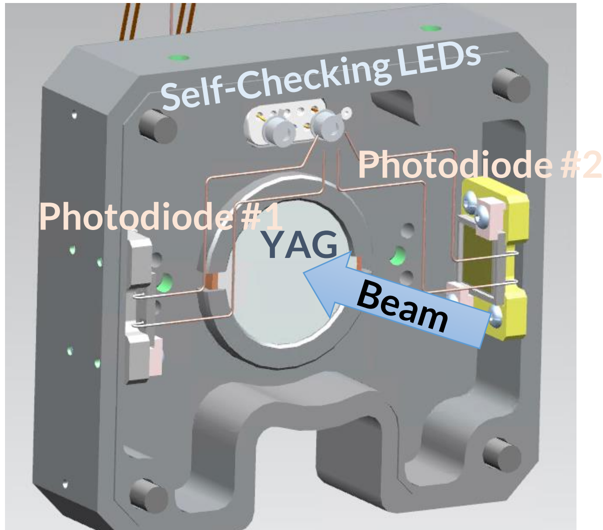
BTM Control Box

BTM Control Box (as built)

New fast-response BTM:

- Dark box with a YAG screen, 2x photodiodes and 2x self-checking LEDs



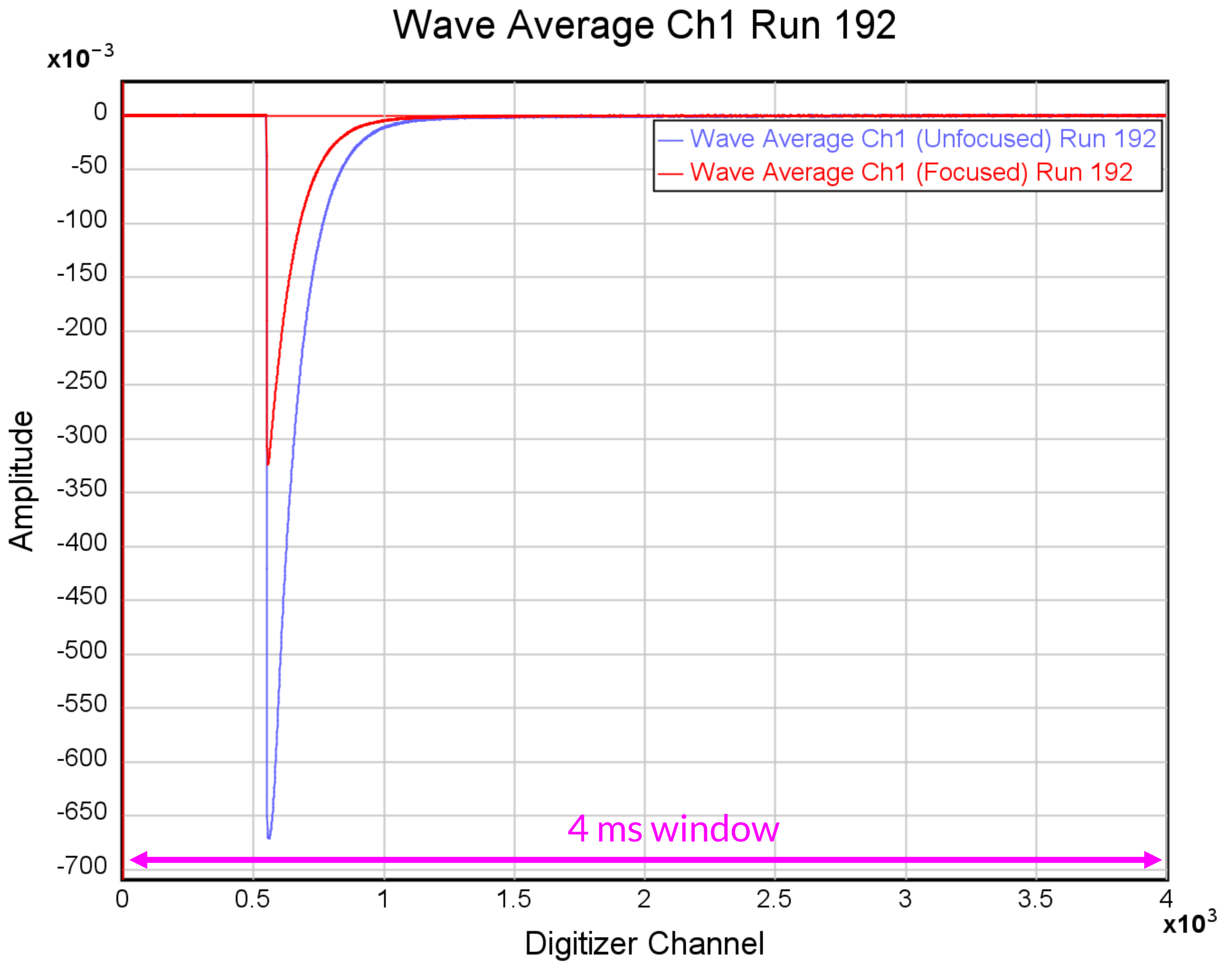


** Front cover removed*

Waveforms from Photodiode

Averaged waveforms were plotted

- Fast response
- The amplitude from focused beam is smaller, because of the absorption of lenses

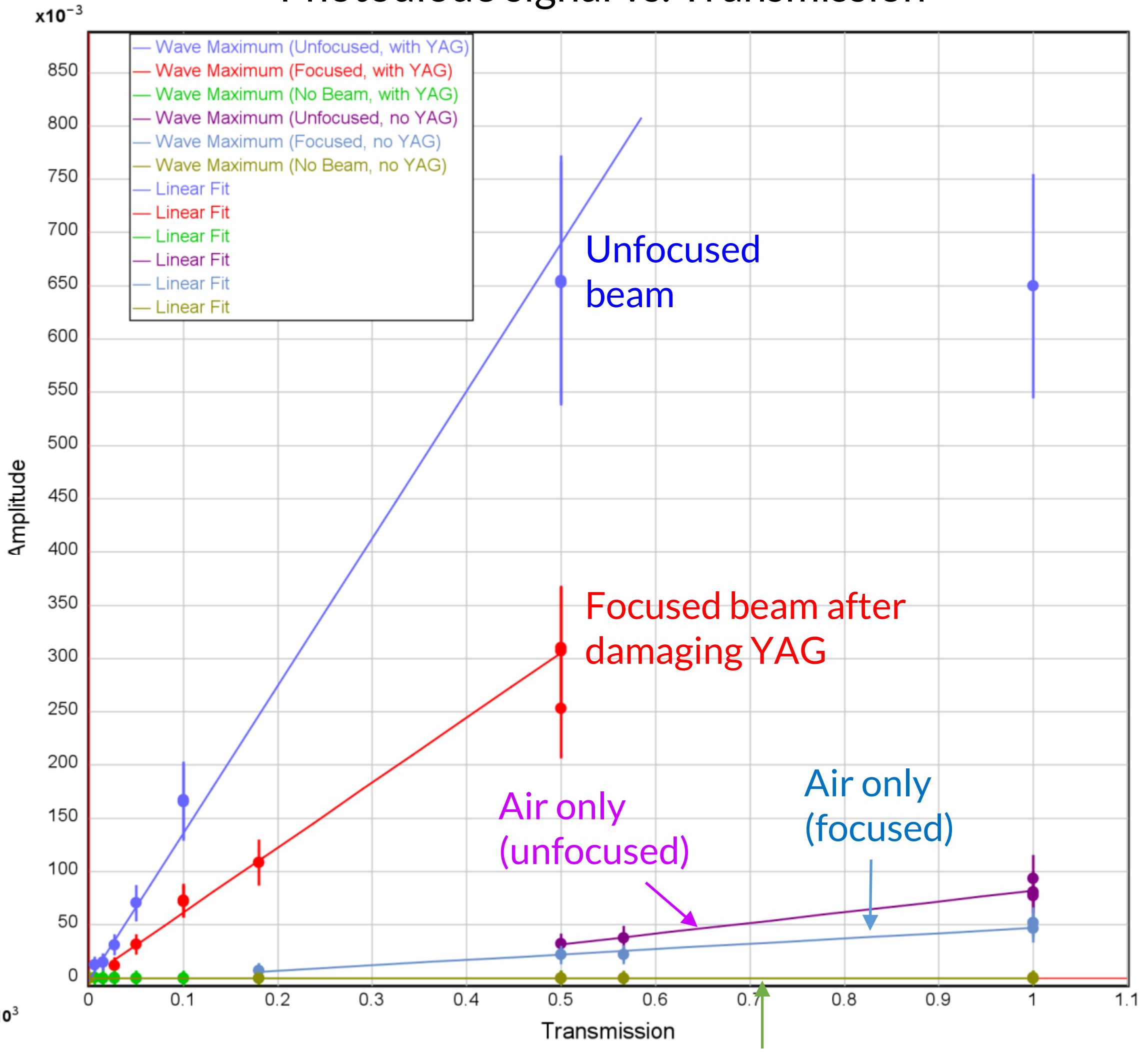


Test for Photodiode BTM

Tested 3 cases at different intensities *(9.8 keV)*:

- Unfocused beam
- Focused beam to damage YAG → ~half signal after damaging
- No YAG (air only) → noticeable signal

Photodiode signal vs. Transmission



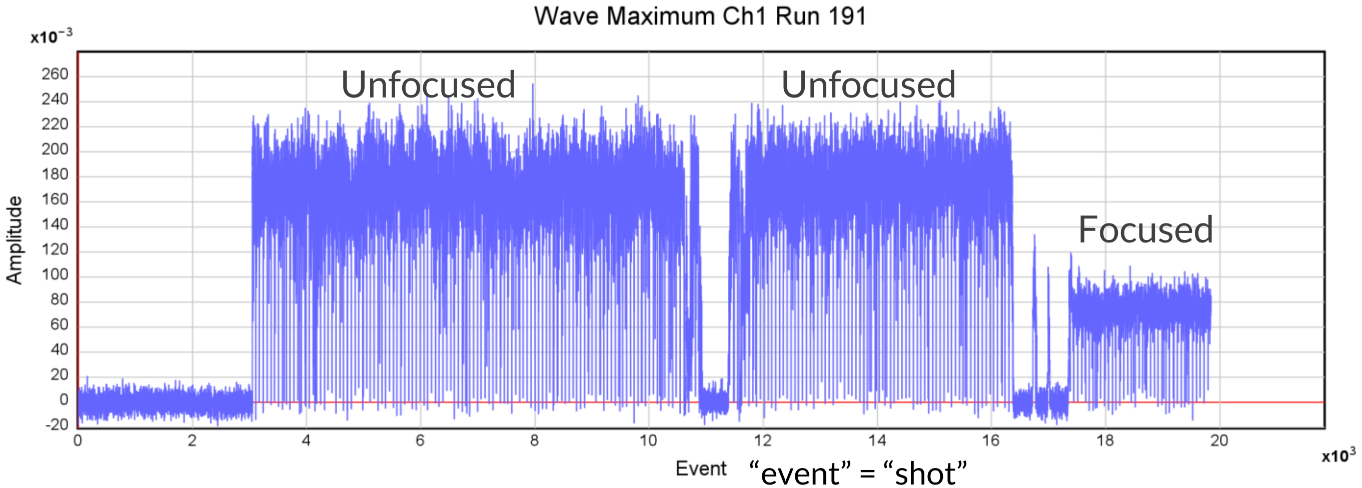
Unfocused beam

Focused beam after damaging YAG

Air only (unfocused)

Air only (focused)

Background (no beam)



Unfocused

Unfocused

Focused

"event" = "shot"

Summary

Various tests were performed to study material damage by FEL beams and how the damage may be detected

- Only Cu Linac beams (120 Hz) were available so far
- The superconducting Linac is under commissioning; no enough power yet
- More tests have been planned during the ramp up of the superconducting Linac

Thank You!