Commissioning Beam-Loss Monitors for the Superconducting Upgrade to LCLS

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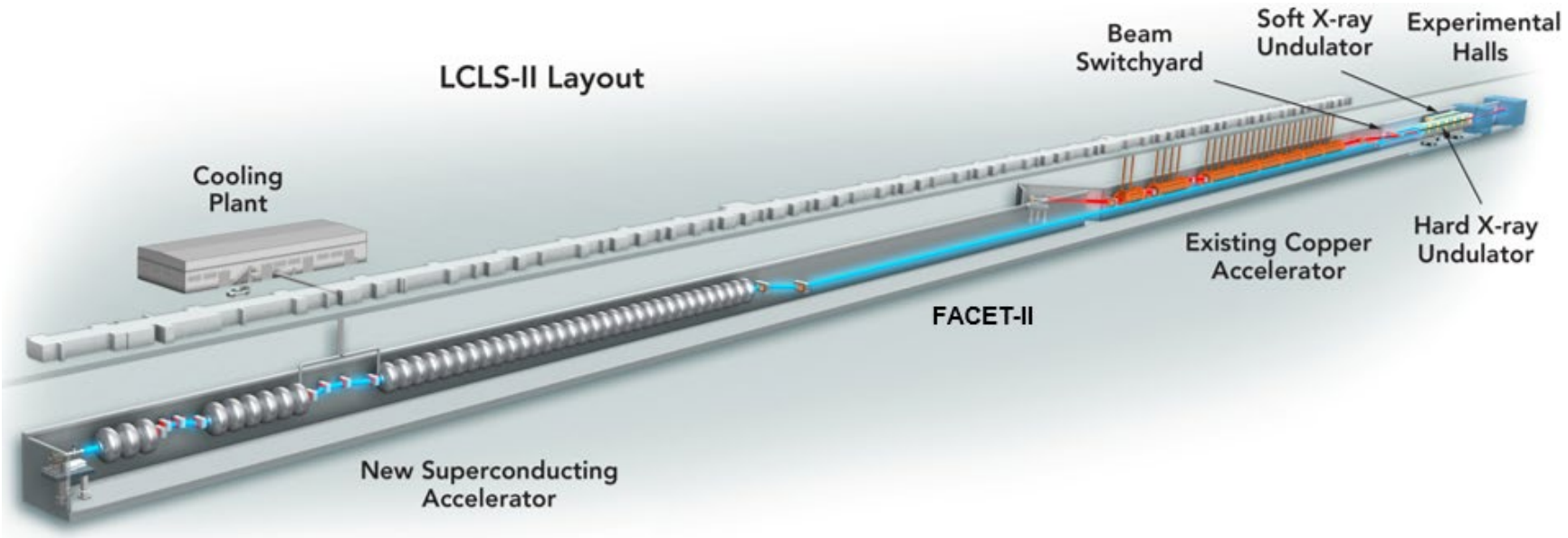
U.S. DEPARTMENT OF ENERGY | Stanford University

SLAC NATIONAL ACCELERATOR LABORATORY

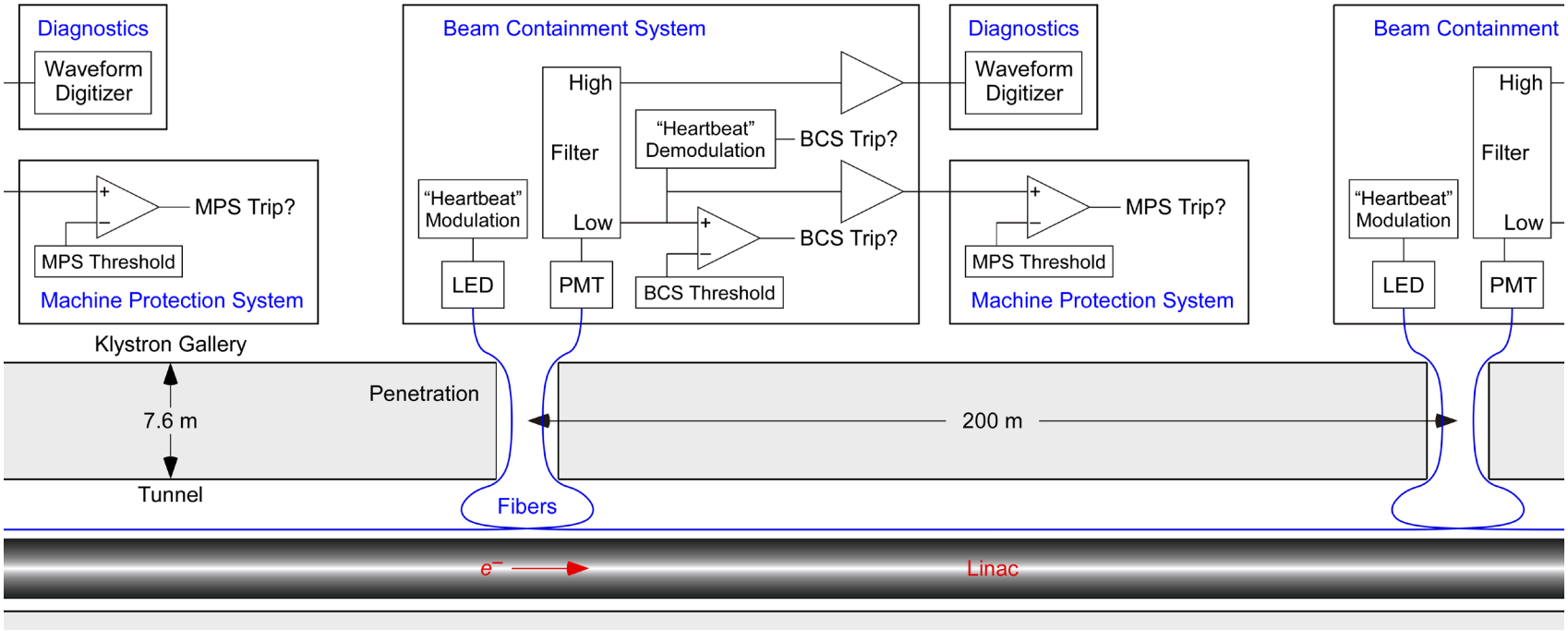
LCLS-II and the SLAC 3-km Linac



Commissioning of the Superconducting Linac and New BLMs

- Commissioning the linac
  - June 2022: Beam through the first cryomodule CM01 (also called L0B) to 100 MeV
  - October 2022: Beam through the full linac to 4 GeV
- Commissioning the beam-loss monitors
  - Average power of up to 120 kW at a maximum rate of 1 MHz (CW)
    - Ion pile-up from high loss could blind our usual ionization chambers
  - Instead, two newer types of BLMs
    - Long BLMs: Cherenkov emission in radiation-hard quartz optical fibers
      - Covering extended regions, typically 200 m
    - Point BLMs: Diamond detectors, covering expected loss points
  - I will present commissioning results only from the first few LBLMs
    - Most PBLMs are at 4 GeV

Layout of the Long Beam-Loss Monitors (LBLMs)



BCS = Beam Containment System

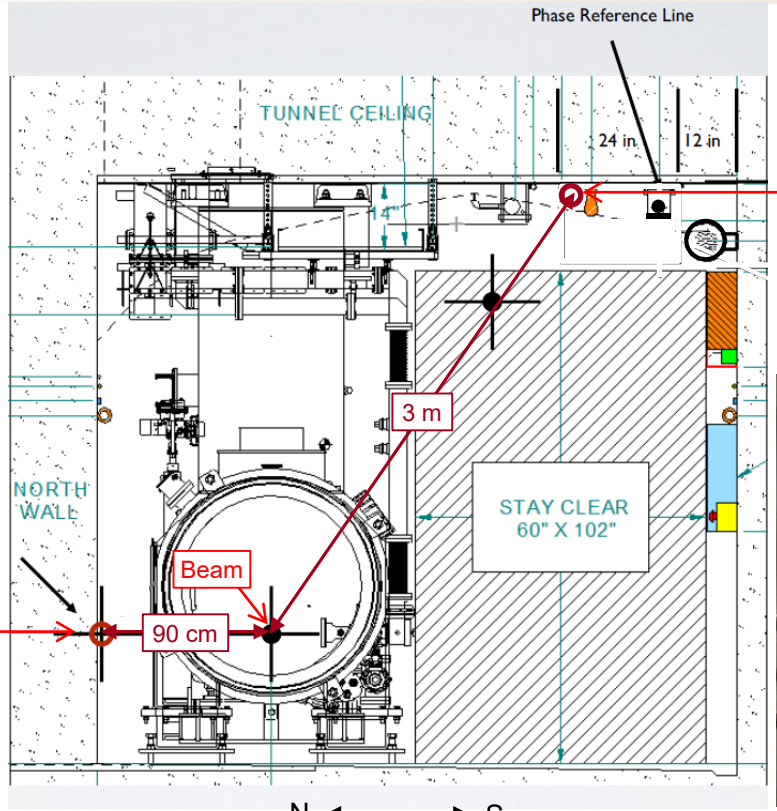
- Protects people and radiation-safety devices
- Shutters photocathode laser, stops RF to cryomodule 1

MPS = Machine Protection System

- Protects accelerator hardware
- Stops the photocurrent or reduces its rate

LBLM Positions along the Linac

LBLM A-chain fiber:
On north wall
at beam height,
90 cm from beam



LBLM B-chain fiber:
On ceiling,
3 m from beam

“Heartbeat” for Continuous Self-Checking

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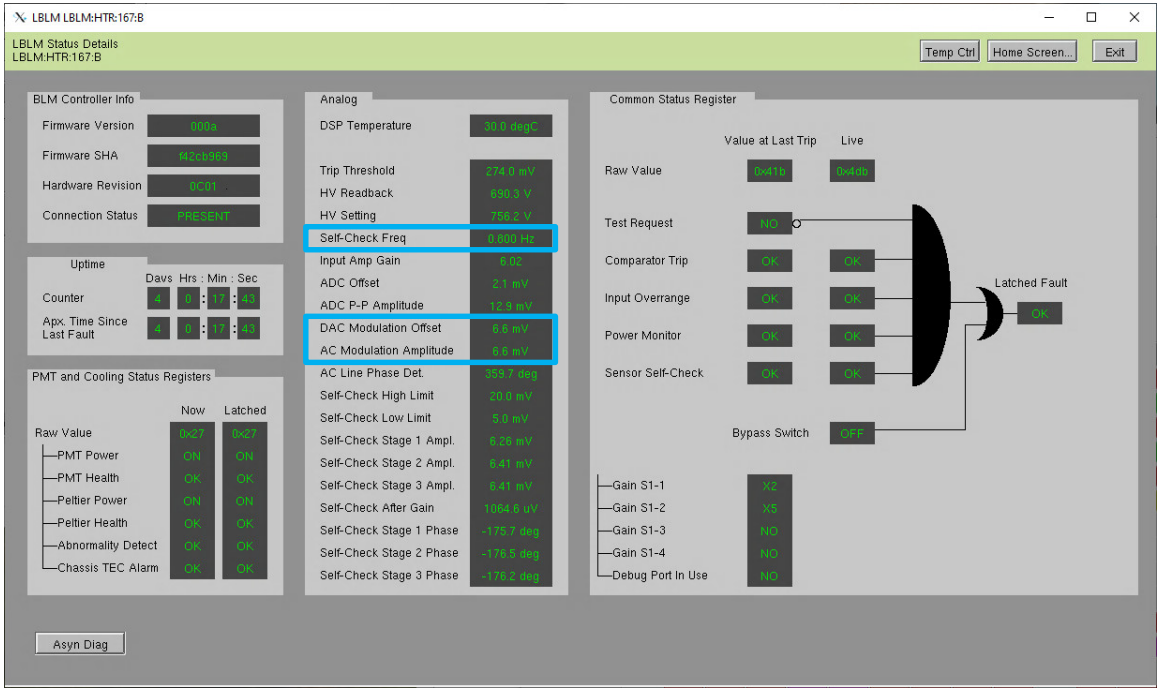
- LED modulated at 0.8 Hz sends weak light to the PMT through the fiber



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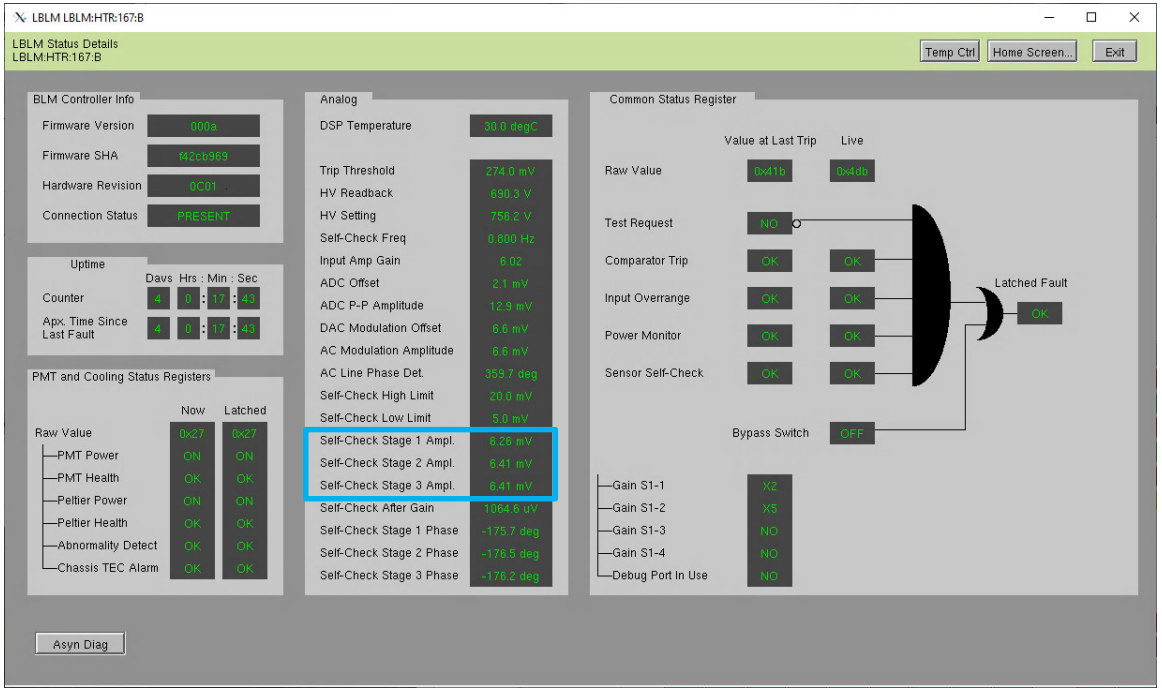
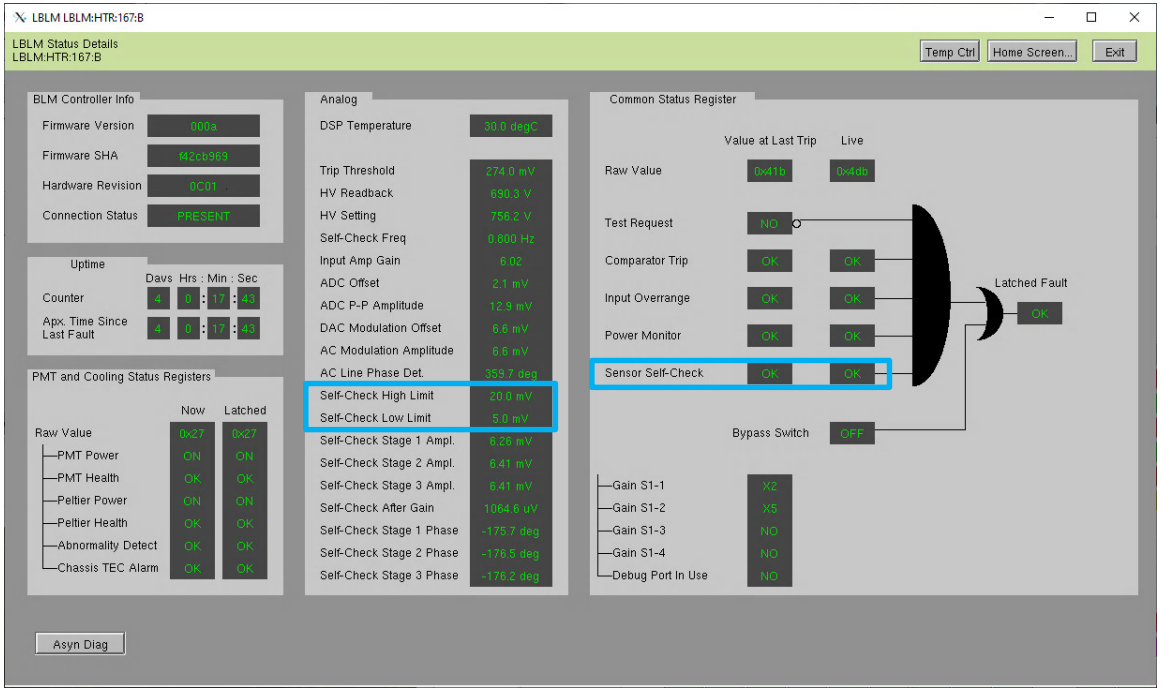


“Heartbeat” for Continuous Self-Checking

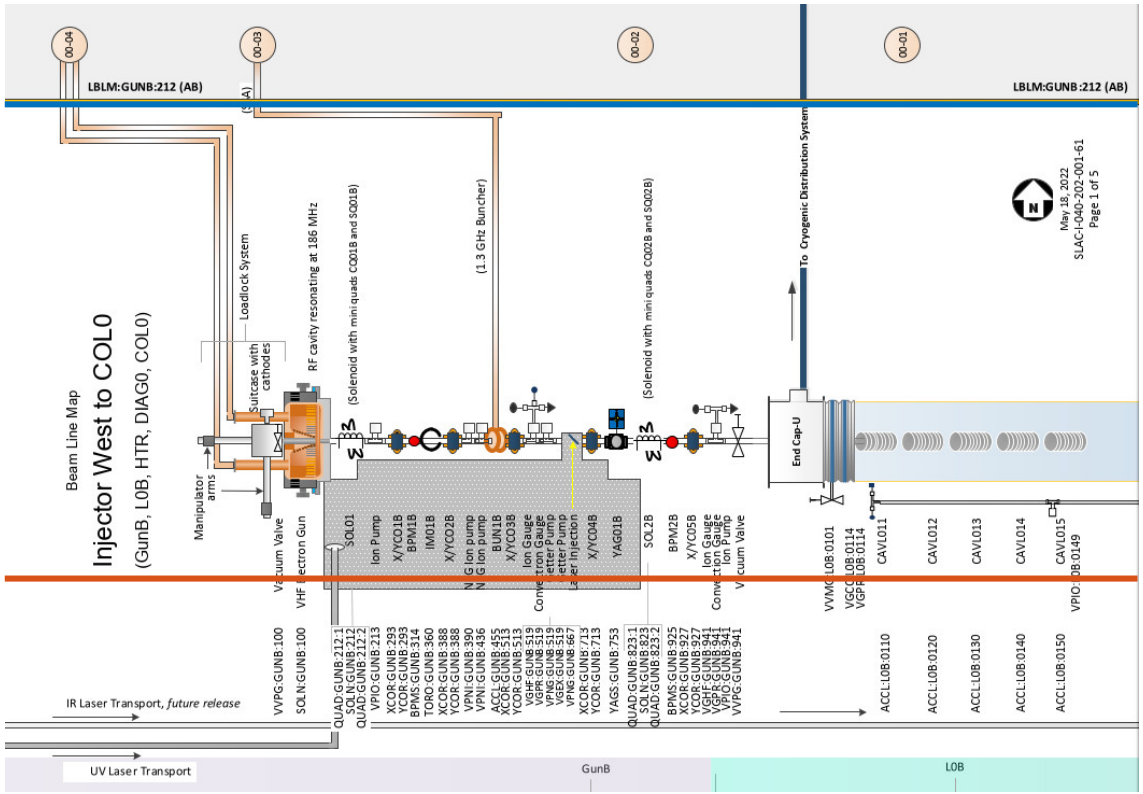
- LED modulated at 0.8 Hz sends weak light to the PMT through the fiber
  - DSP demodulates using the algorithm of a digital lock-in amplifier
- Beam will trip if the fiber breaks, the HV for the PMT fails, radiation raises fiber attenuation…
  - Trips in about 3 minutes



LBLM Locations: Gun to Cryomodule CM01

LBLM:GUNB:212:A

LBLM:GUNB:212:B



A-chain fiber:
On north wall
at beam height,
90 cm from beam

B-chain fiber:
On ceiling,
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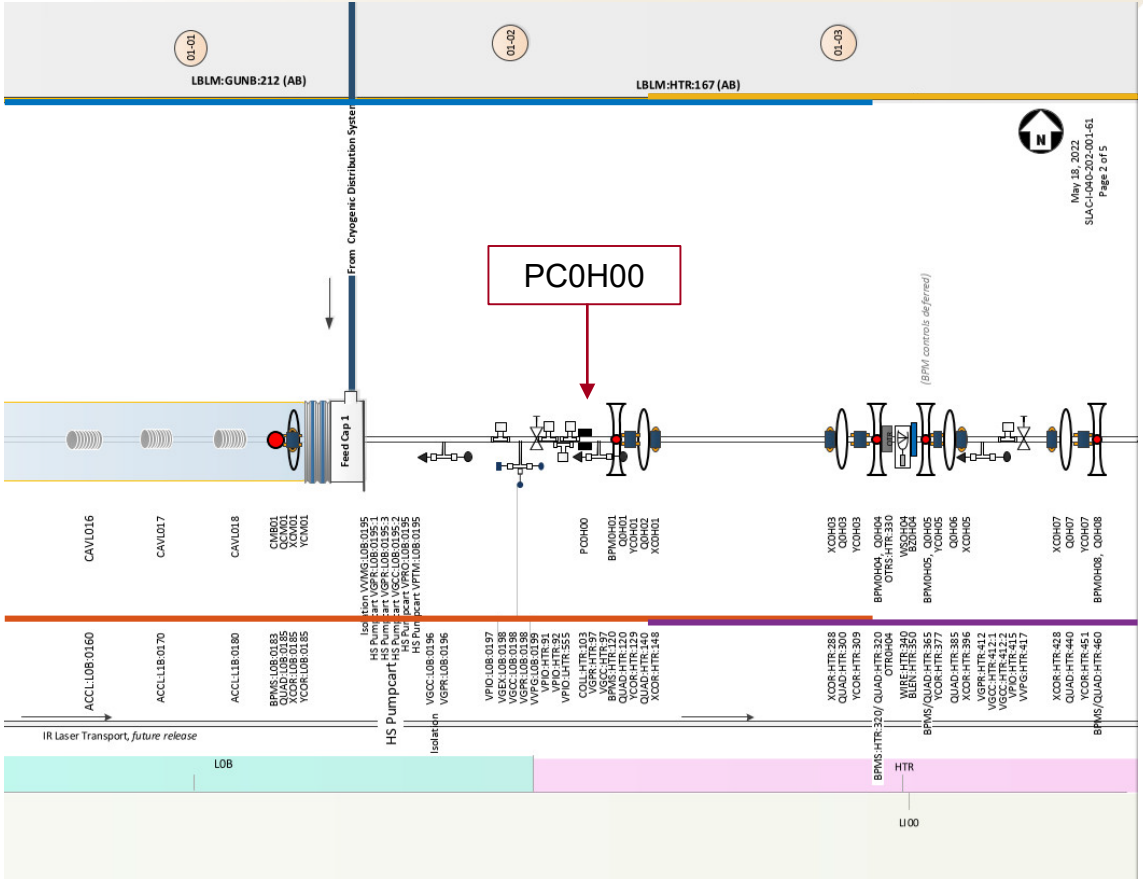

LBLM:HTR:167:A

LBLM:HTR:167:B

LBLM Locations: Heater to Diagnostic Beamline

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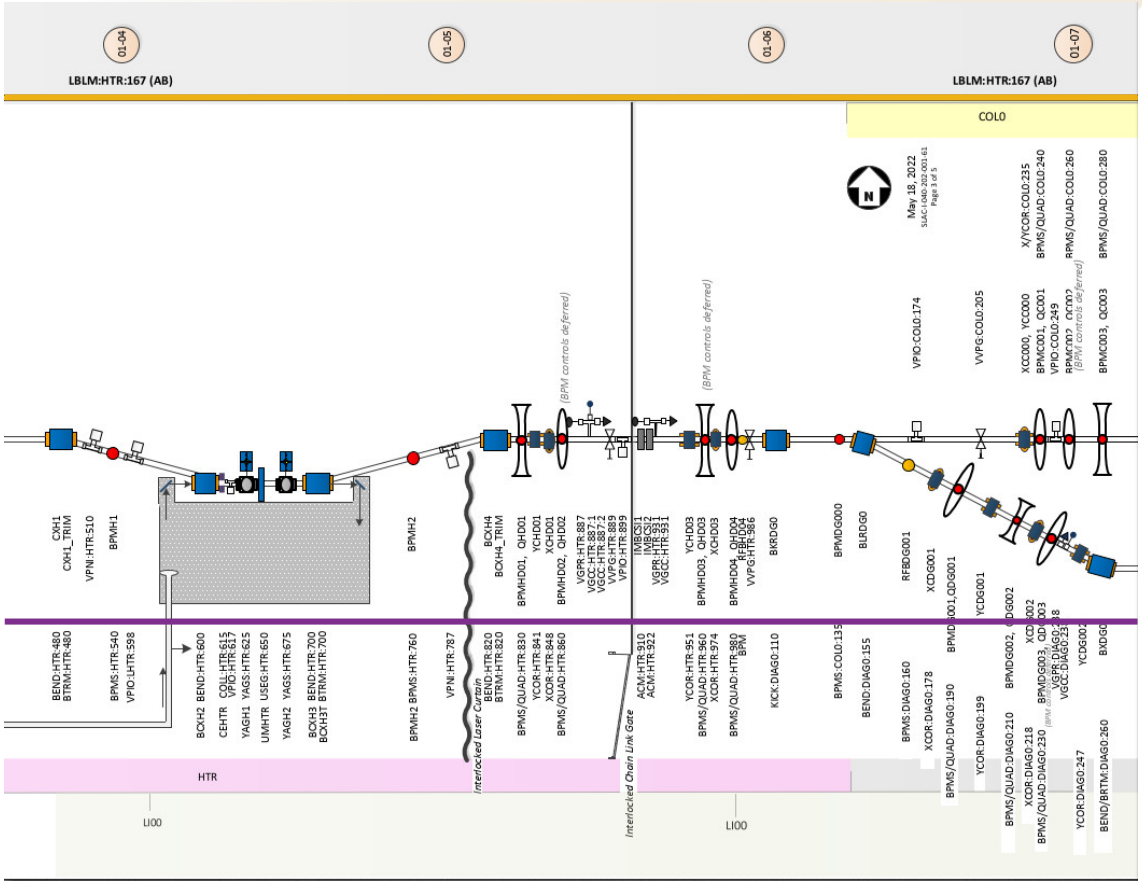

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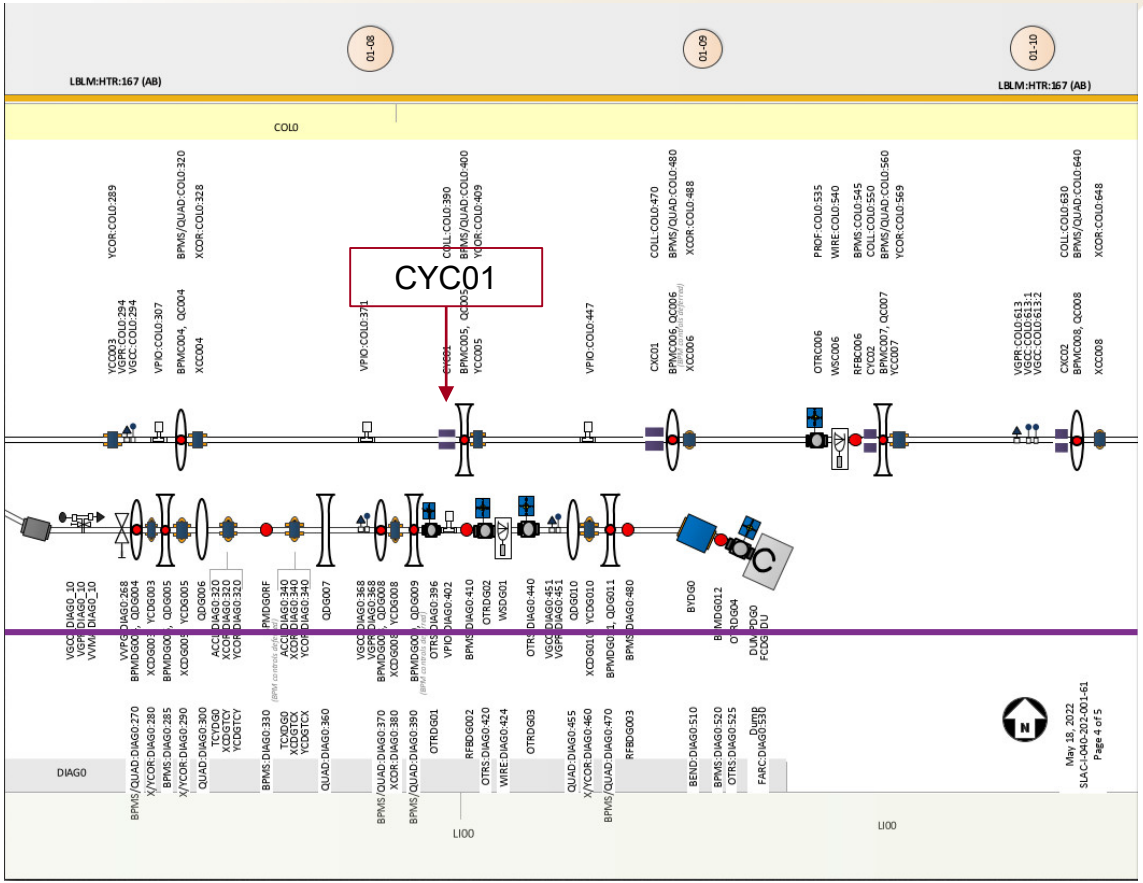
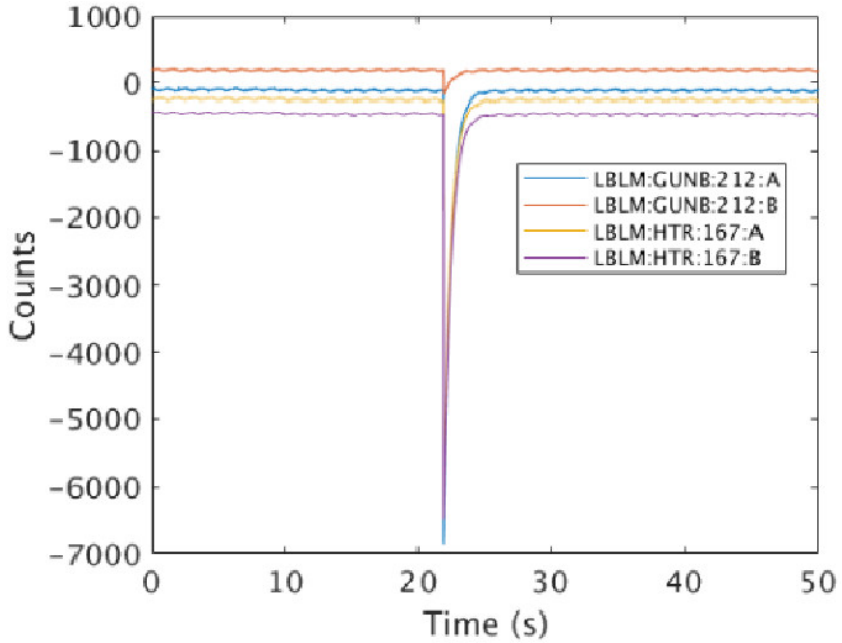


CYC01 collimator: Locked closed to stop beam during commissioning

Response to a Burst of Bunches

- Each bunch 220 pC, 80 MeV → 17.6 mJ
- 500 bunches with 2-μs spacing → 8.8 J
  - Abrupt start, 500-ms *RC* decay



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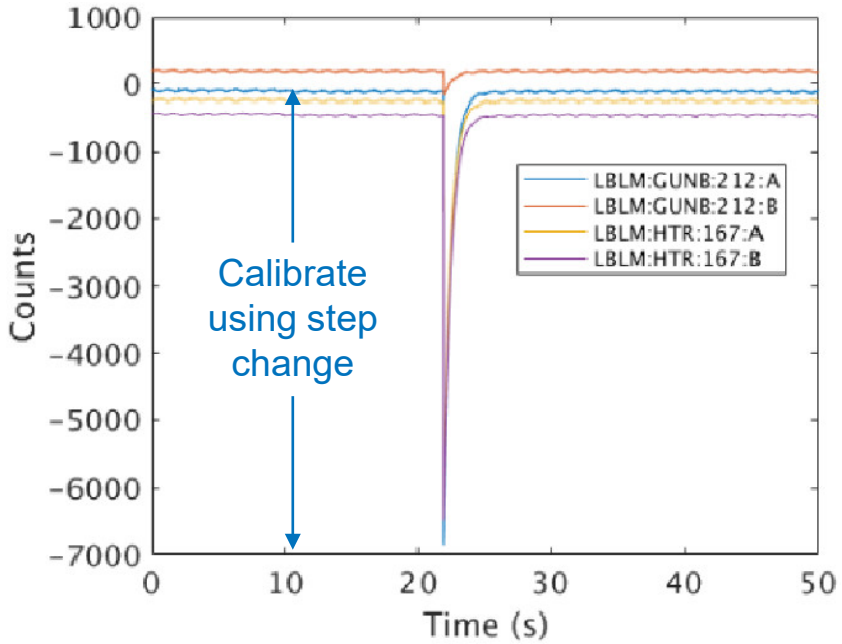

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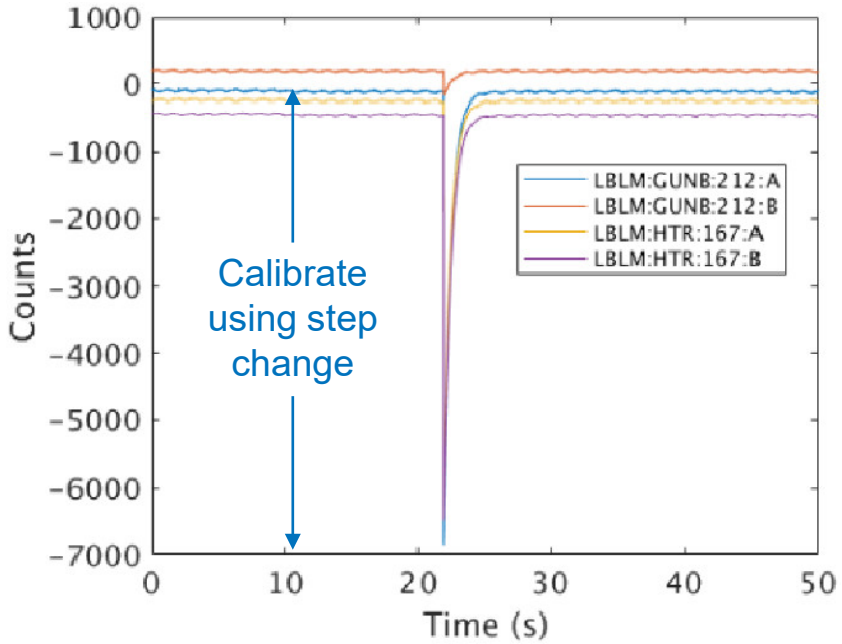
  - Calibrate with the step change from baseline to peak
- Baseline consists of:
  - Constant BCS self-check at 0.8 Hz
  - Offset of each ADC channel
    - ADC acquires data for MPS and EPICS
    - BCS does not use the digitizer
    - MPS will soon measure offsets and subtract
  - Dark current (largely from the gun)
    - Often strong, depending on settings…

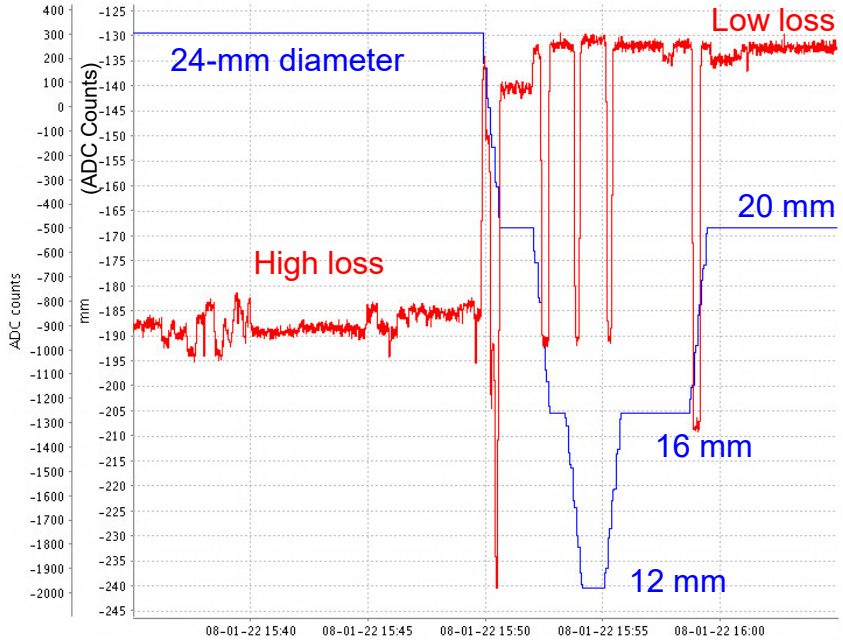


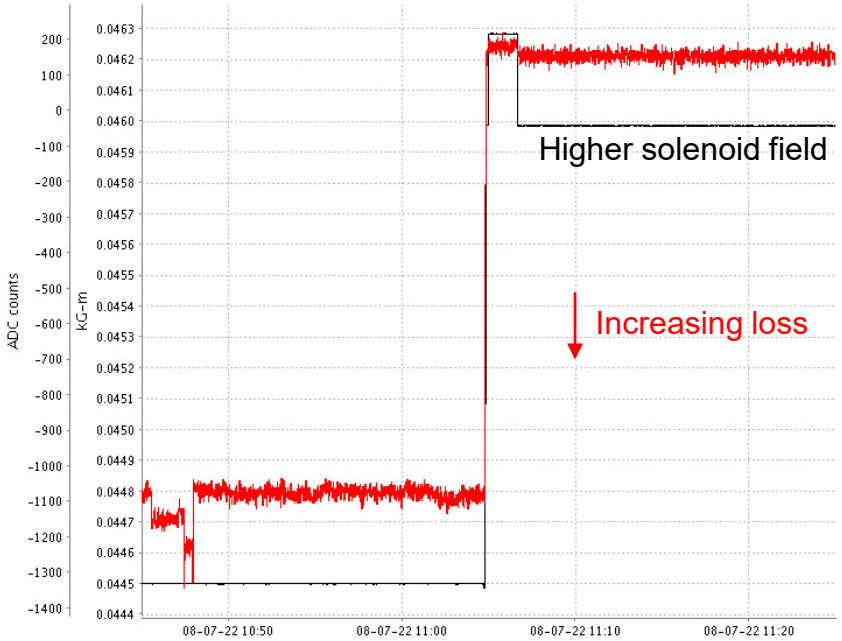
LBLM Responds to Gun Dark Current

Collimating apertures before CM01
(motor position)

LBLM:HTR:167:B

Focusing
solenoid at gun

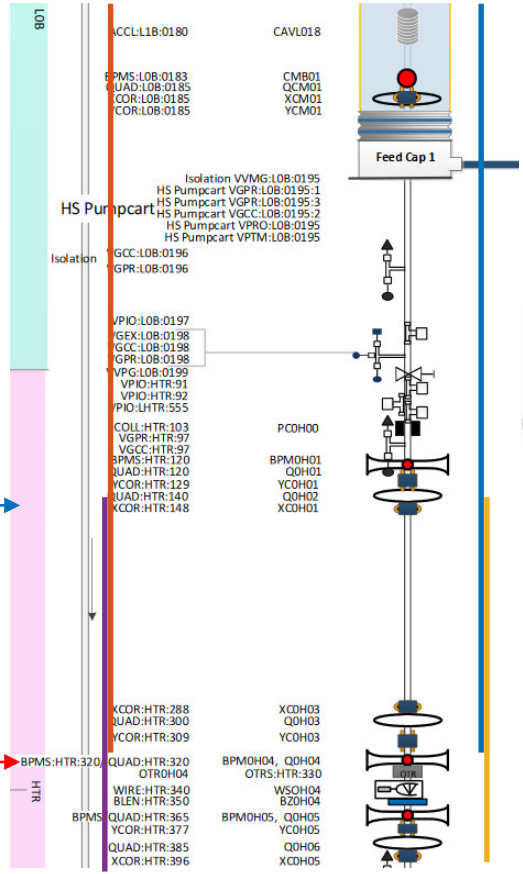


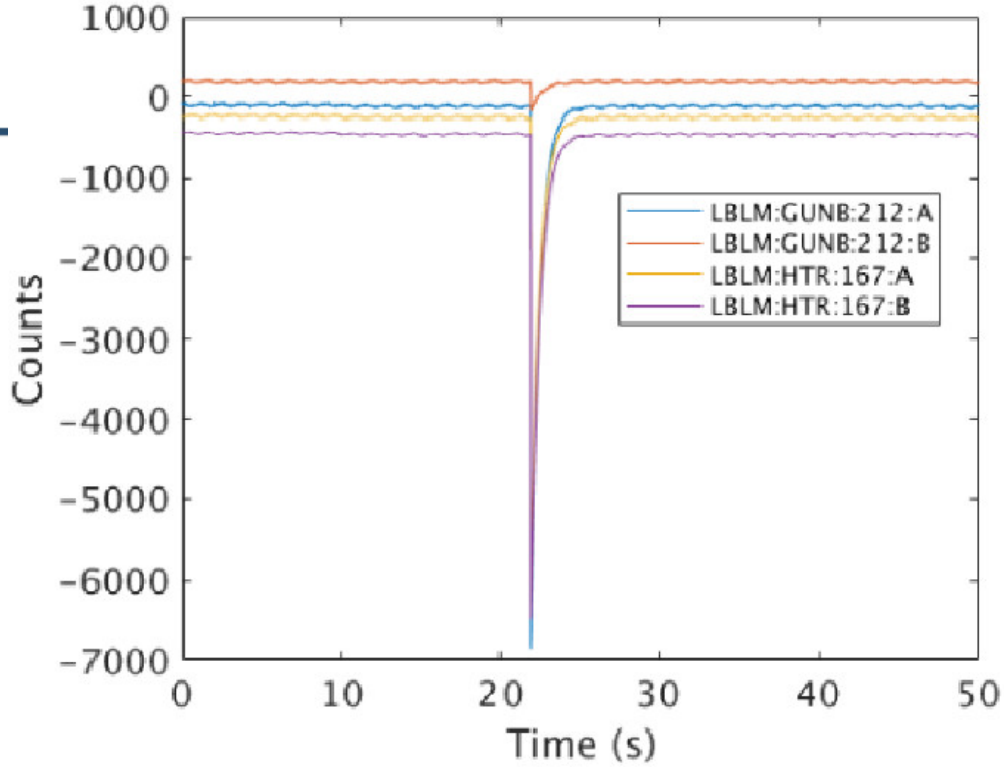


Loss at Grazing Incidence on the Beampipe: Location 1

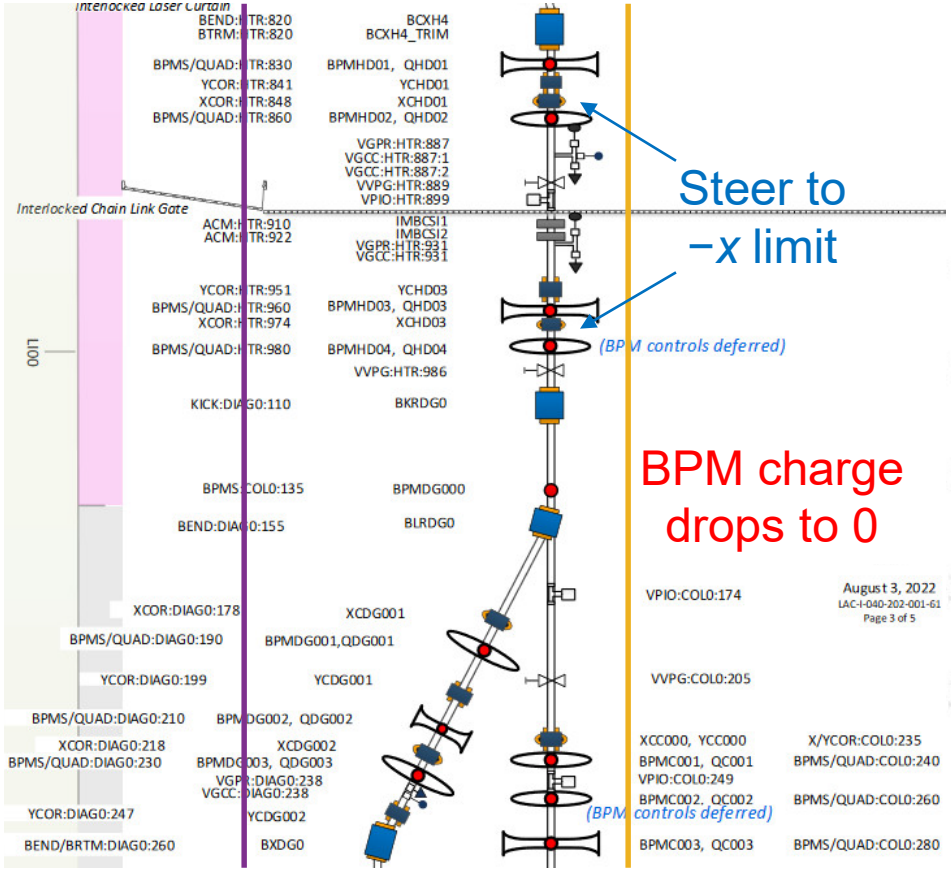
Steer to
+*x* limit

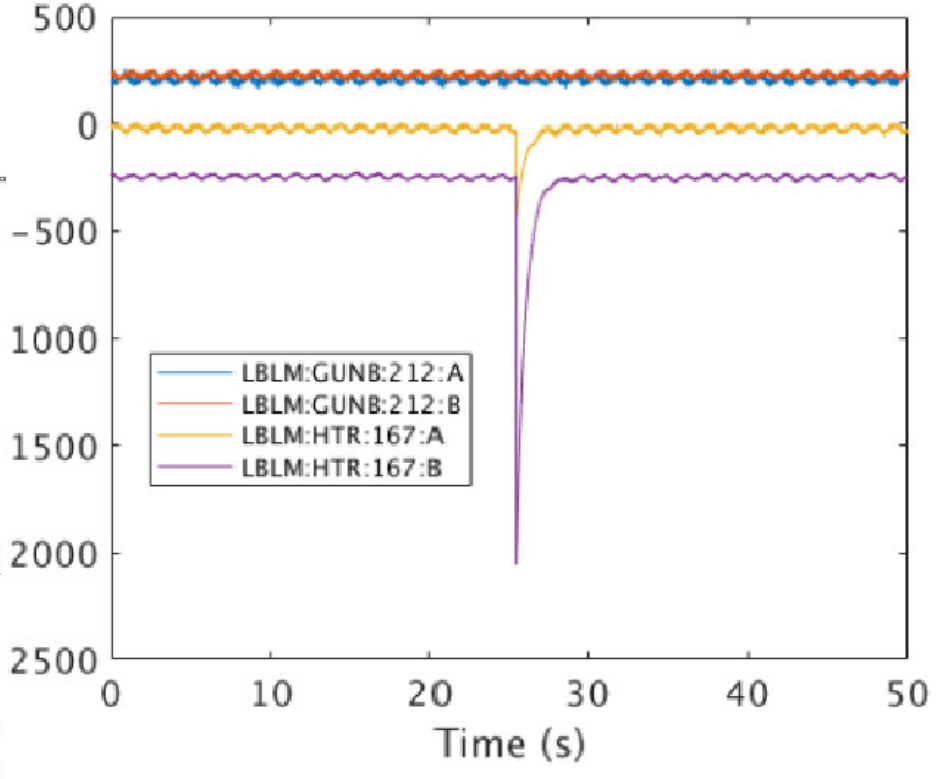
BPM charge
drops to 0



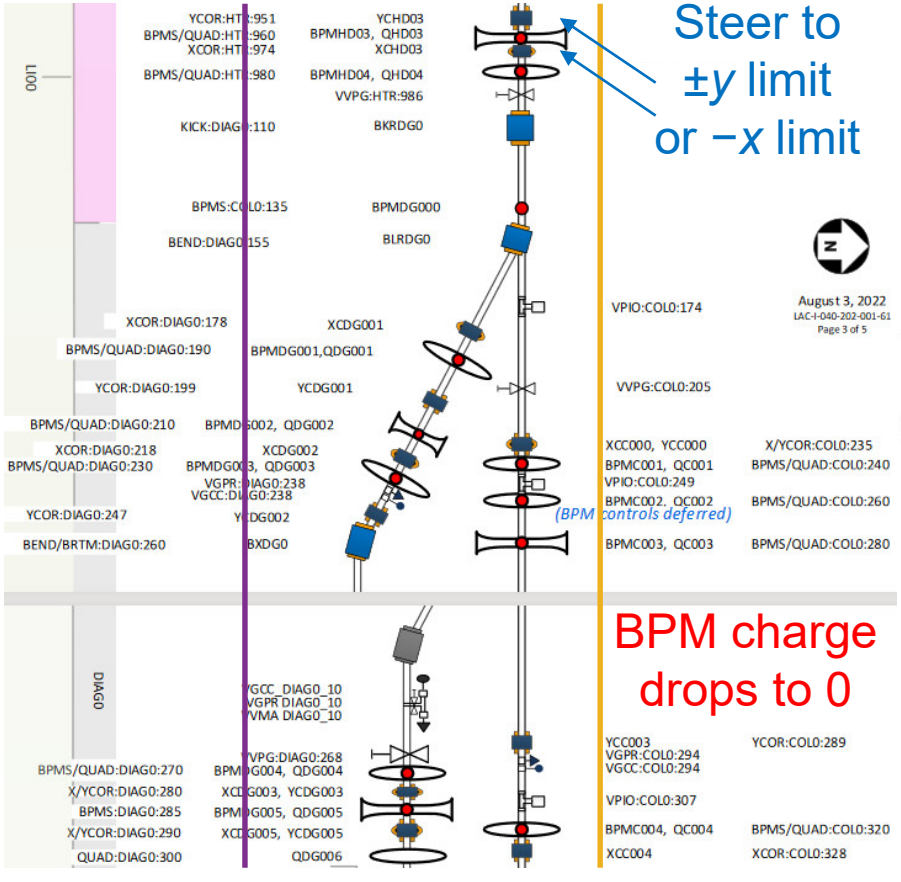


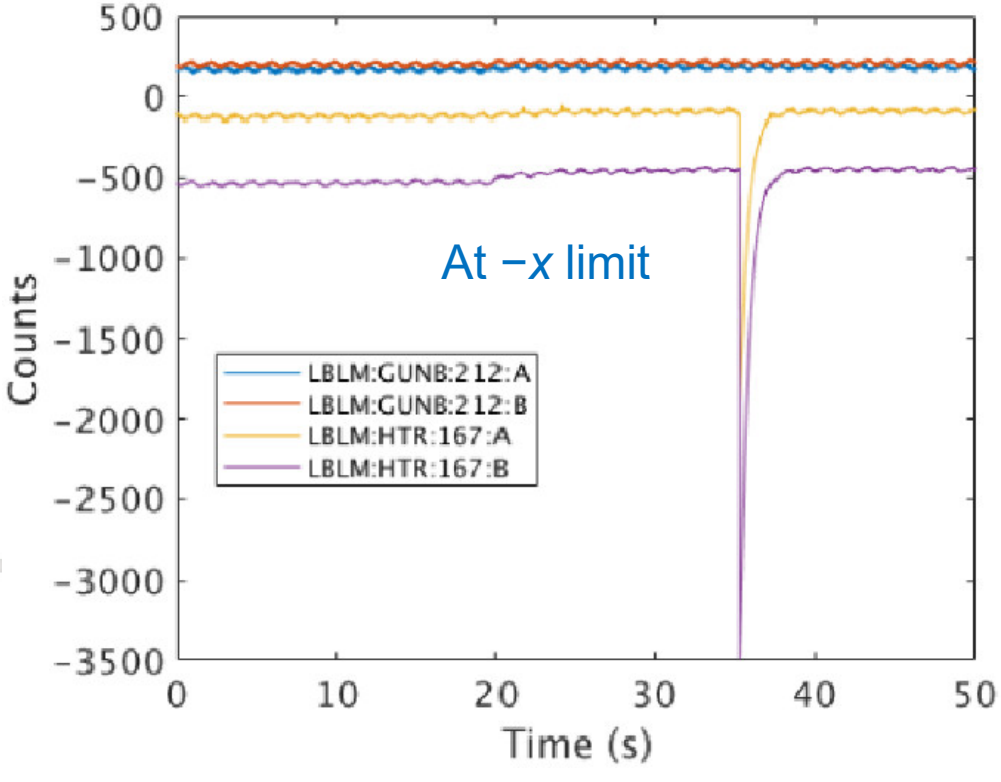
Loss Location 2



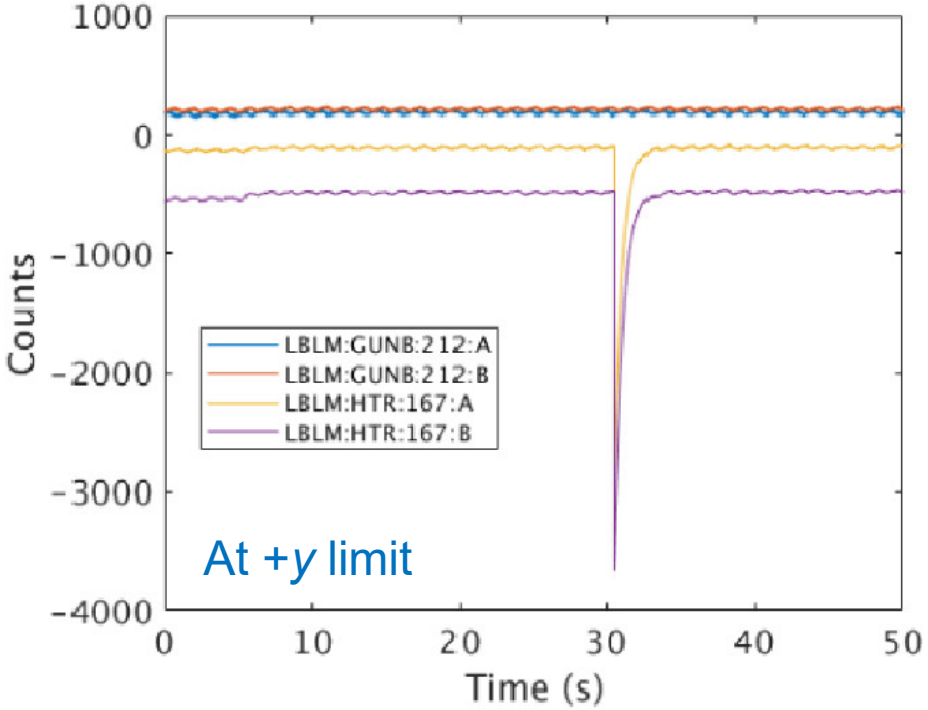


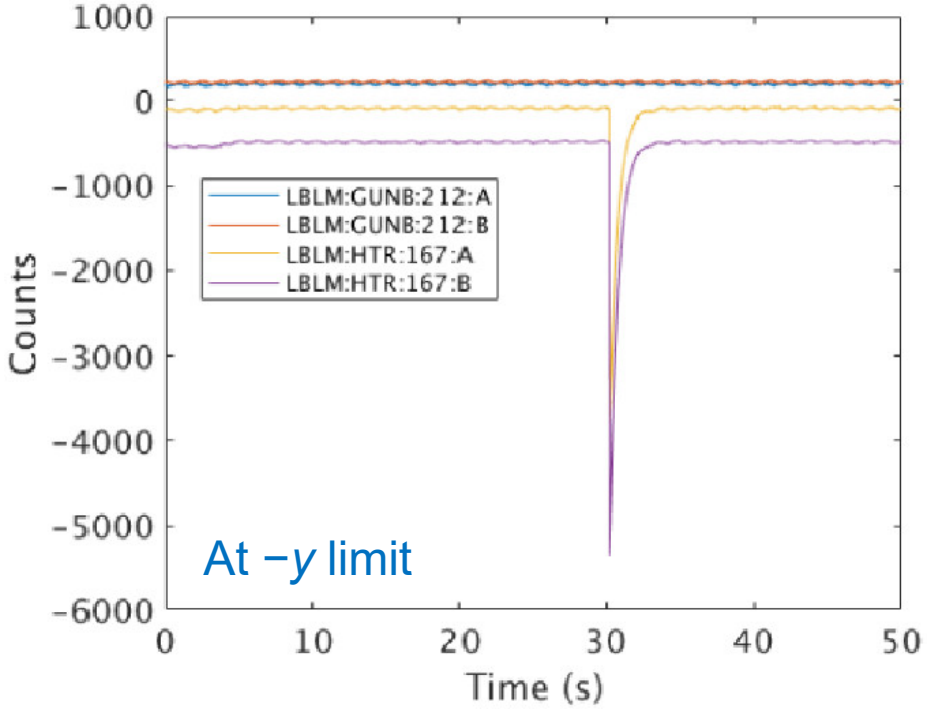
Loss Location 3





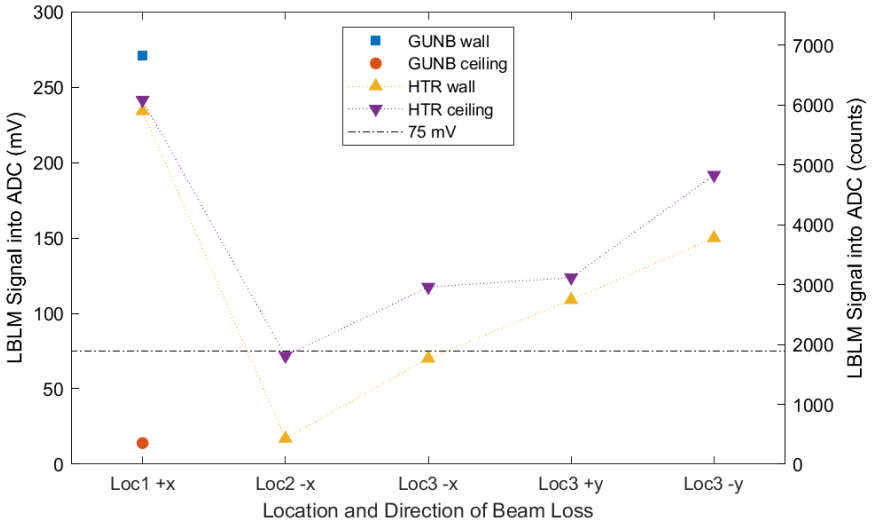
Loss Location 3: Vertical Loss





Steering *down* gives a *larger* signal on the ceiling: Local shielding means more than loss direction

LBLM Response along the Beamline



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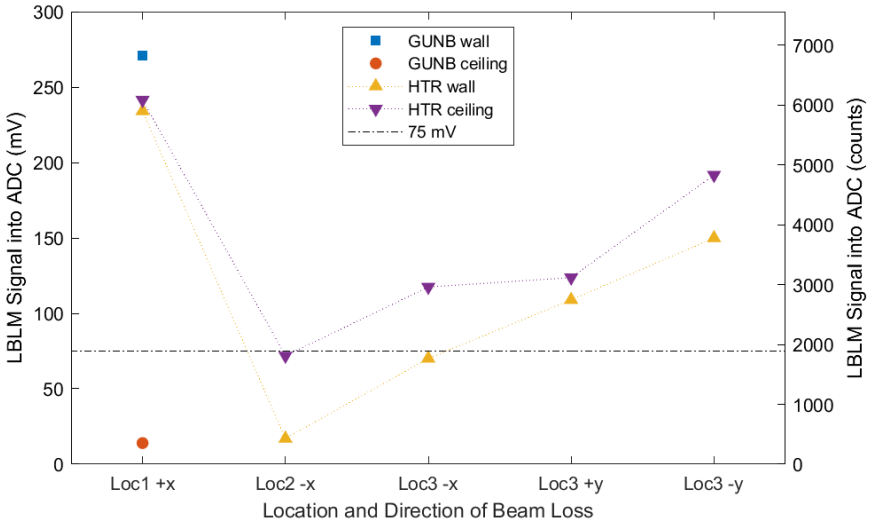

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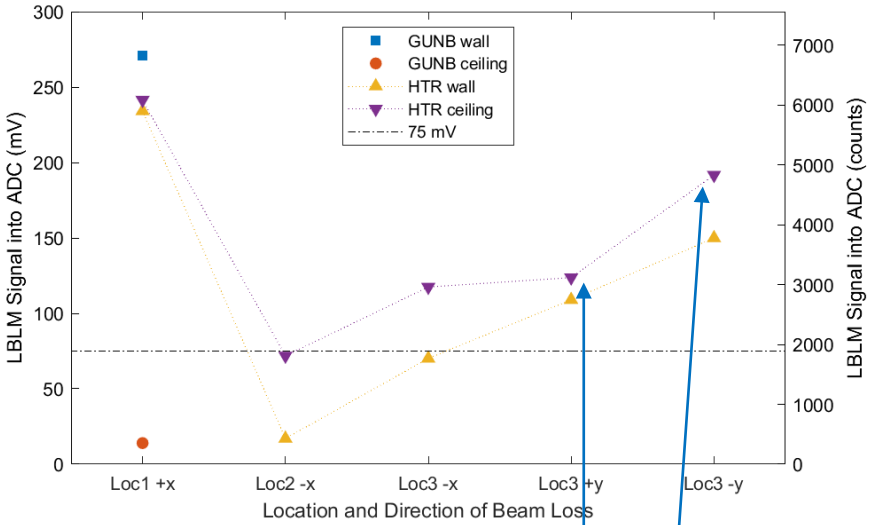

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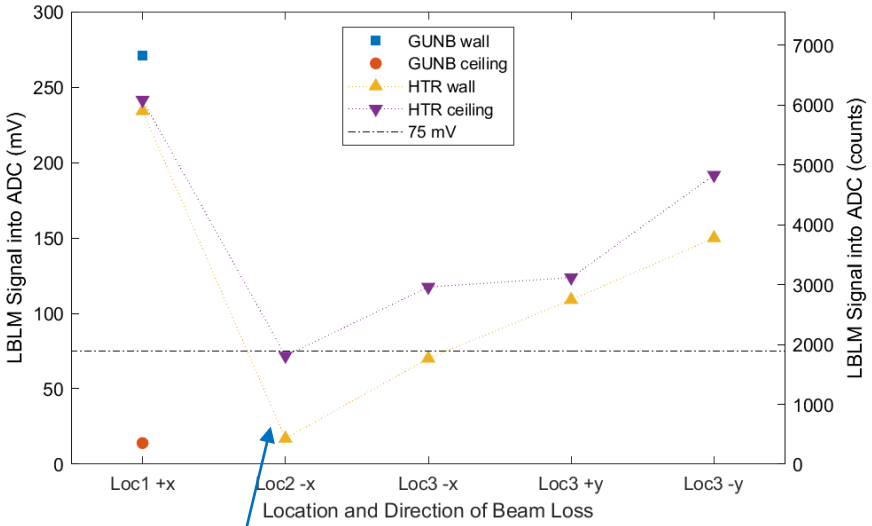

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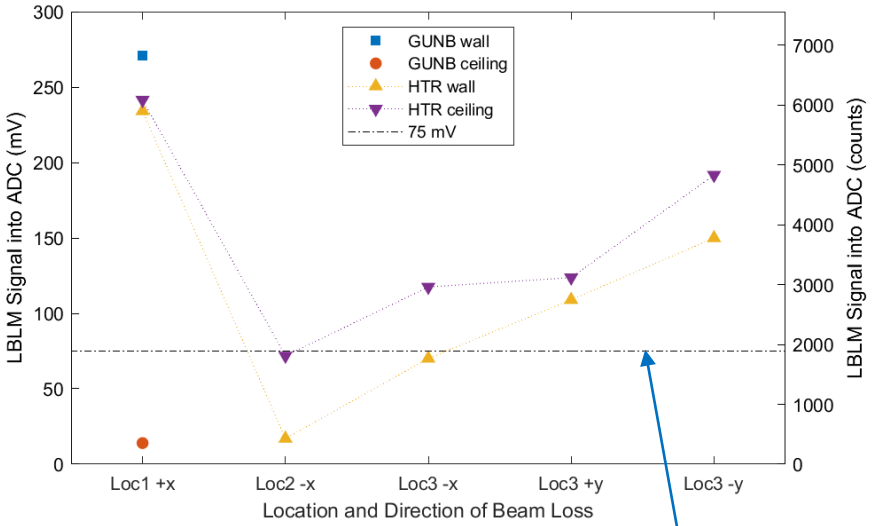

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- Calibrate using a typical or lower response (not maximum): 75 mV for the 8.8 J lost.

Calibration Example

- Begin with the burst measurement of the fiber: 8.8 J → 75 mV

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- In a *uniform* loss of 8.8 J over 500 ms (→ 17.6 W), the integrator's *RC* decay of early pulses lowers the response: $(1-e^{-1})\cdot(75\text{ mV}) = 47.4\text{ mV}$ → 2.7 mV/W

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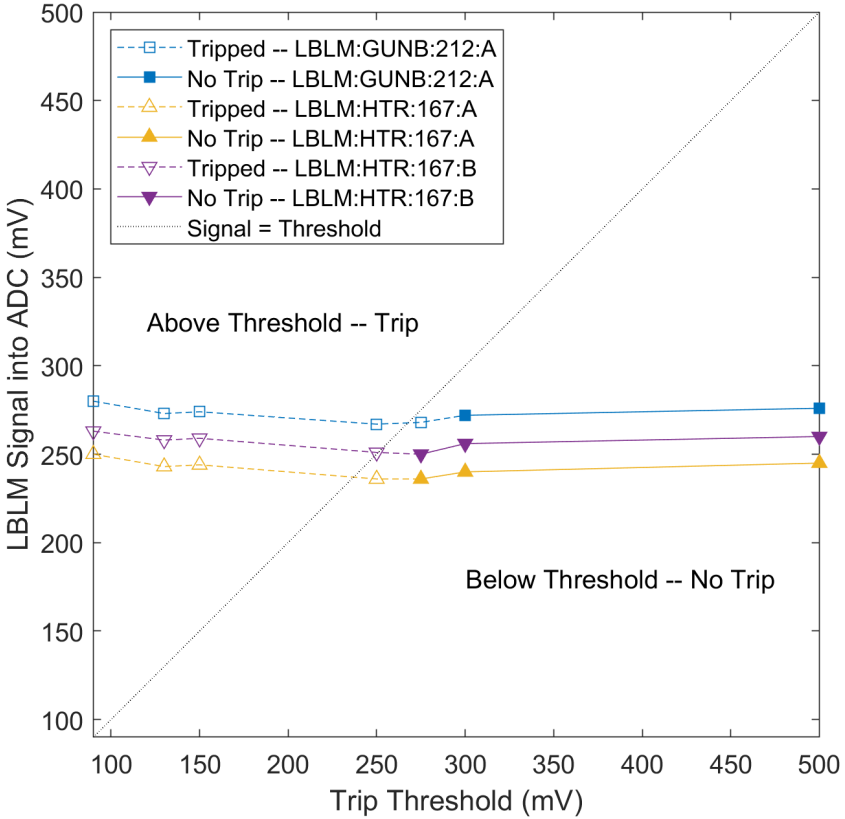
  - Stops photocurrent *and* RF to CM01: slower recovery and so a higher threshold
- But we haven't yet measured the response to thick targets (*e.g.*, collimators)
- Use a cautious, low threshold until we complete calibrations up to 4 GeV

LBLM BCS Trip Verification at Loss Location 1



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  - 3 fibers with good signals at Location 1
  - Tripped when signal exceeded threshold

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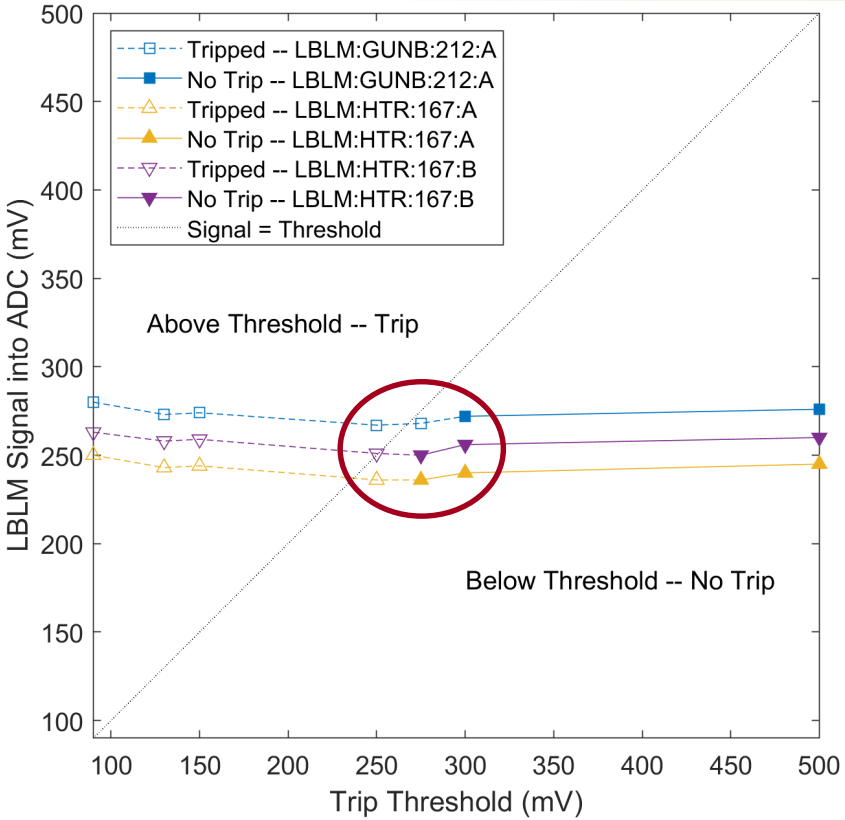

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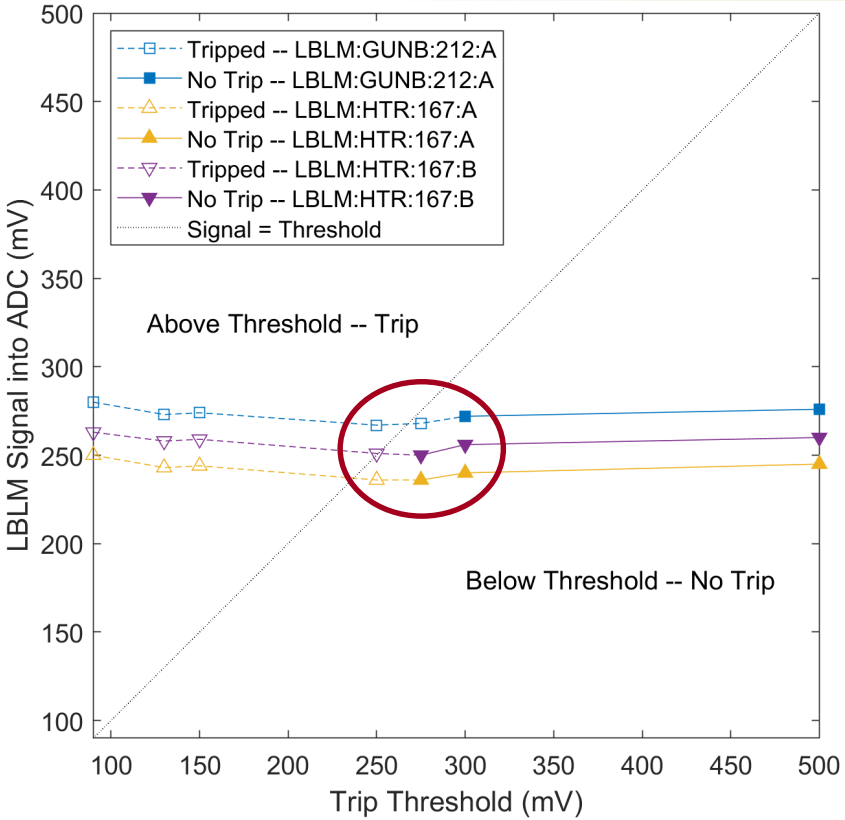
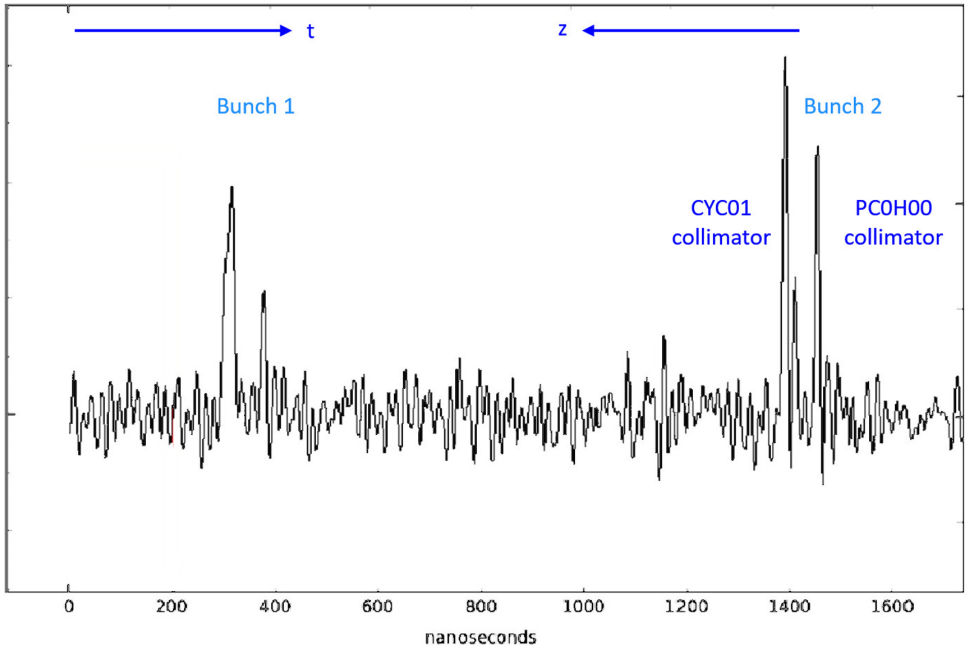


- Bursts with various trip thresholds
  - 3 fibers with good signals at Location 1
  - Tripped when signal exceeded threshold
- Some trips appear to happen slightly below the threshold: Readout offset
  - MPS software combines dark current and the channel's digitizer offset
  - Dark current contributes to BCS and MPS trips, but not included in plot
  - Offset is seen only in the MPS digitizer
    - Offsets will soon be measured and subtracted by software

Diagnostic Waveform: 2 Bunches, Each with 2 Loss Points



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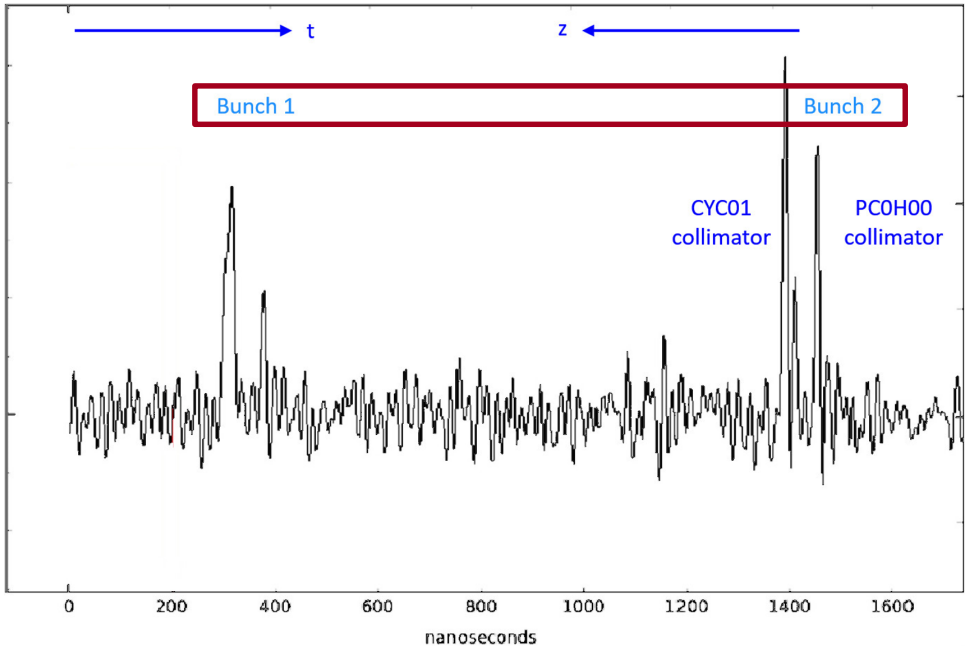

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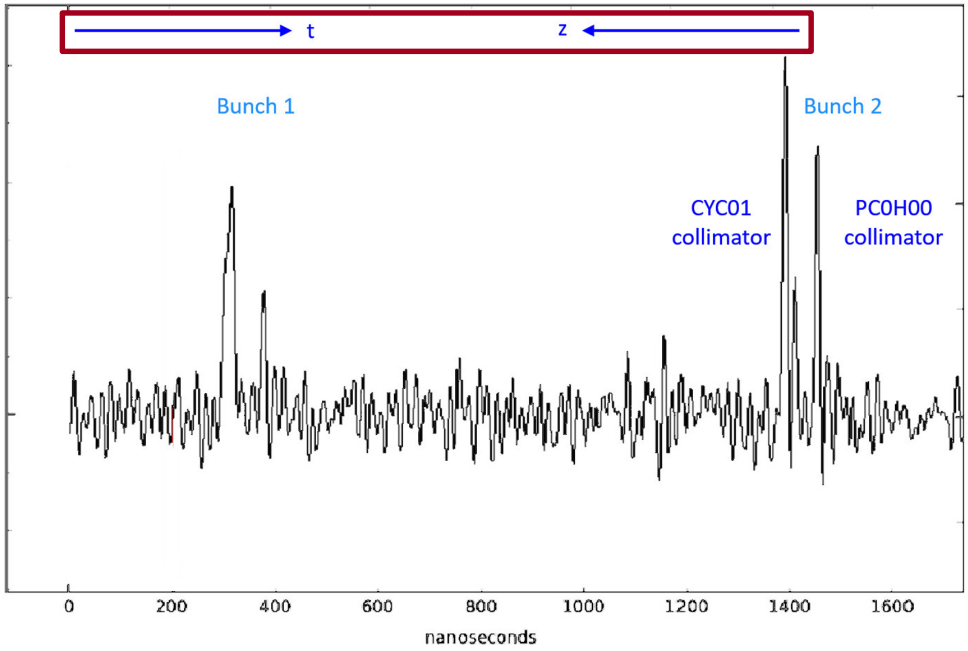

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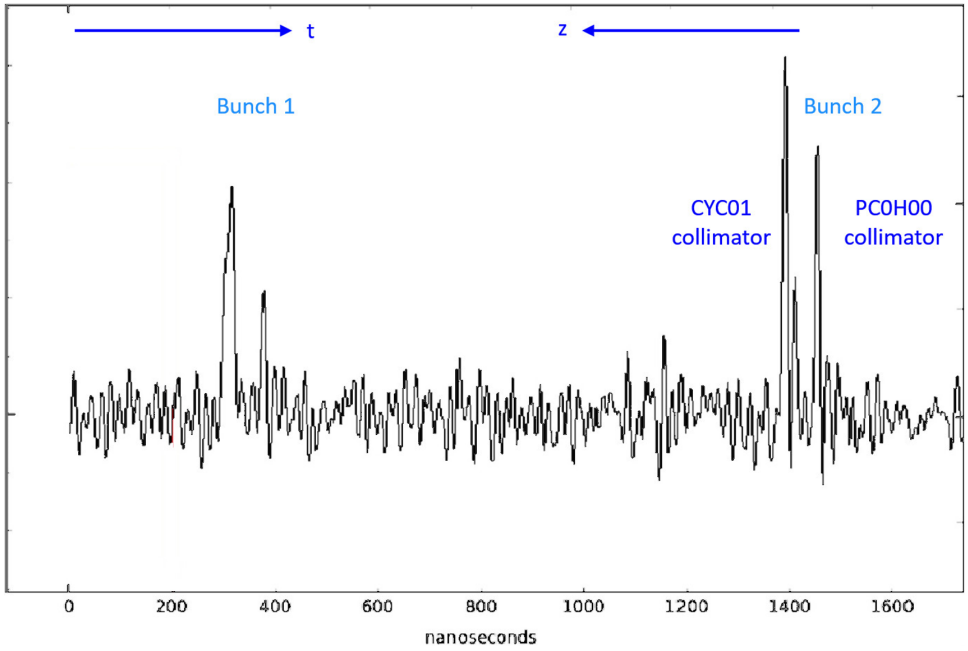

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- 2 collimators, 38 m apart:
  - Beam first scraped on PC0H00
  - Then it hit CYC01

Conclusions

- The LBLMs have demonstrated a strong and robust response to losses
  - Requires acceleration in CM01, above the gun's 750 keV
  - Good coverage, with some variation due to local shielding
- Successful test of BCS trip response
- PMT waveform provides a diagnostic signal
  - Loss locations and as a detector for wire scanners

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- Next:
  - Further tests hitting thick targets (collimators) and cryomodule CM01
  - We plan to accelerate the first beam to 4 GeV in October.
    - Calibrate with losses all along the path: 3.2 km from gun to high-power tune-up dump

Conclusions

- The LBLMs have demonstrated a strong and robust response to losses
  - Requires acceleration in CM01, above the gun's 750 keV
  - Good coverage, with some variation due to local shielding
- Successful test of BCS trip response
- PMT waveform provides a diagnostic signal
  - Loss locations and as a detector for wire scanners
- Next:
  - Further tests hitting thick targets (collimators) and cryomodule CM01
  - We plan to accelerate the first beam to 4 GeV in October.
    - Calibrate with losses all along the path: 3.2 km from gun to high-power tune-up dump

Thank you!