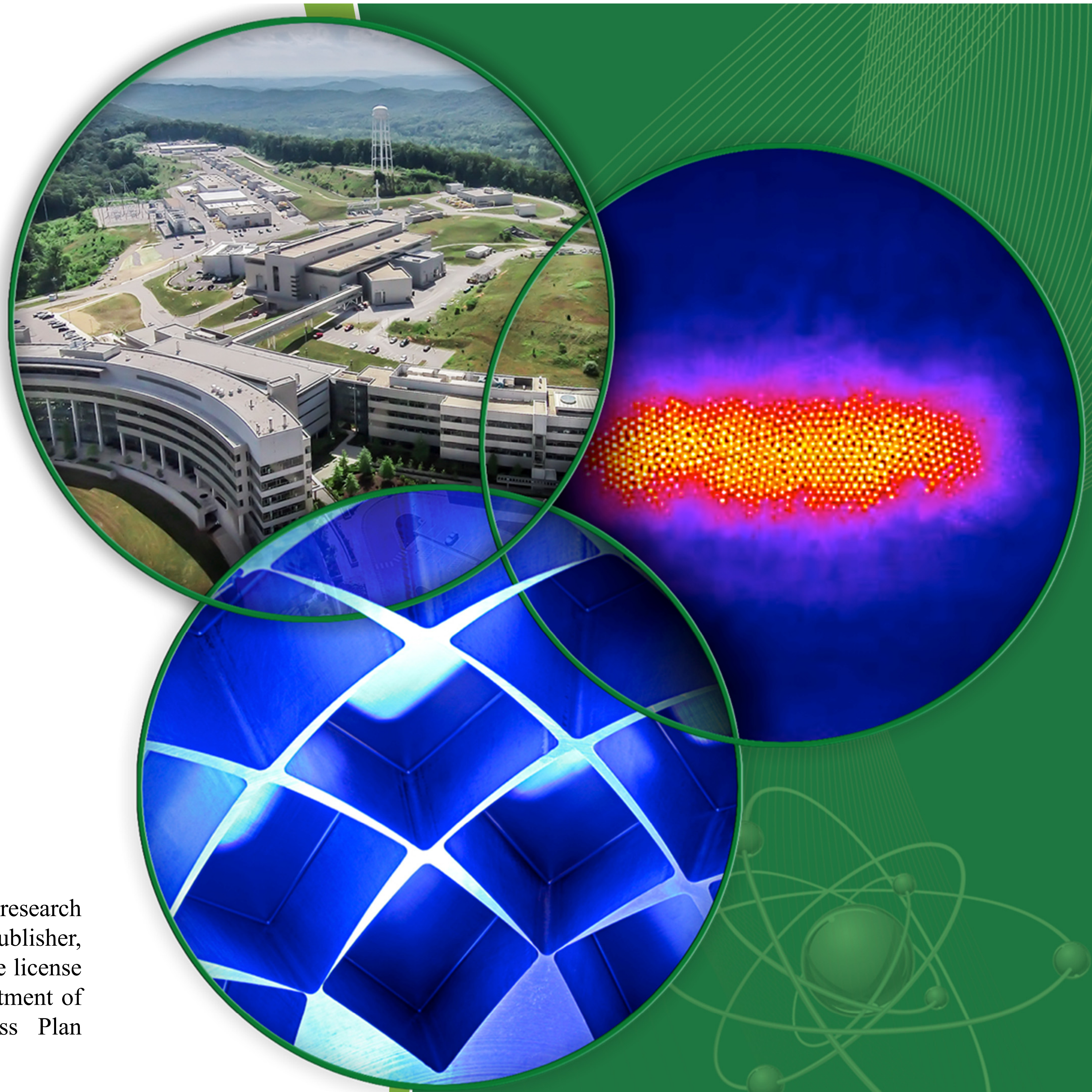
STRAIN AND TEMPERATURE MEASUREMENTS FROM THE SNS* MERCURY TARGET VESSEL DURING HIGH INTENSITY BEAM PULSES

Willem Blokland †, Yun Liu, Bernie Riemer, Mark Wendel, Drew Winder



*Spallation Neutron Source

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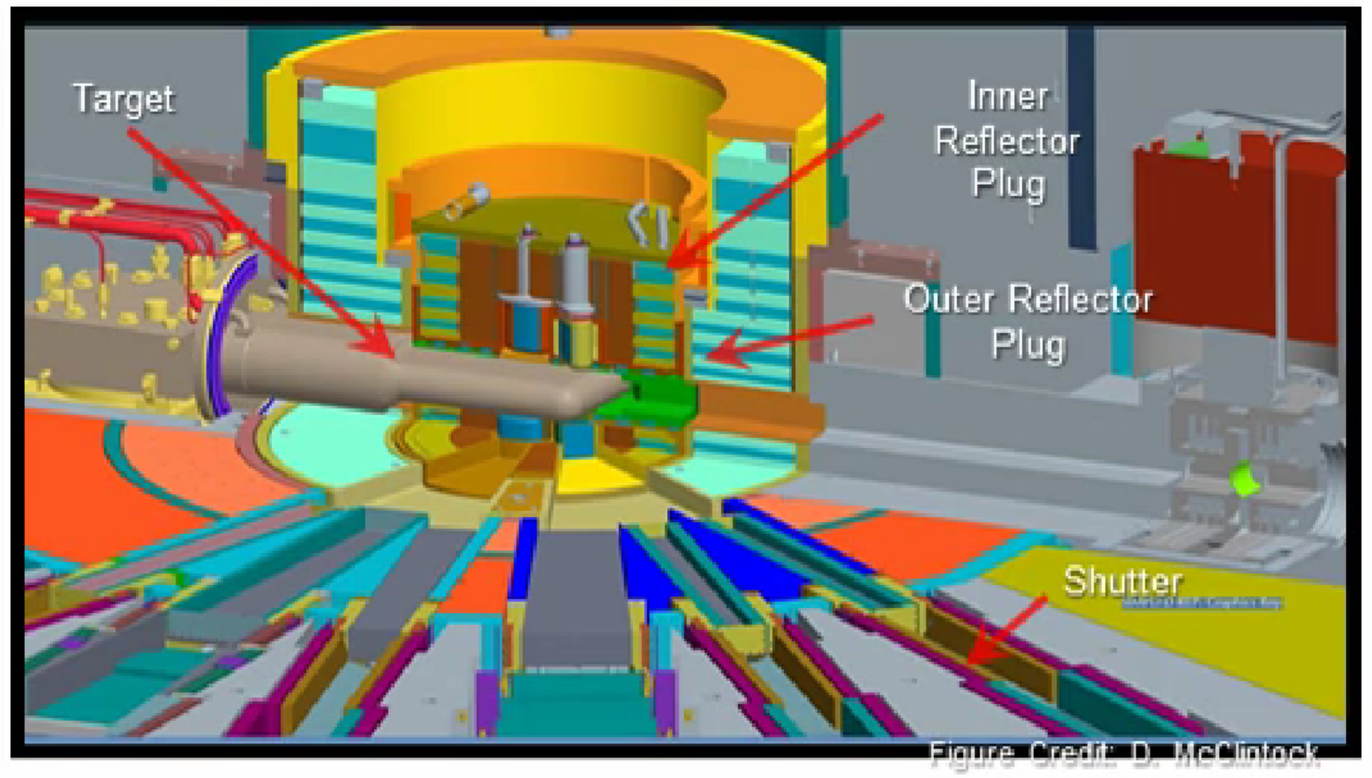
† blokland@ornl.gov

Introduction

- The Spallation Neutron Source uses neutrons for materials research:
  - 1 GeV proton beam directed at a target vessel filled with mercury to produce neutrons
- But the target has limited lifetime at 1.4MW and we have seen unexpected failures:
  - We want to understand the target lifetimes better:
    - Are we hitting a resonance frequency?
    - Is the strain on the target higher than we expected?
    - How will we know if future mitigation methods are working?

  → Measure the strain by adding sensors



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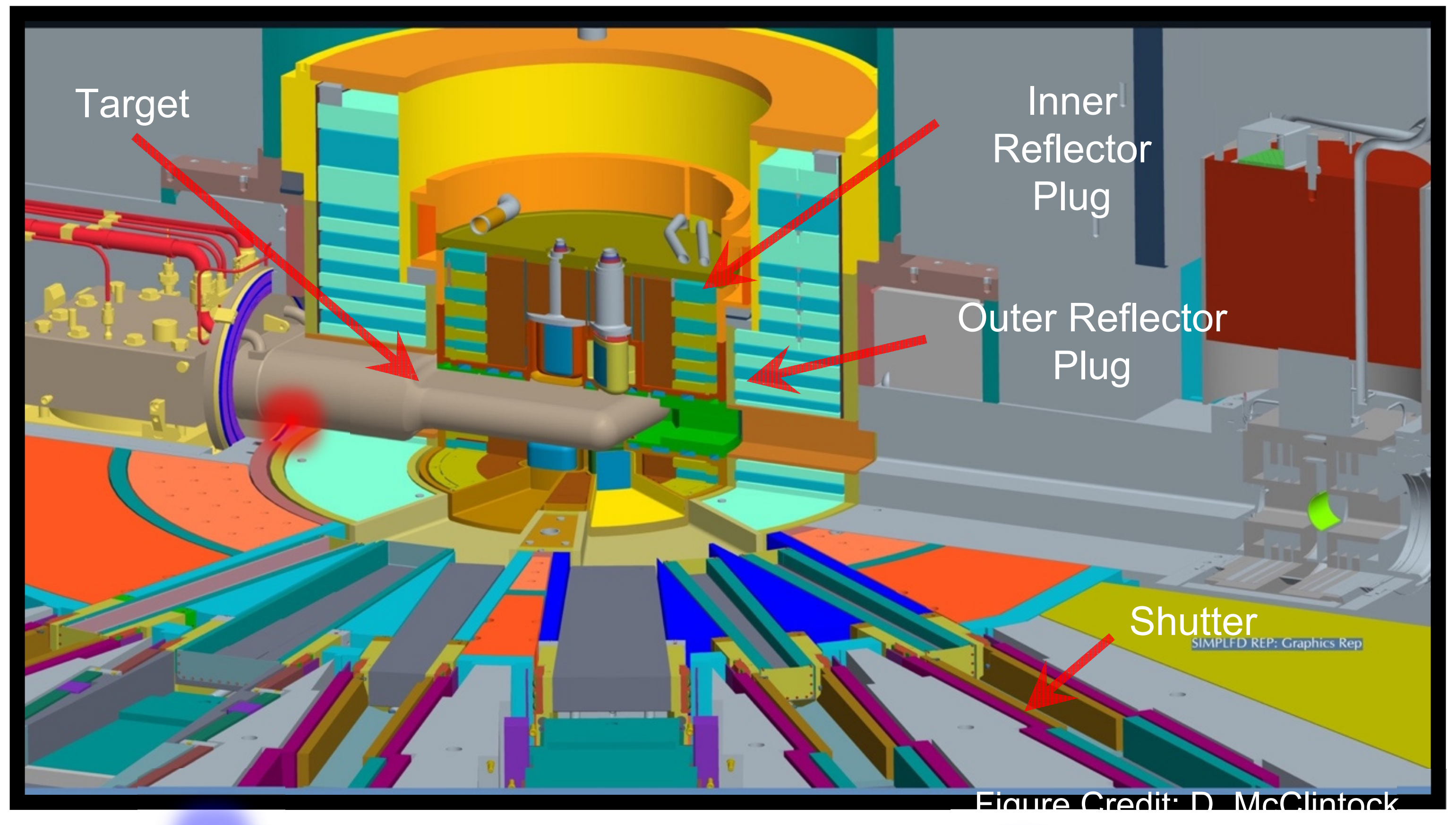

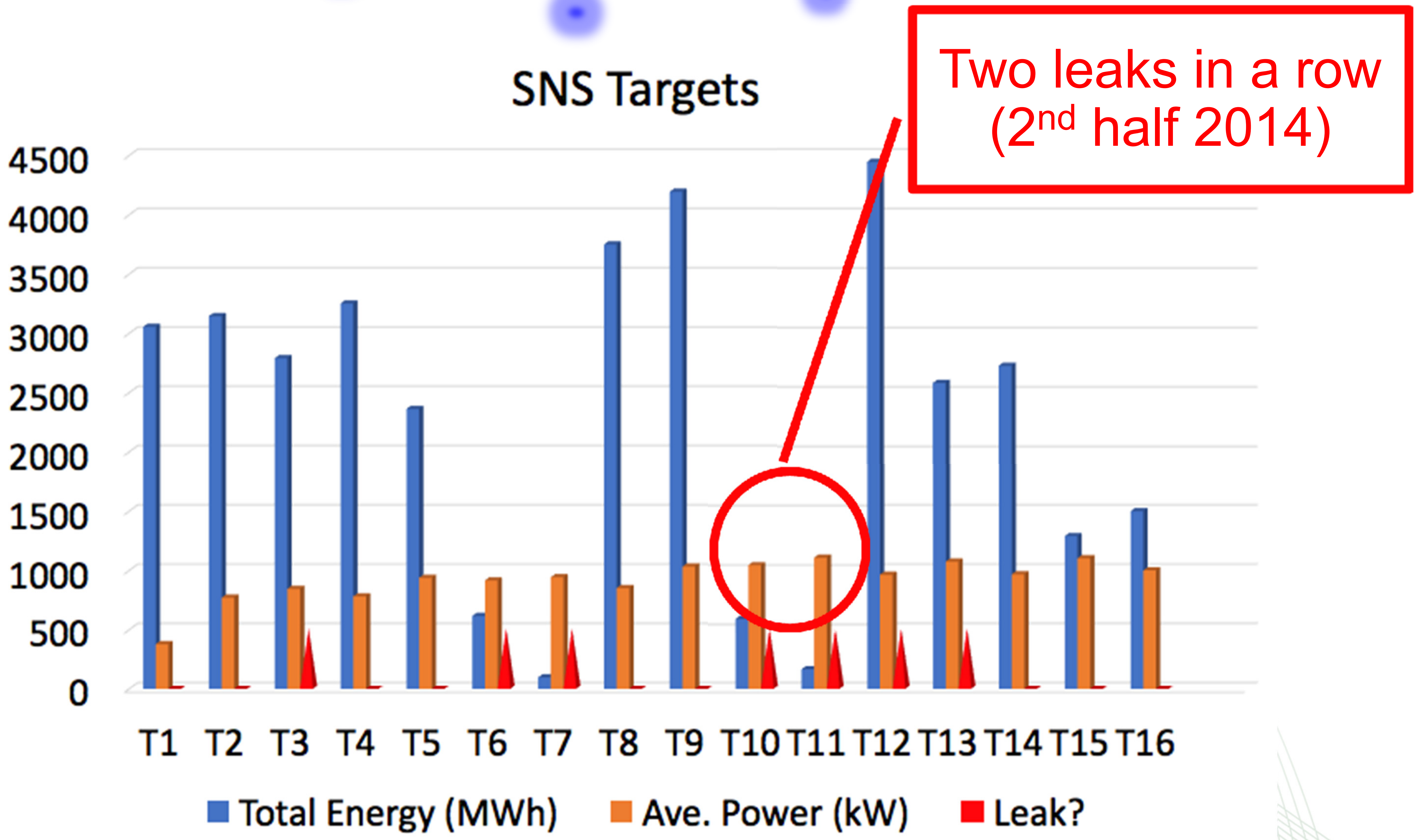

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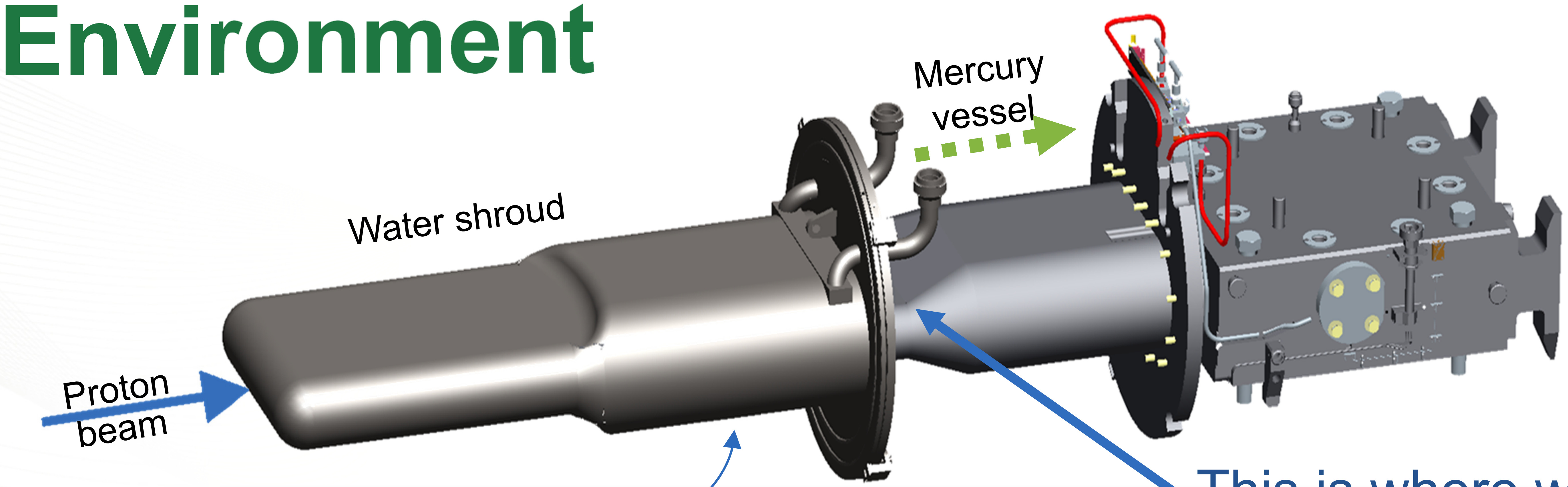
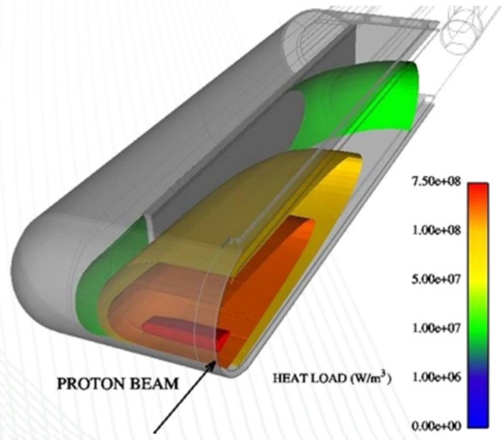
Sensor Environment



- Leak detector
  - Cannot affect detector → minimize introducing new materials
- Interstitial space
  - <3 mm height
- Electrical noise
  - Beam pulse of ~24μC in 600ns, 50-100 A
  - Pumps and other equipment

- Proton beam impact
  - ~60% of beam energy is deposited as heat in the target producing a shockwave
    → 10 - 500 με on wall
    → 25 -100 Celsius



- Radiation at sensor locations
  - During production: from 1 MRad/MWhr up to 2.5 GRad/MWhr

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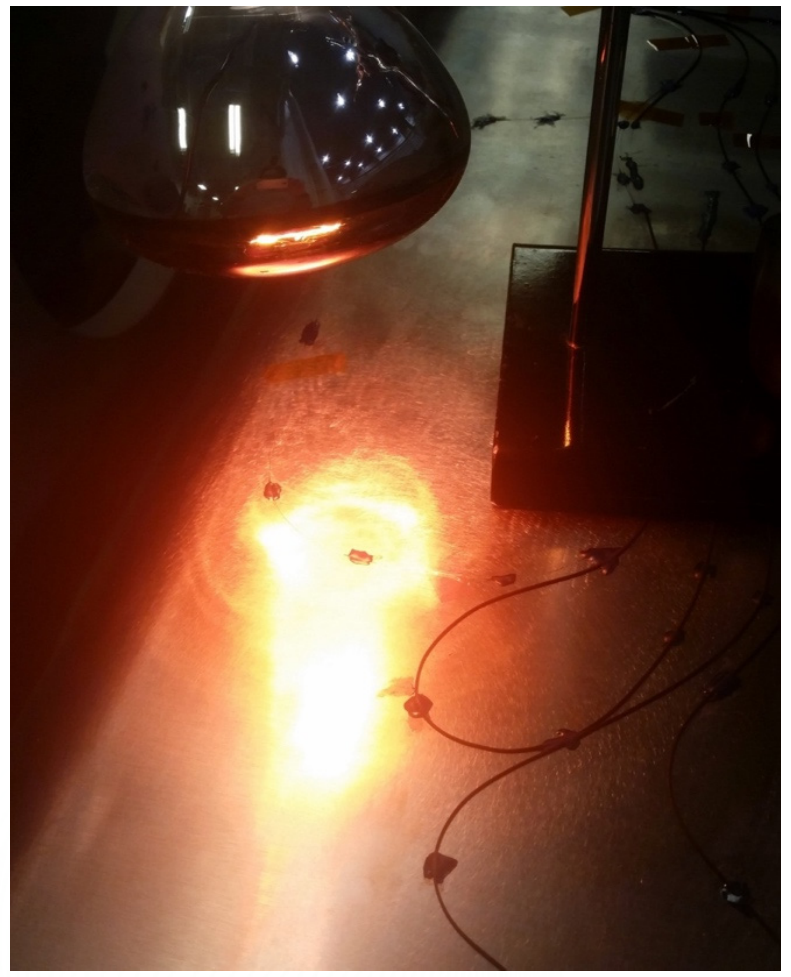
Optical strain sensor

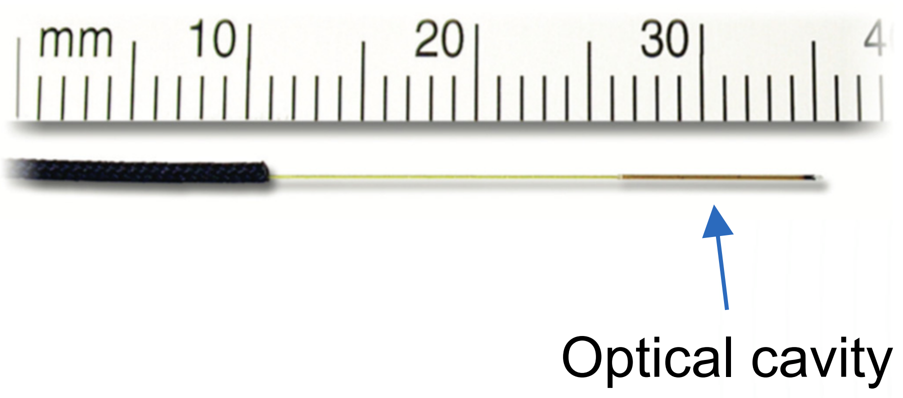
- We picked an optical strain sensor from FISO
  - Fast enough: 100 kHz
  - Small enough: 1.5 mm (with glue)
  - Not sensitive to EMP: optical
  - Is proven to work (LANL experiment)
  - Doesn't affect leak detector: no corrosive chemicals, not conductive, will not evaporate, small amount

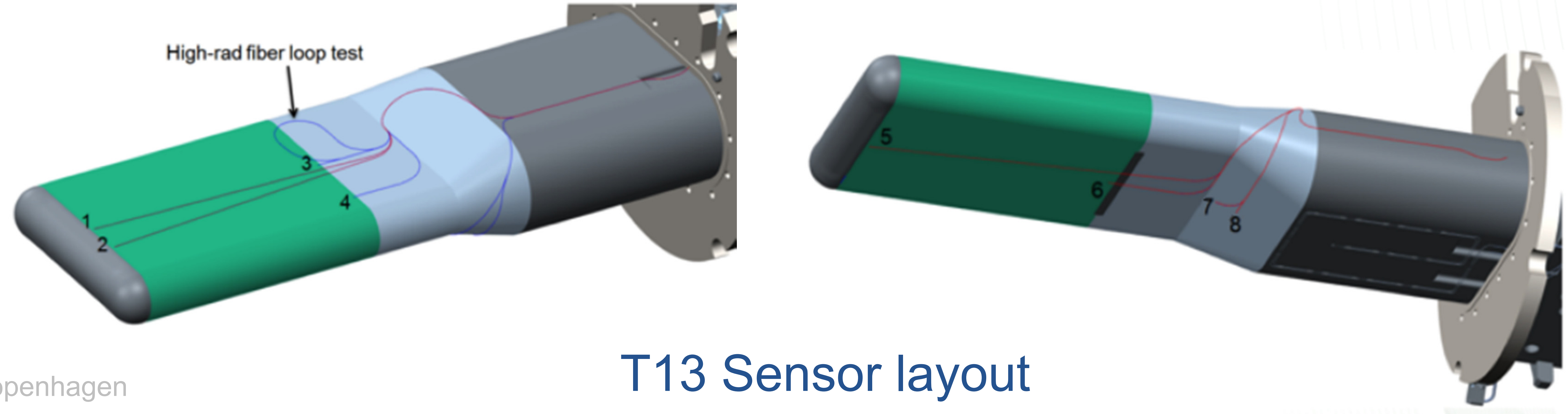
Laying out the sensors (at manufacturer)



Curing of epoxy

FISO FOS-N Strain Sensor





T13 Sensor layout

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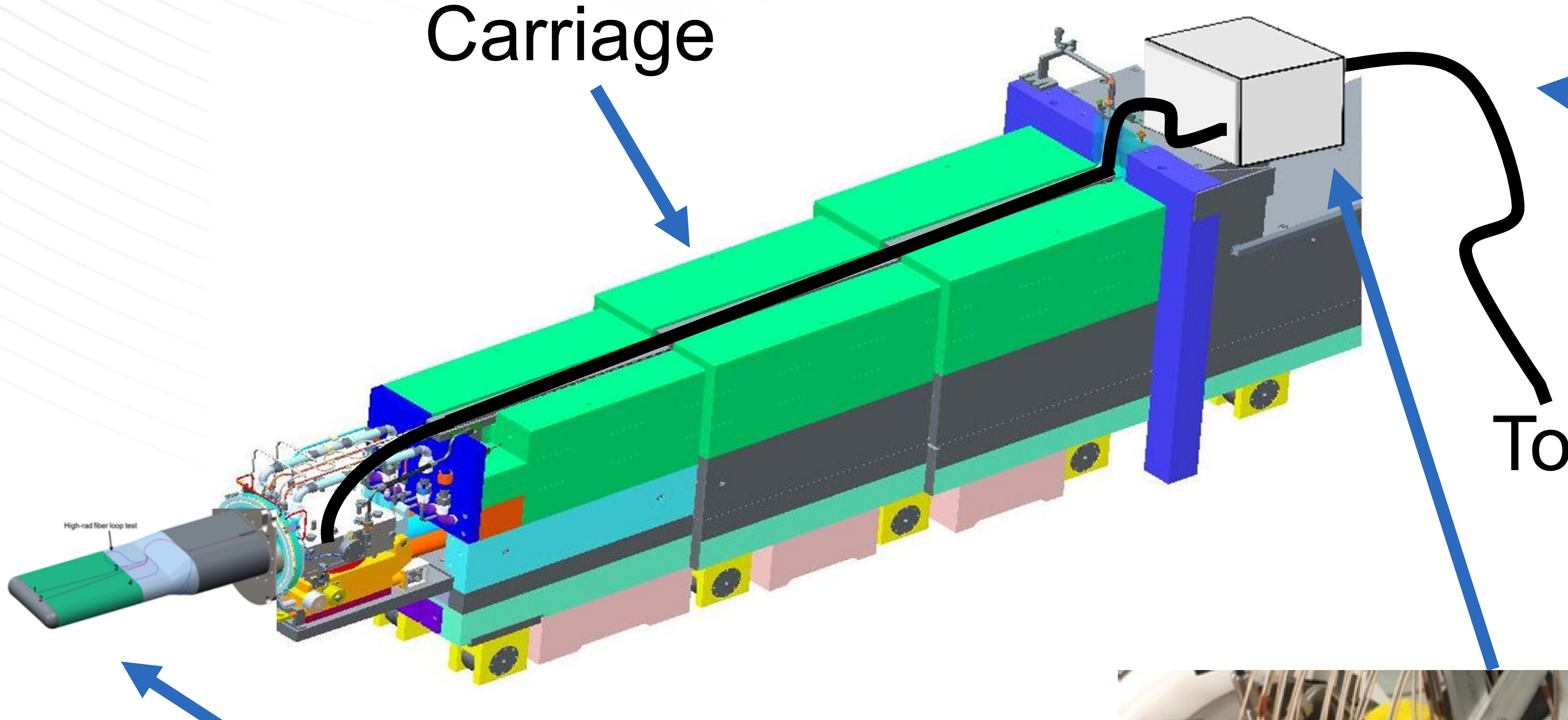
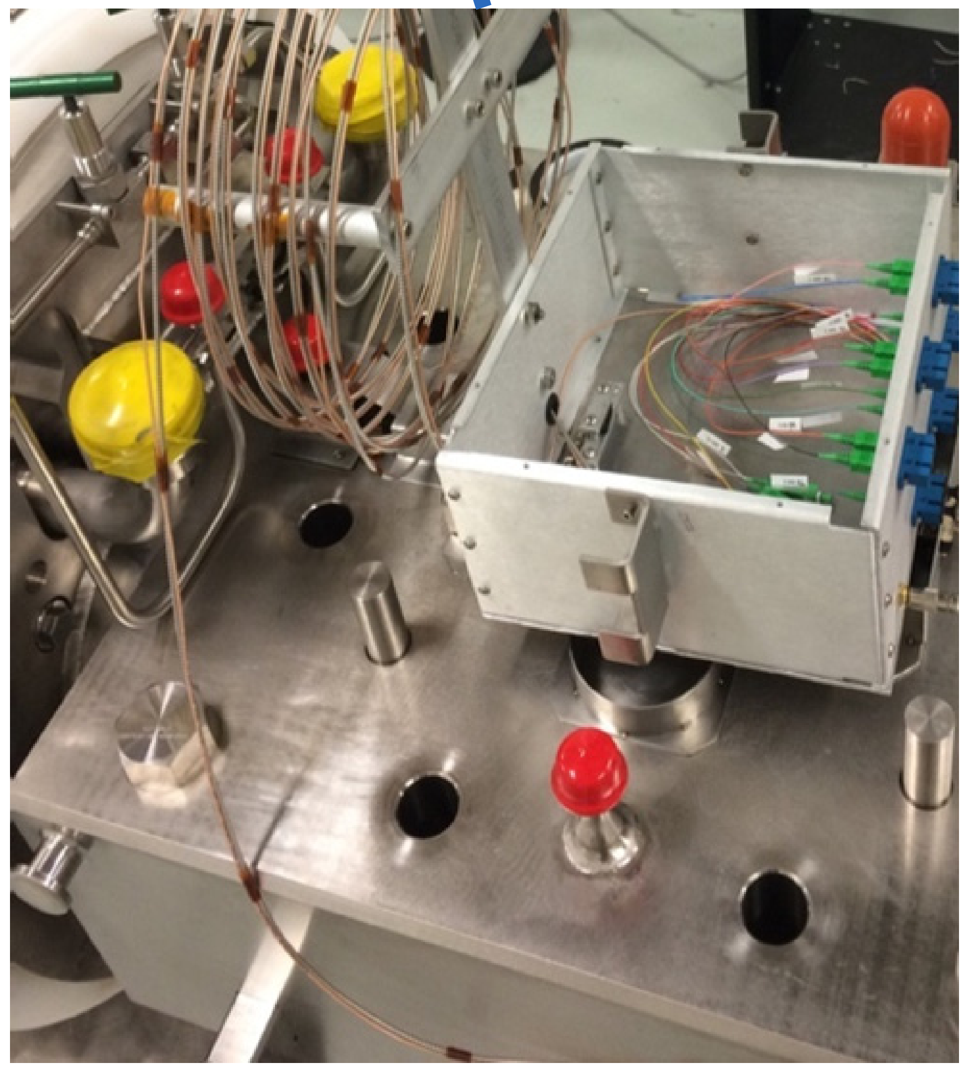
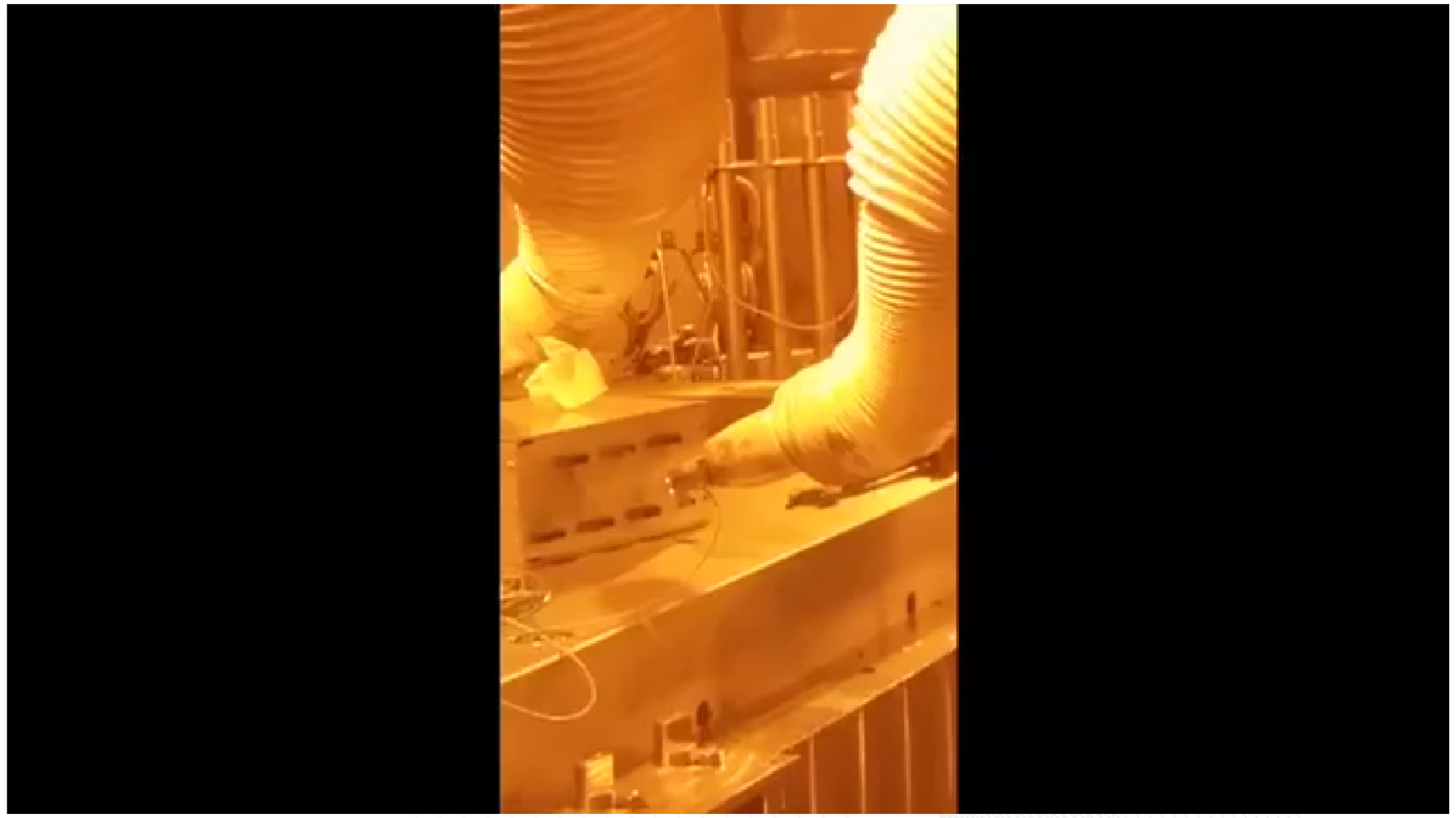
Installation

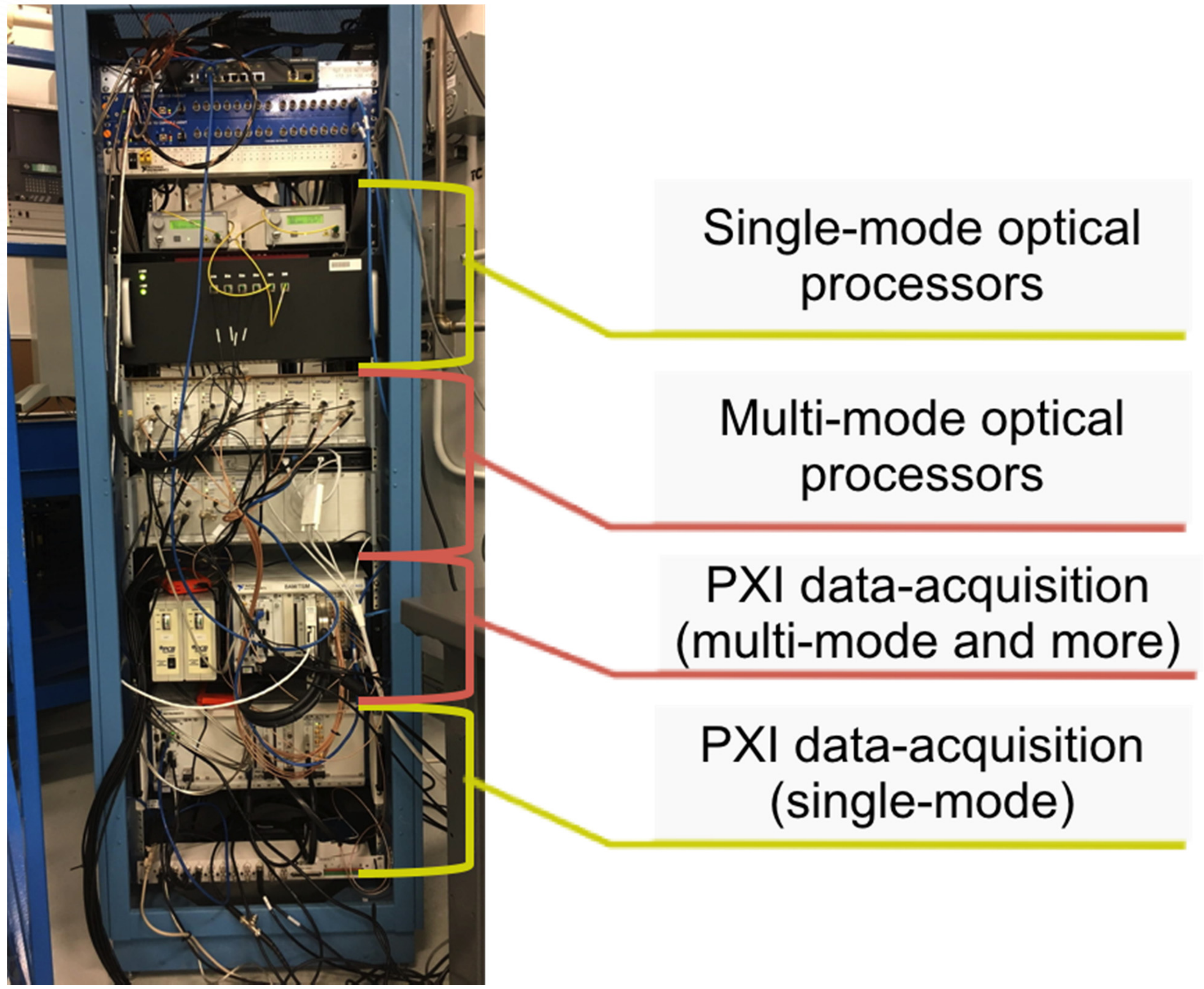
- Part of the installation has be done with remote manipulators







The data acquisition system and installed sensors



Rack with equipment

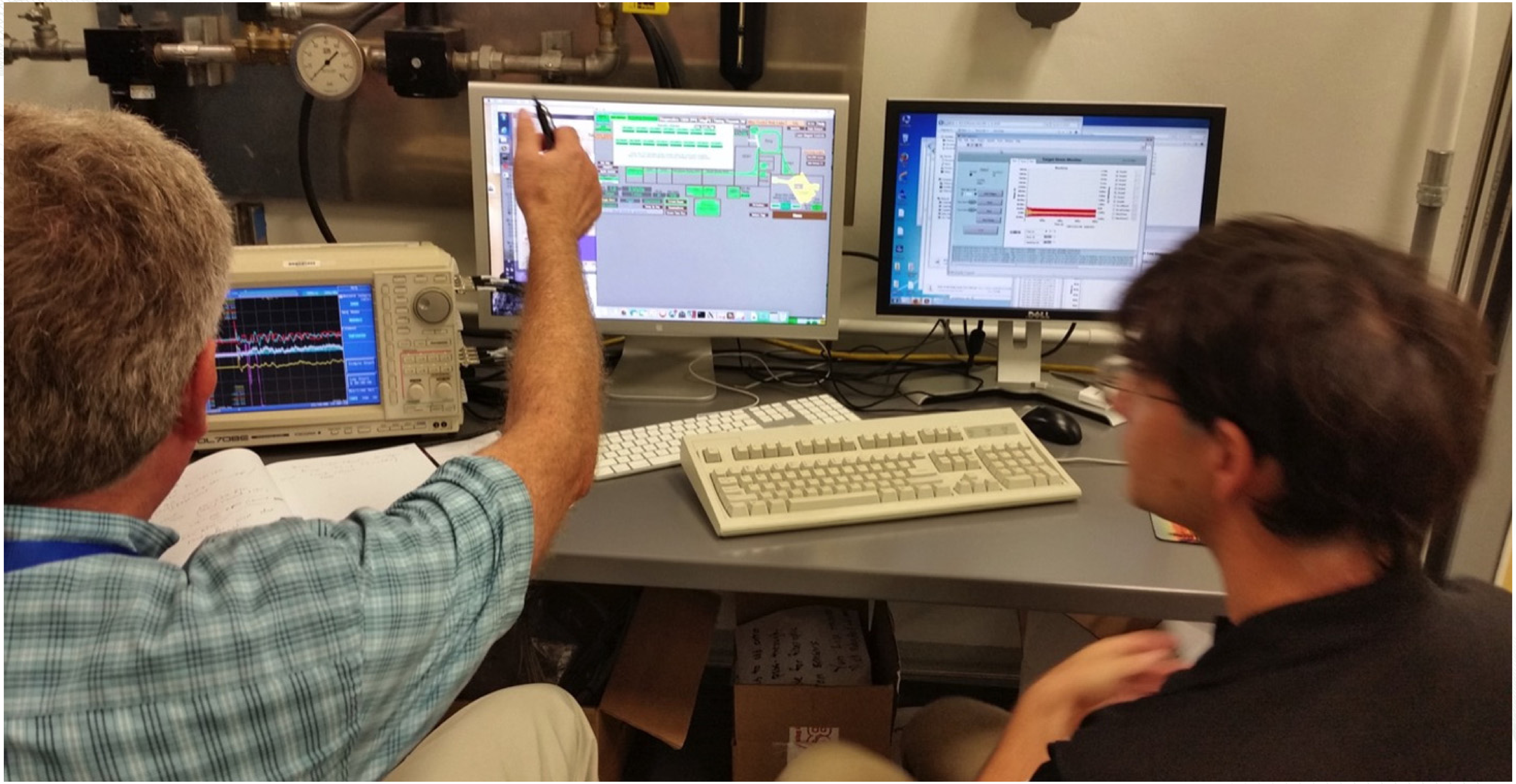
Acquisition program

Working/installed

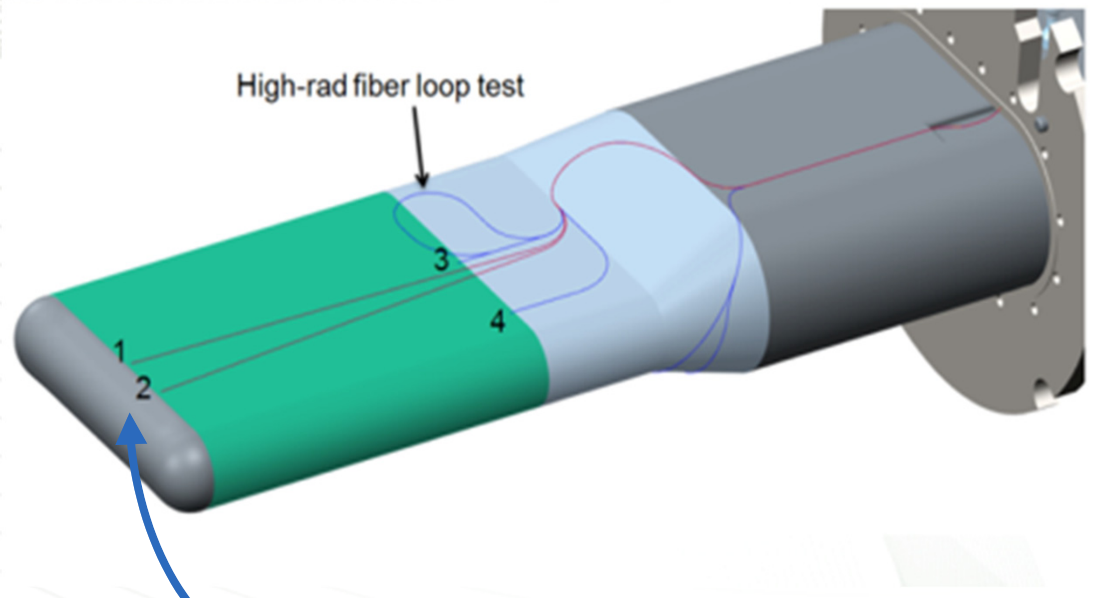
Target	MM Strain	SM Strain	Thermo-couple	Metal strain	Accelerometer
T13 (standard)	4/8	-	-	-	2/2
T14 (standard)	3/8	2/4	2/2	-	2/2
T15 (standard)	9/12	3/4	2/2	1/2	2/2
T16 (jetflow)	10/12	3/4	2/2	2/2	2/2

Waiting for beam on first instrumented target

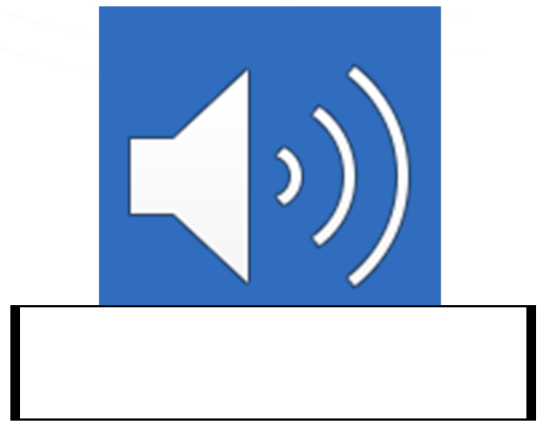
First strain data!



What did we see? T16 Data: Sensor 2



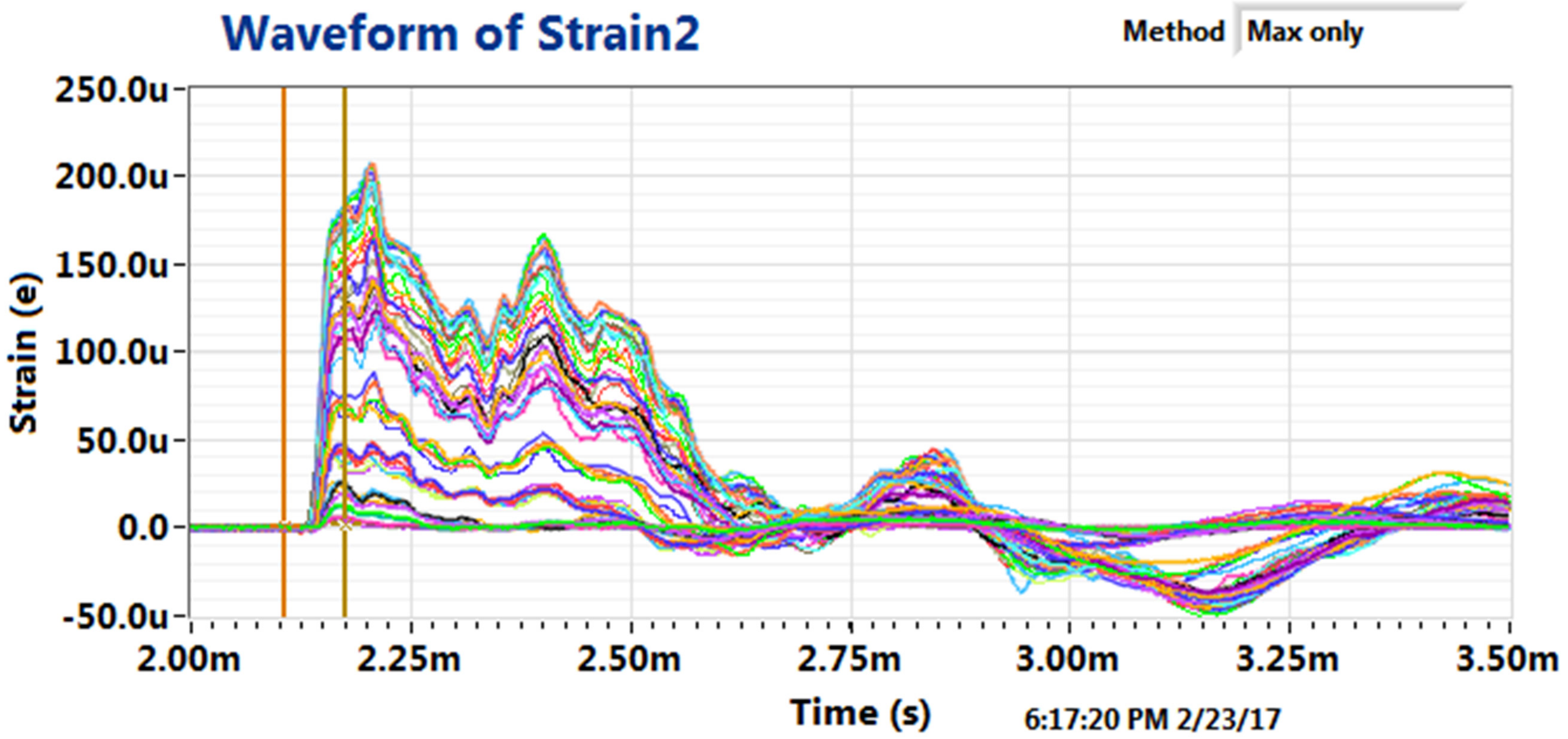
Sensor 2



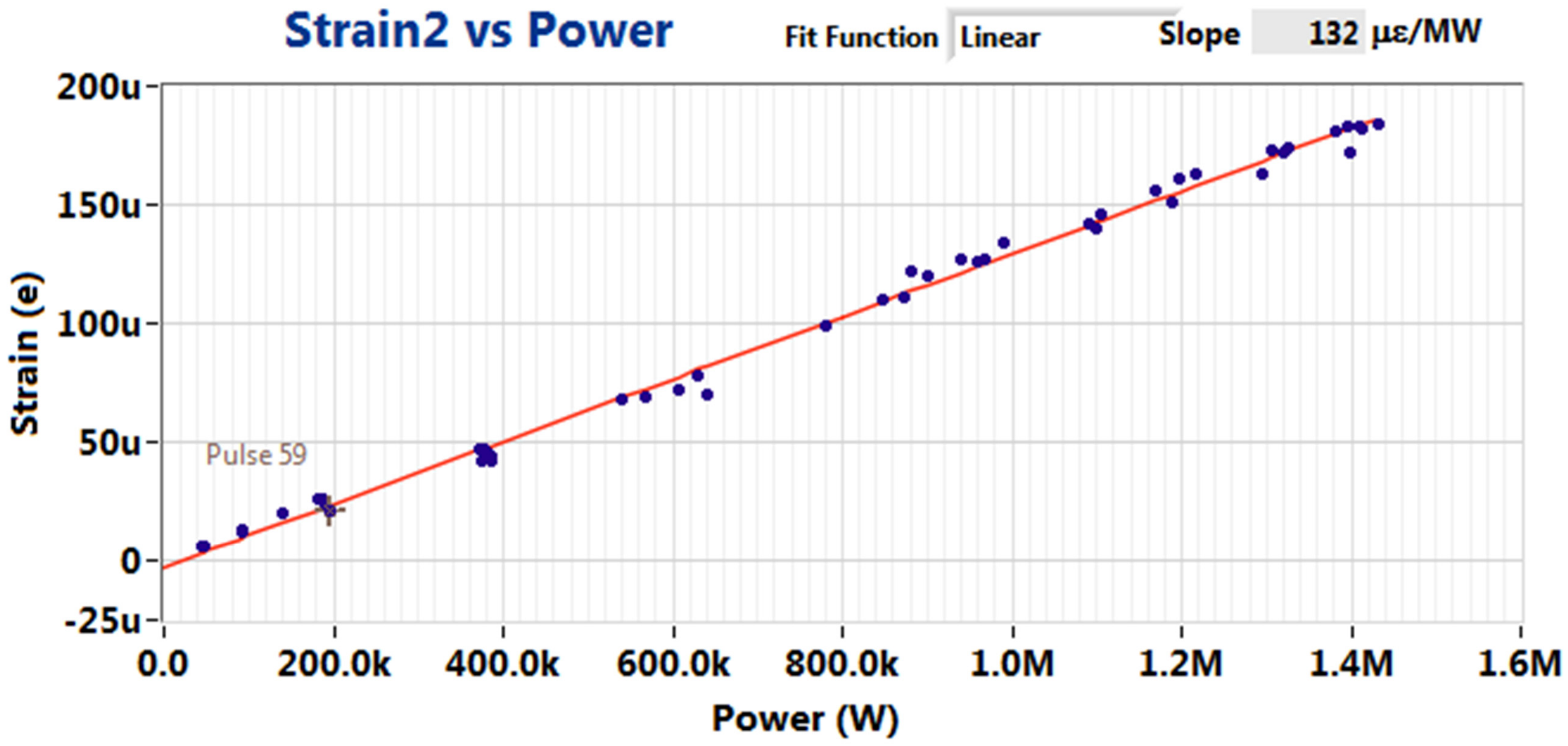
Pulse 12 at 6.4μC

Pulse 21 at 23.8μC

Consistent looking strain waveforms

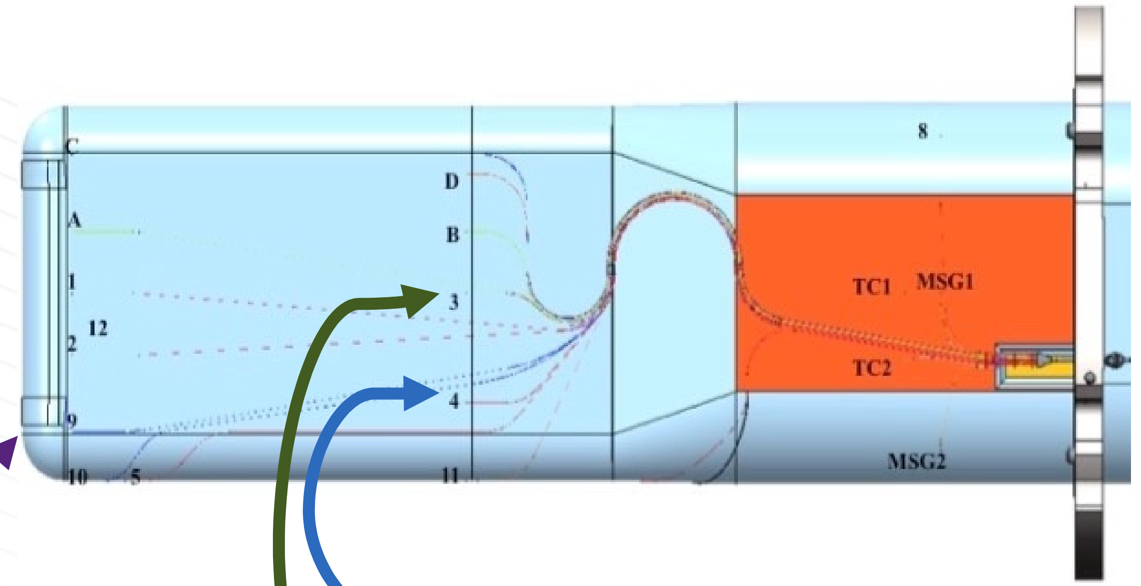


Mostly linear relationship between strain and beam charge



Is there a resonance?

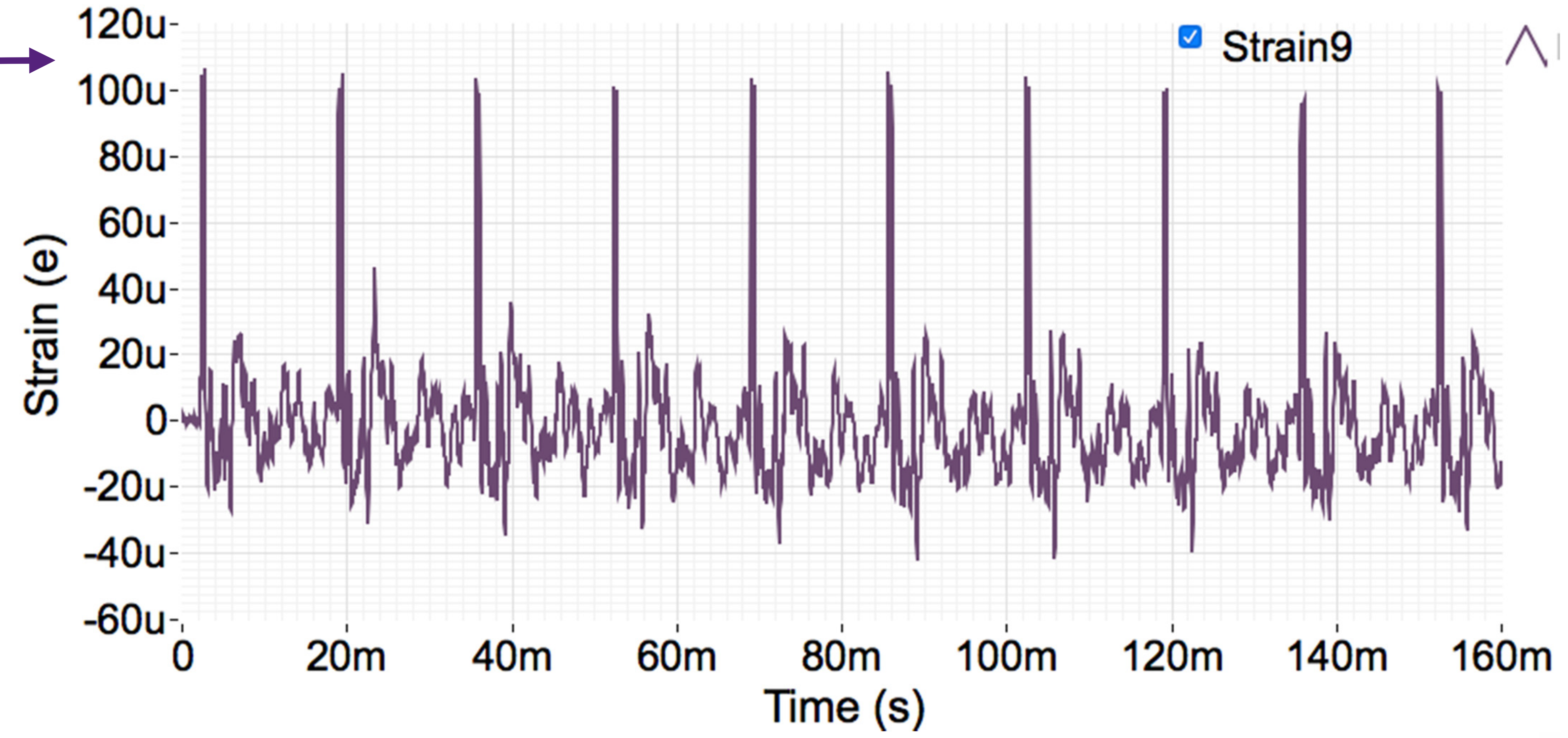
Sensor 9



Sensor 4

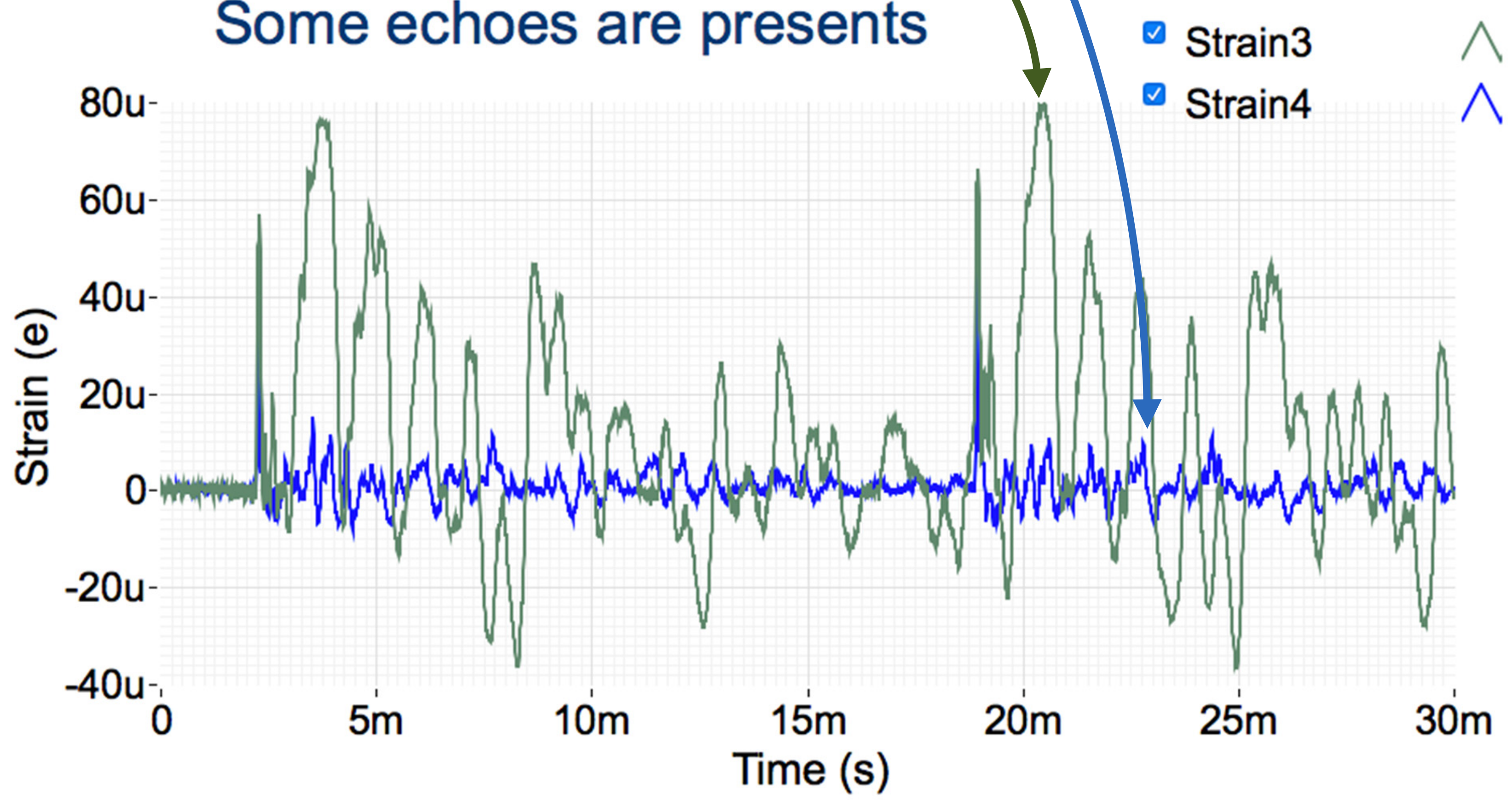
Sensor 3

10 Pulses in a row at 20.8 uC on strain 9



Signal repeats, no resonance detected

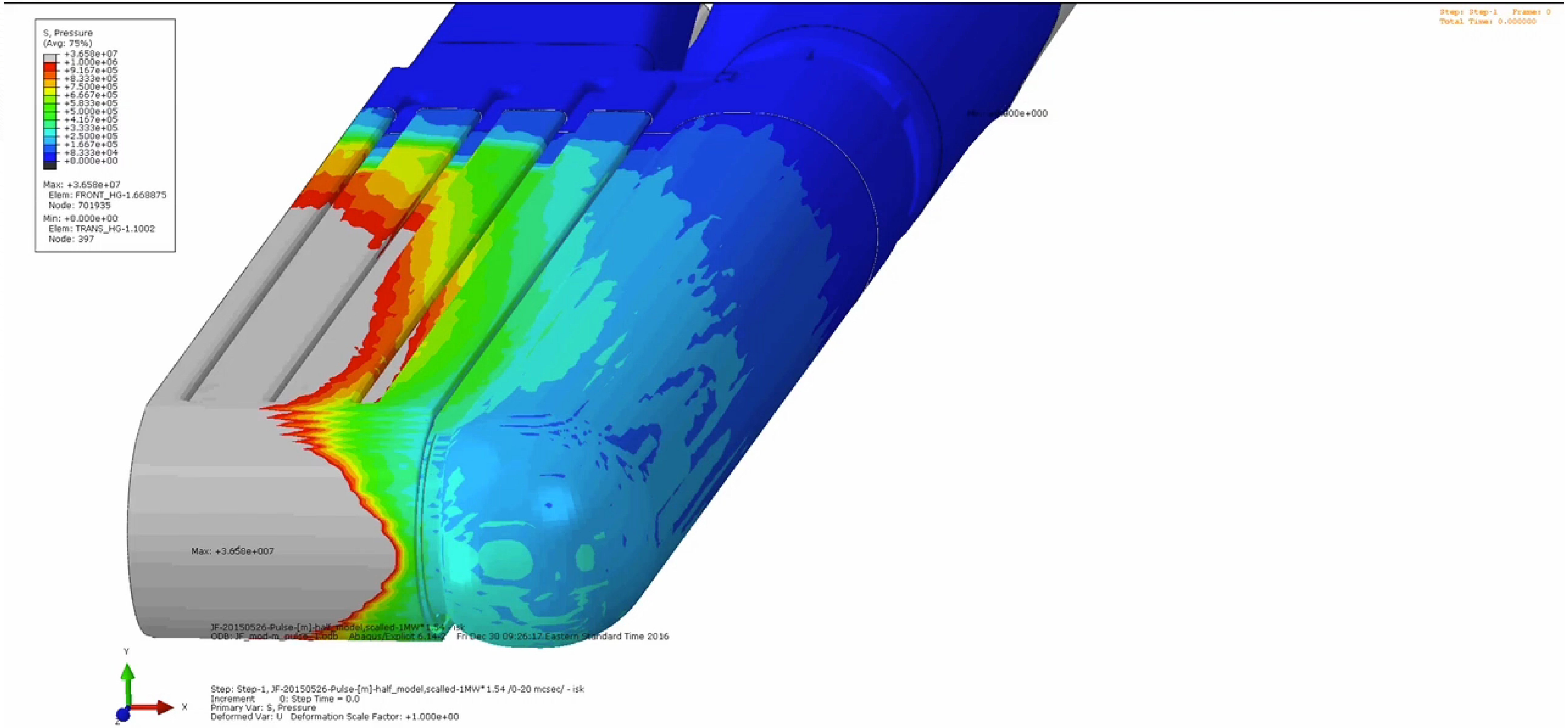
Some echoes are presents



Echoes, stronger in the locations in the back, especially near internal baffle

0.5 seconds of beam

Simulation of mercury pressure



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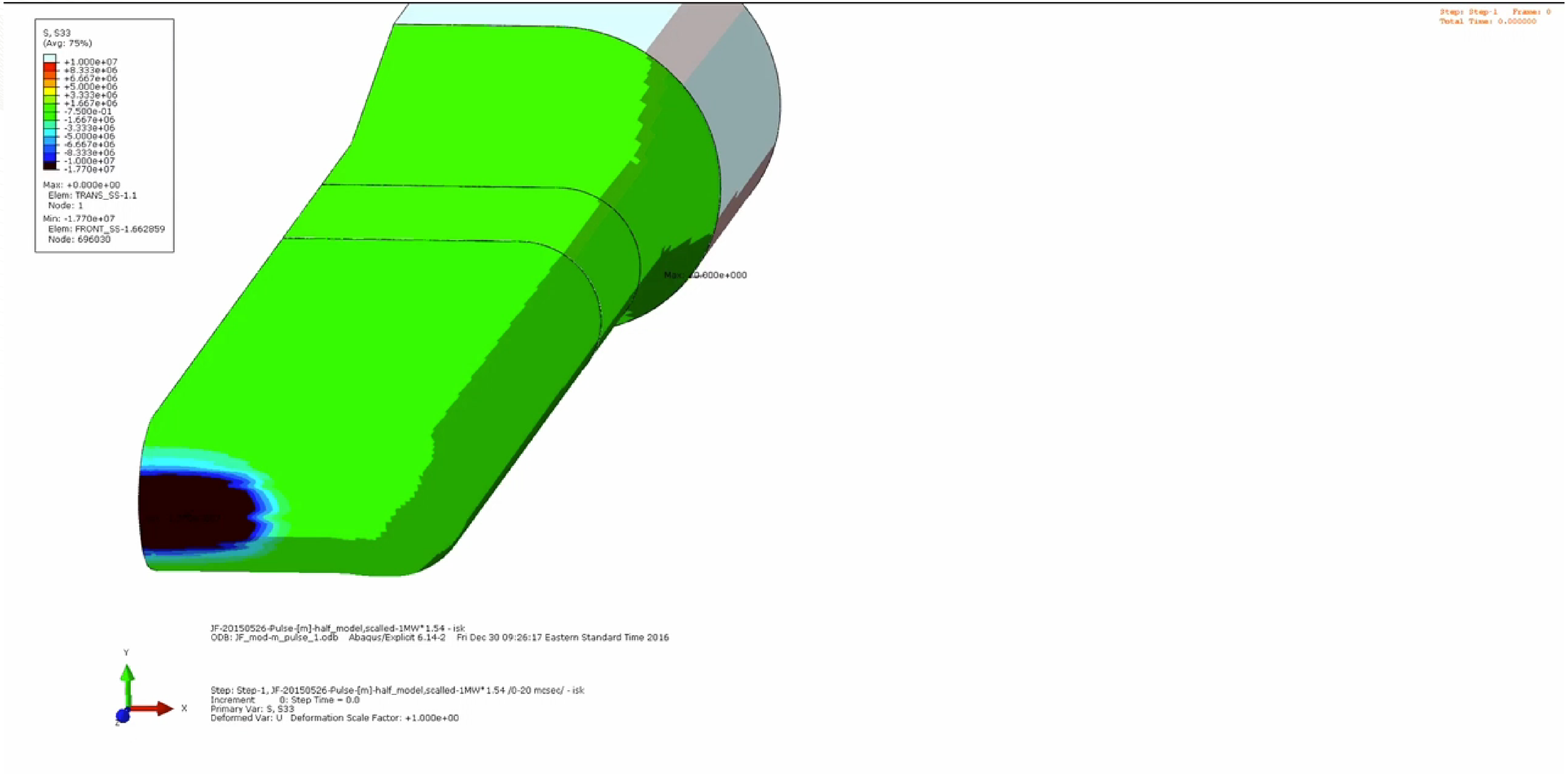
Simulation of strain on mercury vessel



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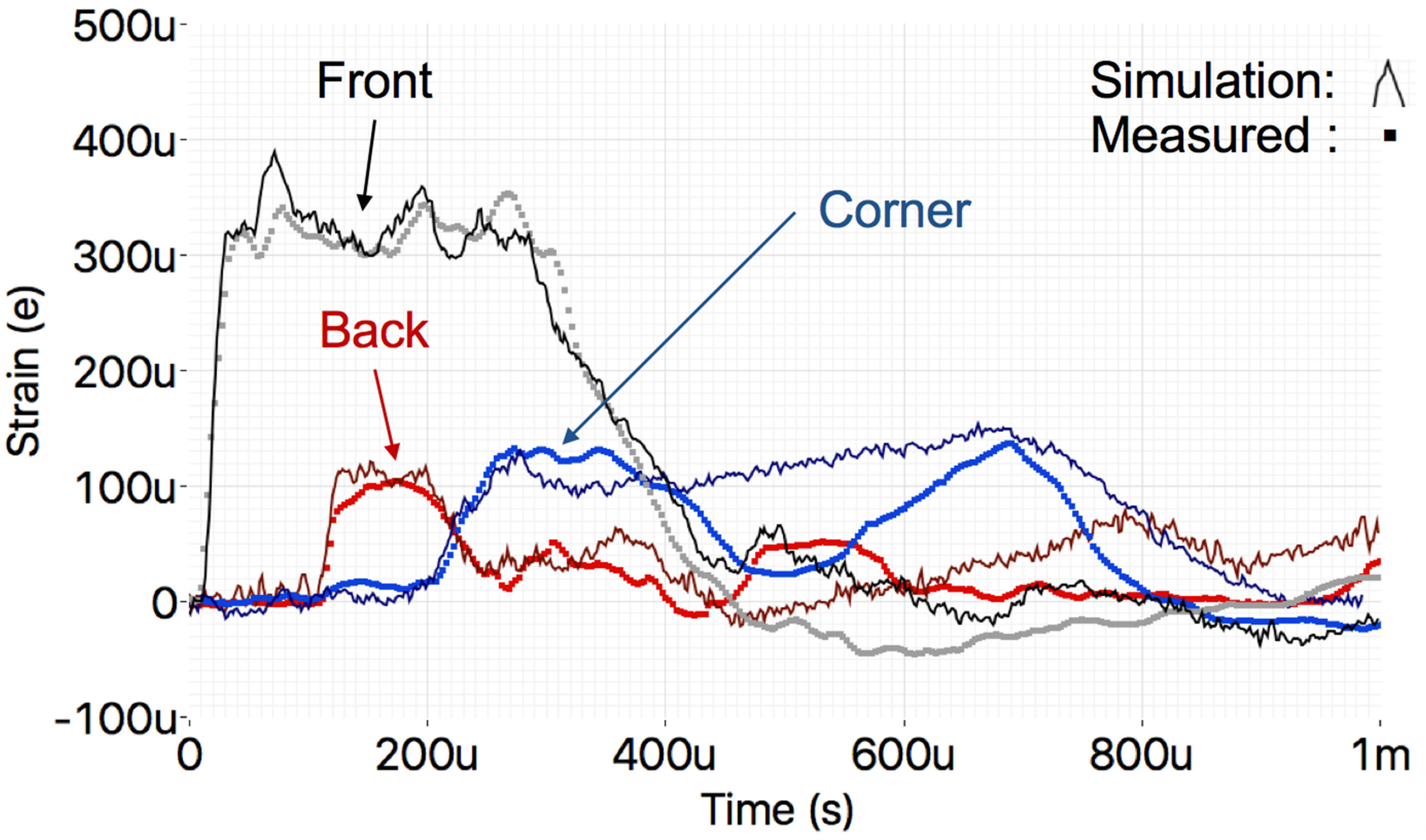
Do the measured and simulated strain agree?

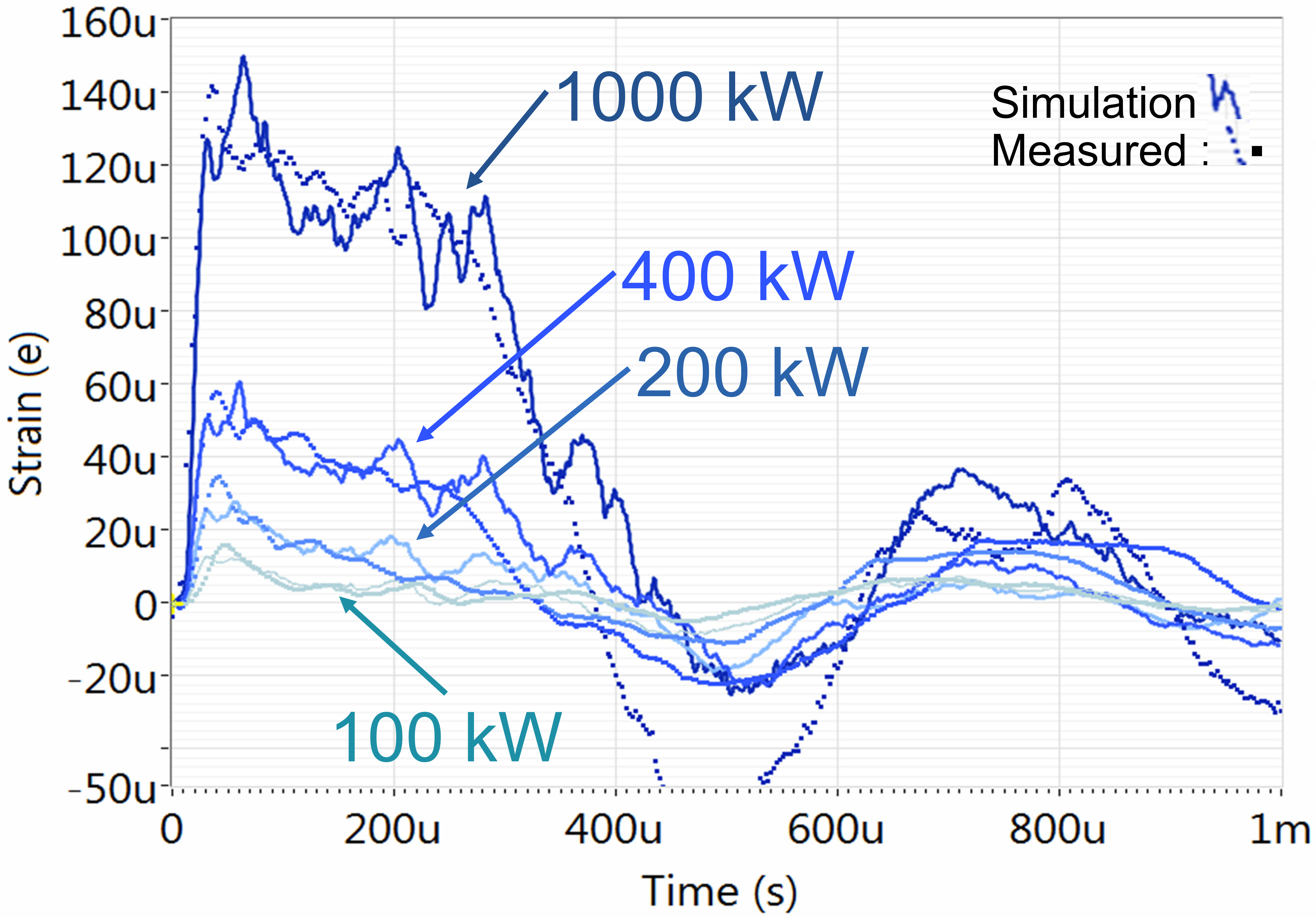
- The back sees the strain before the front corner as predicted by the simulation
- Waveforms are similar in amplitude and shape
  - Front locations agree best,
  - begin of waveform matches better than end



Comparing arrival times of strain waveform from T16 and simulation

Do the measured and simulated strain agree?

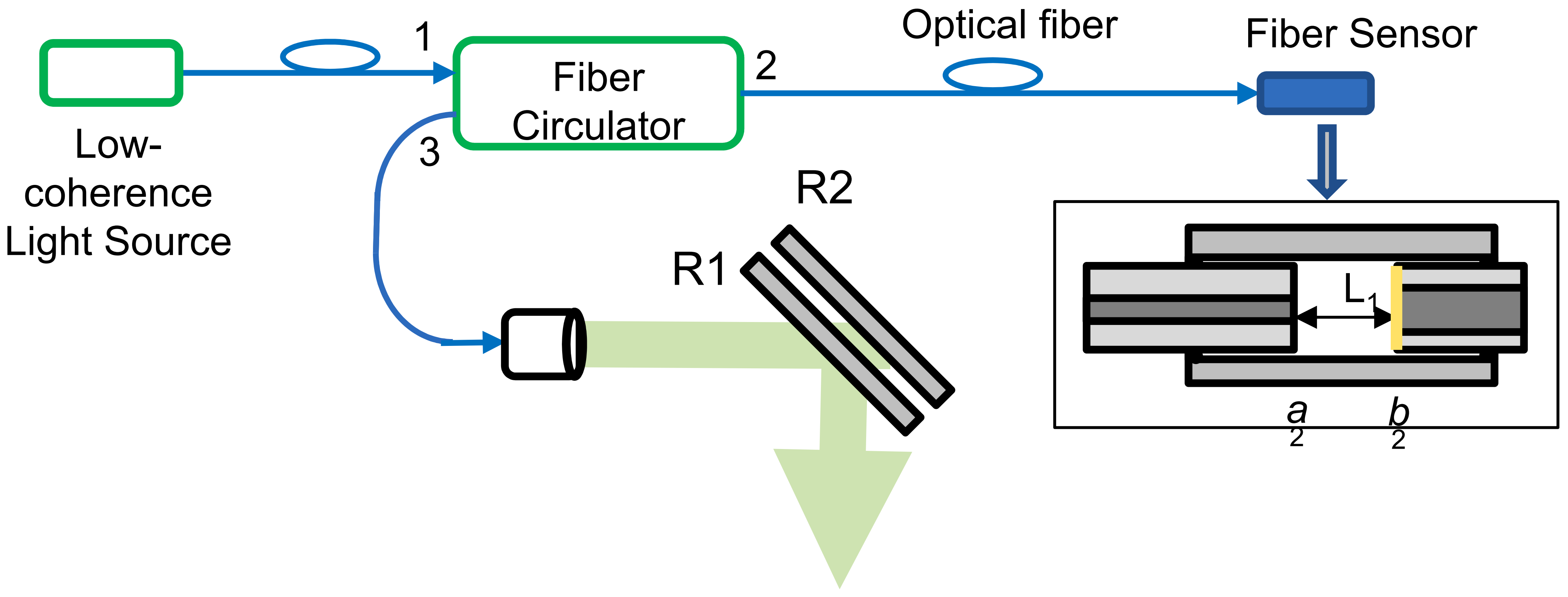
- As we change the beam power, we see that the simulated and measured both change in shape
- Often the front part of the waveform increases linearly with power but not the second part



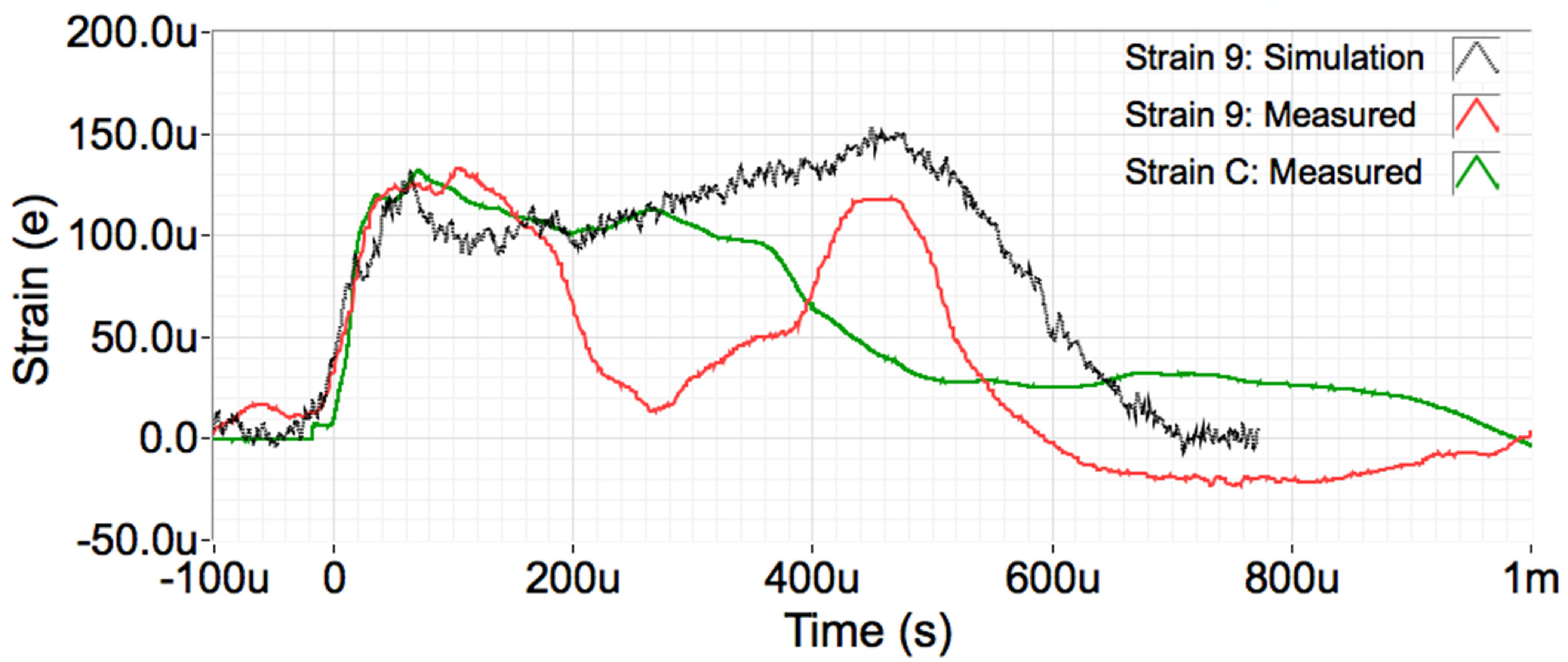
Strain waveforms for sensor 2 (front) for T15 and simulation

Single-mode sensor

- Prototype developed at SNS to get:
  - Longer lasting lifetime to see if we can detect structural failures
  - Higher bandwidth to see if we can detect cavitation
- Prototypes are working well:
  - Tested in lab with know strain setup
  - Similar waveforms as multi-mode sensors



Optical demodulator based on low-coherence light



Target 16 Strain from simulation, multi-mode, and single-mode sensor

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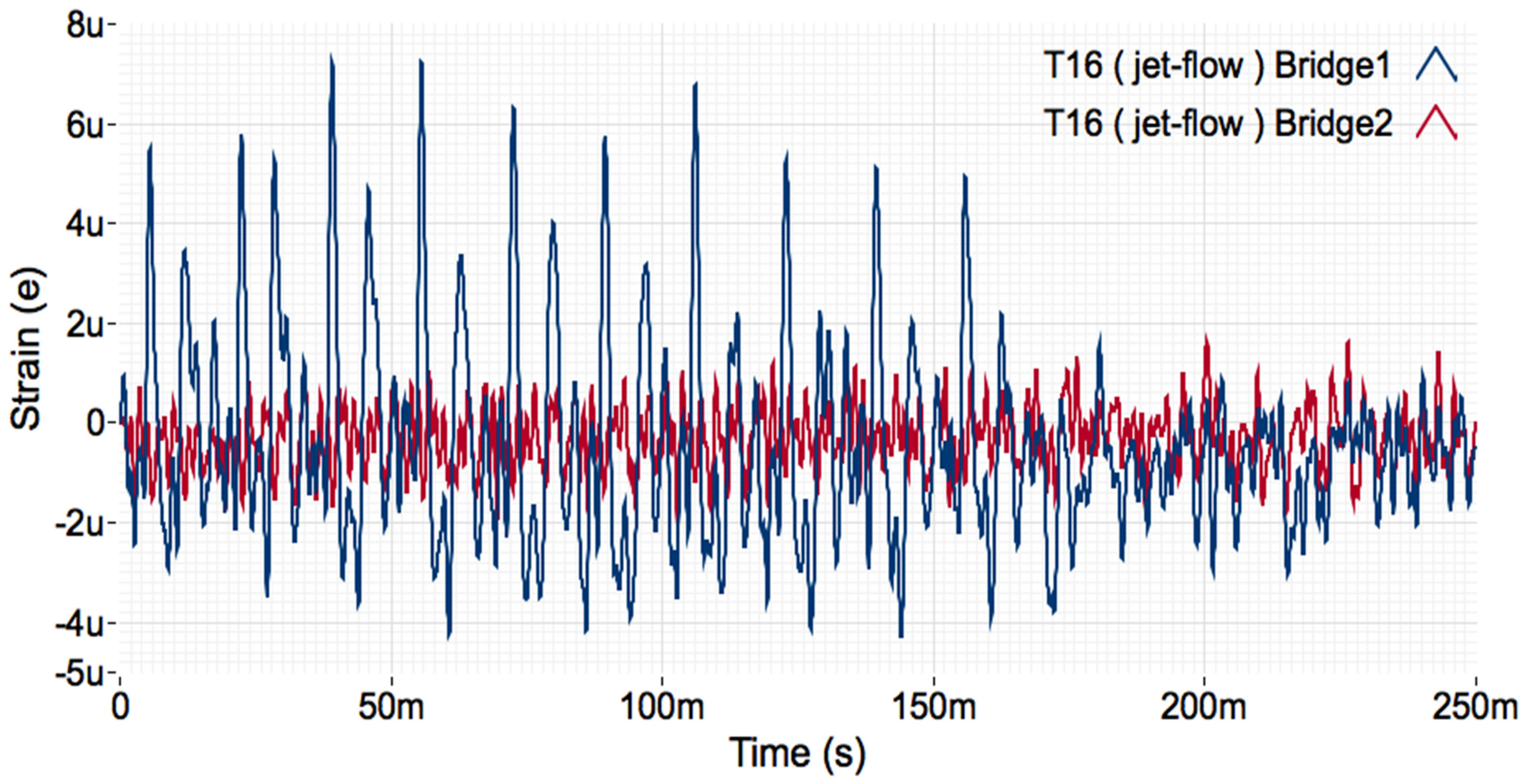
Metal strain sensors



Ten pulses in a row on the metal strain gauge

- Strain sensors are far in the back → low signal
- Need processing to see signal of a few microstrains
- Bandwidth is only about 5 kHz to start and around 1KHz after filtering

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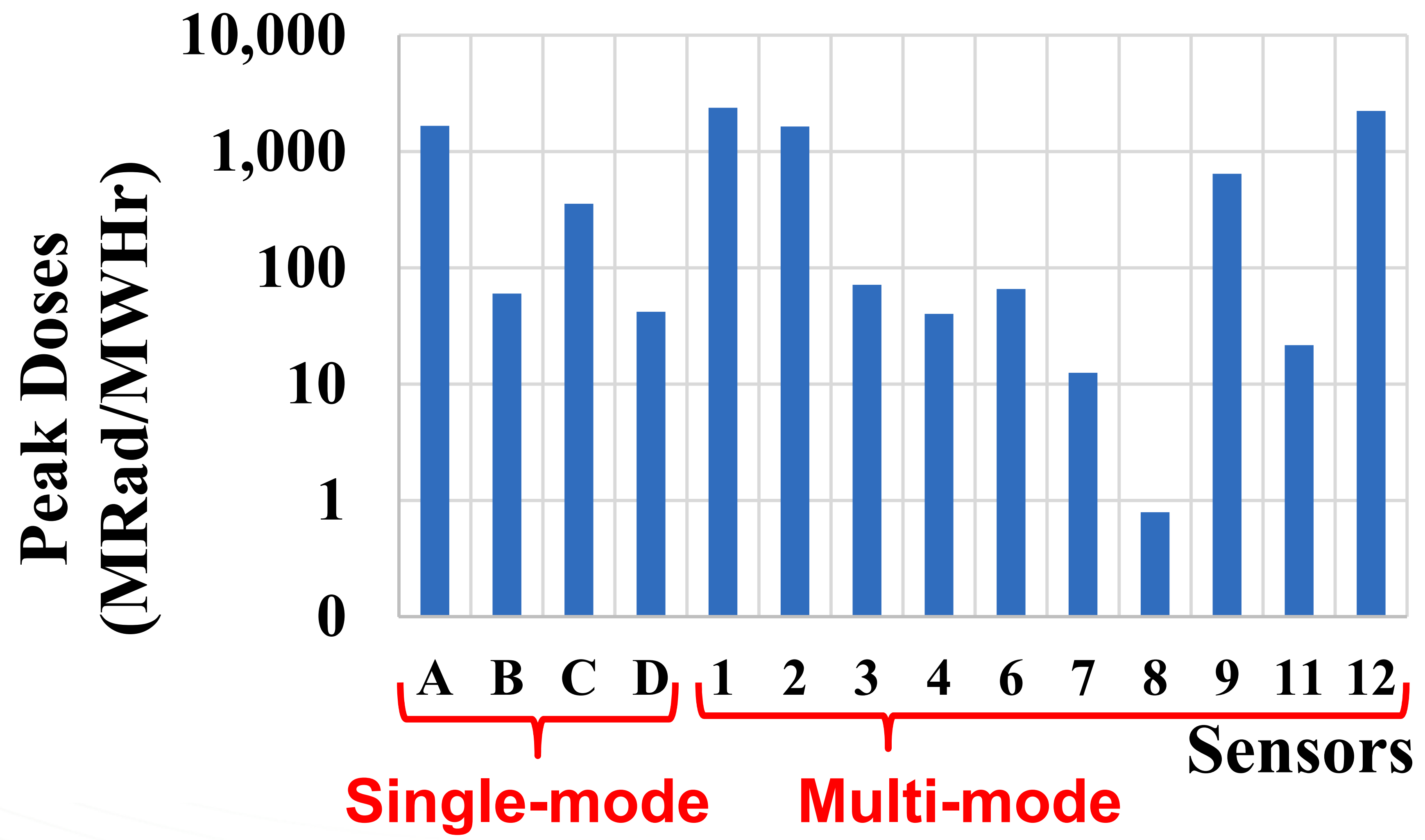
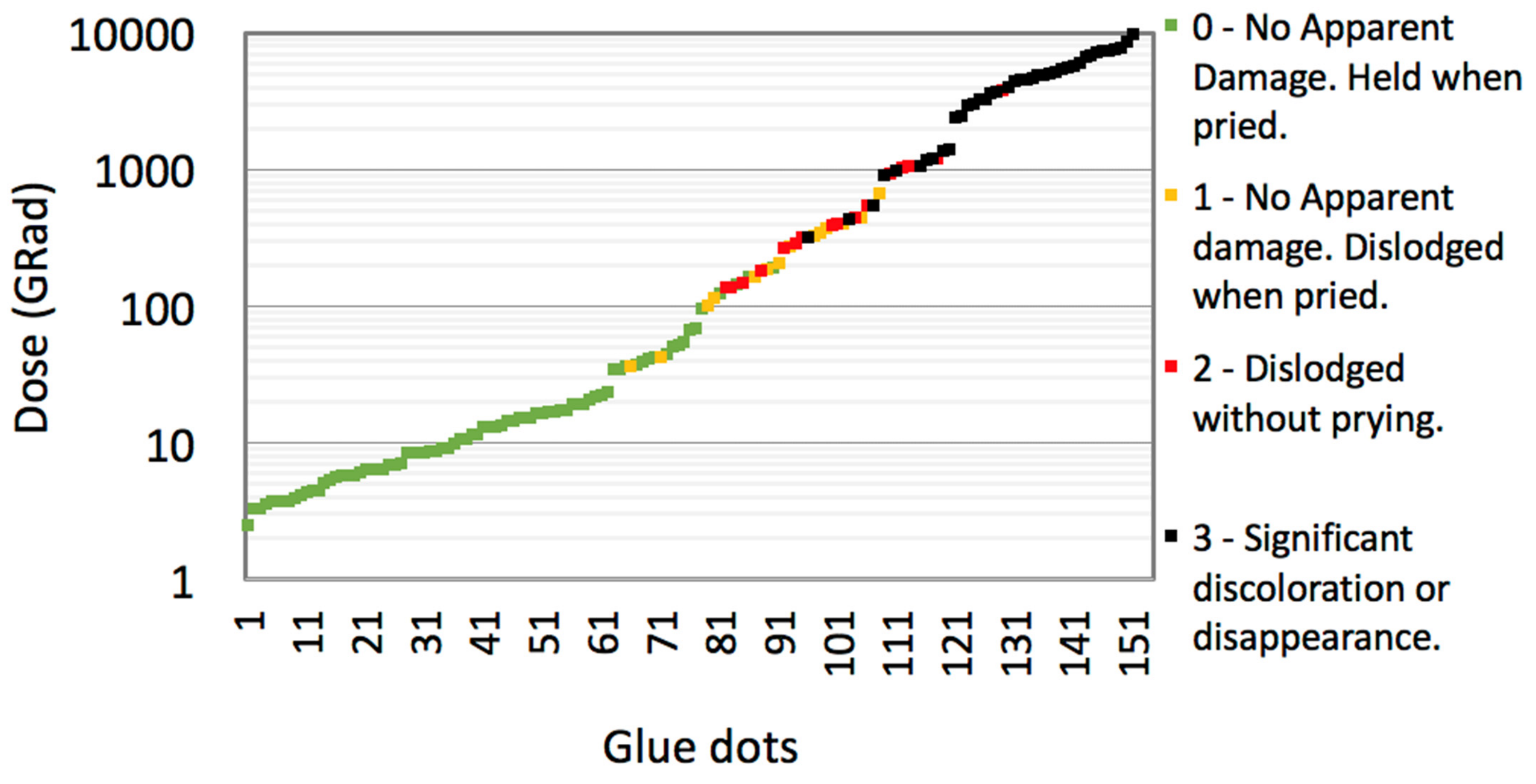
Radiation



T15 total radiation dose per sensor



T13 total radiation dose per glue dot

- High OH content rad-hard multi-mode sensors that last about 3.5 GRads (4 hrs up front)
- Super rad-hard single-mode sensors that last up to 120 GRads. That is 4 days at 1MW beam power in the front or about the lifetime of the target in the back for the single-mode
- The epoxy glue, Stycast 2850FT, is testing by trying to dislodge a drop of glue (along the optical fiber) and we found that it starts failing around 100 GRads

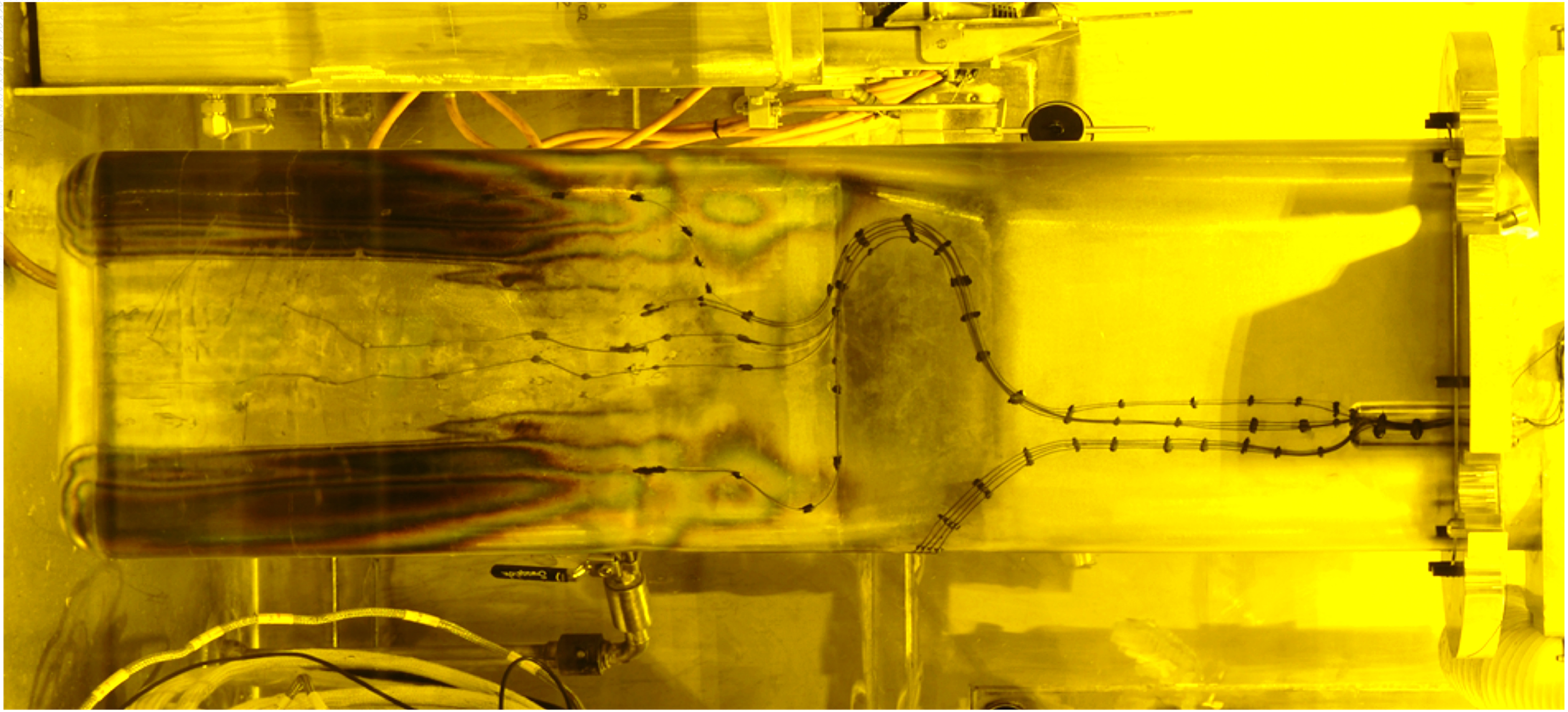
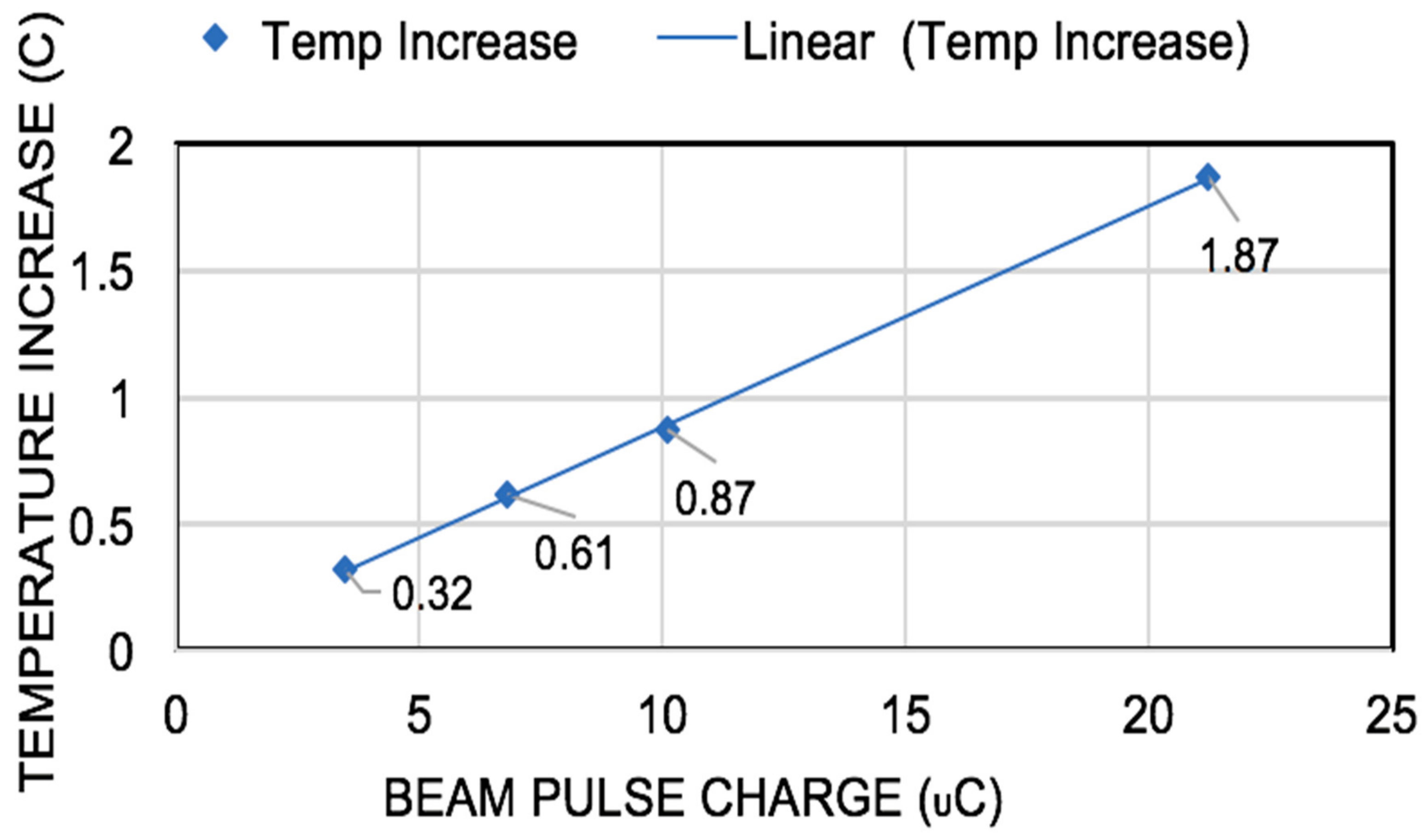
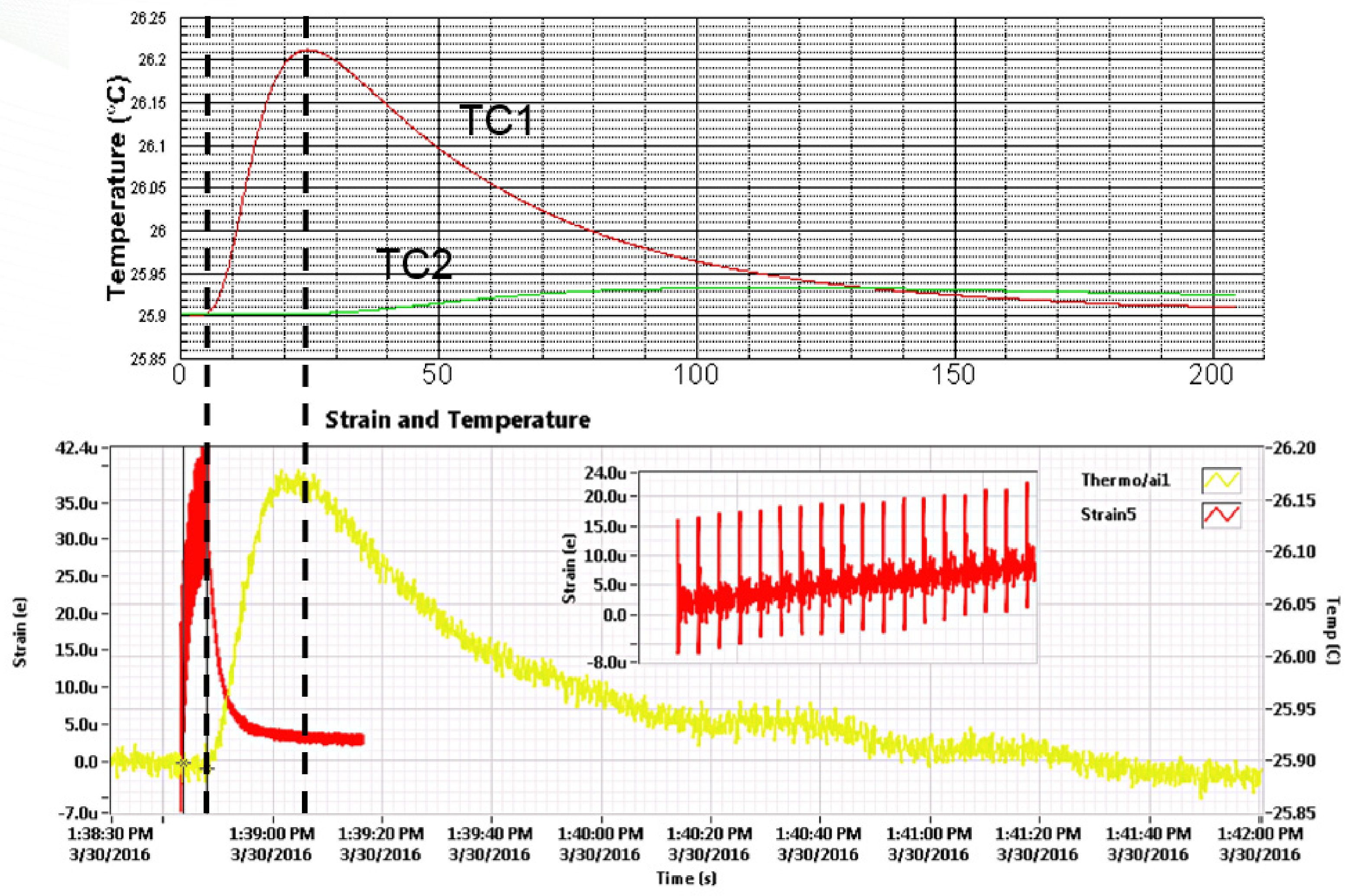


Image of the target mercury vessel after its production cycle

Temperature response



Temperature increase vs beam charge



600 pulses of 3.5 μC on sensor 5

- Instantaneous temperature increase is linear with deposited beam power (short burst of pulses)
- Temperature rise and cooldown over longer time agrees with simulations

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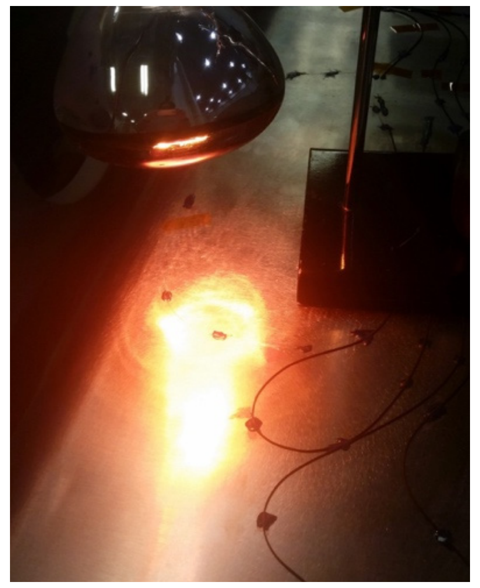
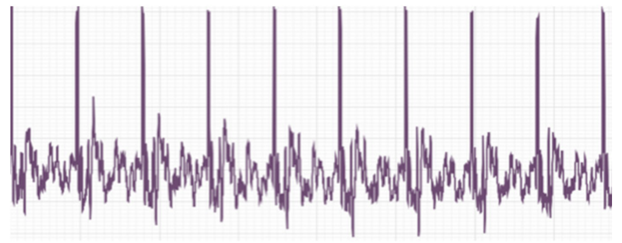
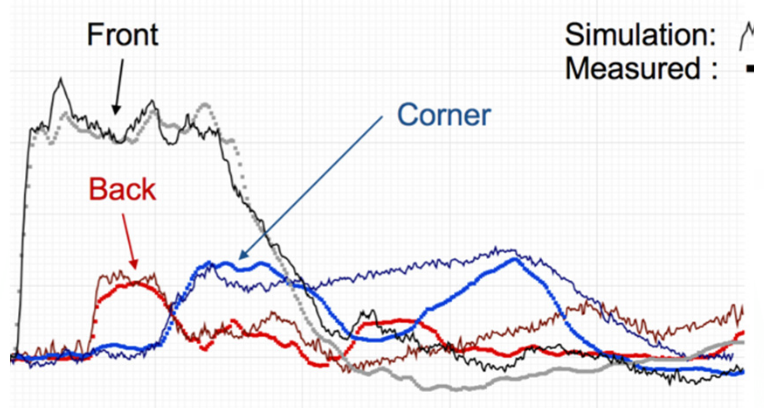
Summary



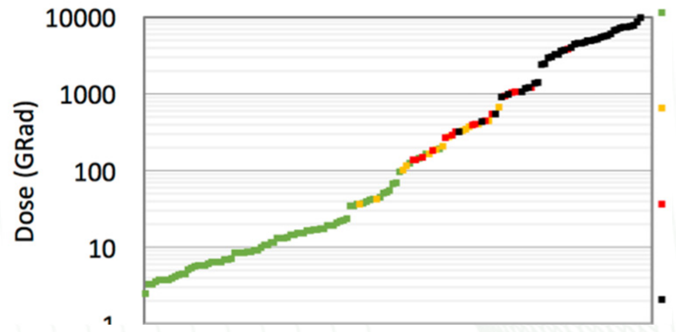
- We have now instrumented 4 targets and have been steadily improving our sensor installation process.
- No structural resonances found



- We have good similarities between the simulation and the measurements → proceed with more confidence in designing and building targets using the simulations as a guiding tool.



- Differences (later in the waveform) between the measurements and simulations are investigated to improve the simulations



- Single-mode sensor performs well and has much better radiation resistance but we need better glue
- We are ready to take measure the effectiveness of damage mitigation methods such as jet-flow and gas bubble injection