

# Commissioning Beam-Loss Monitors for the Superconducting Upgrade to LCLS

Alan Fisher, SLAC

IBIC 2022, Kraków



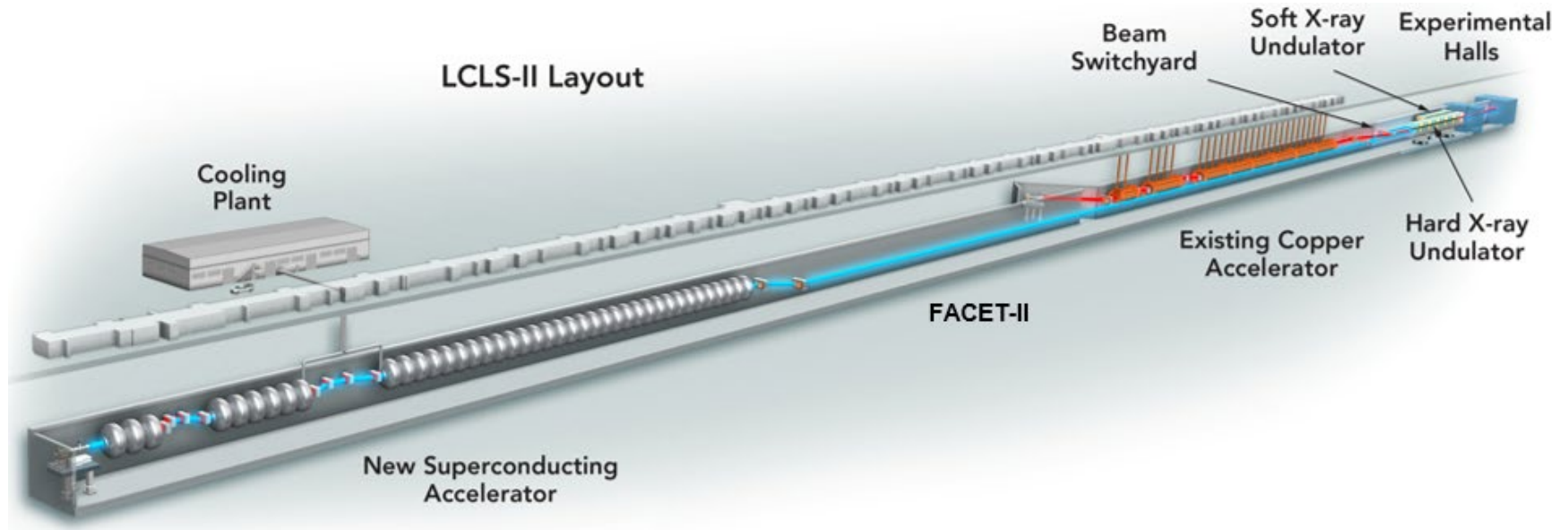
U.S. DEPARTMENT OF  
**ENERGY**

Stanford  
University



NATIONAL  
ACCELERATOR  
LABORATORY

# LCLS-II and the SLAC 3-km Linac

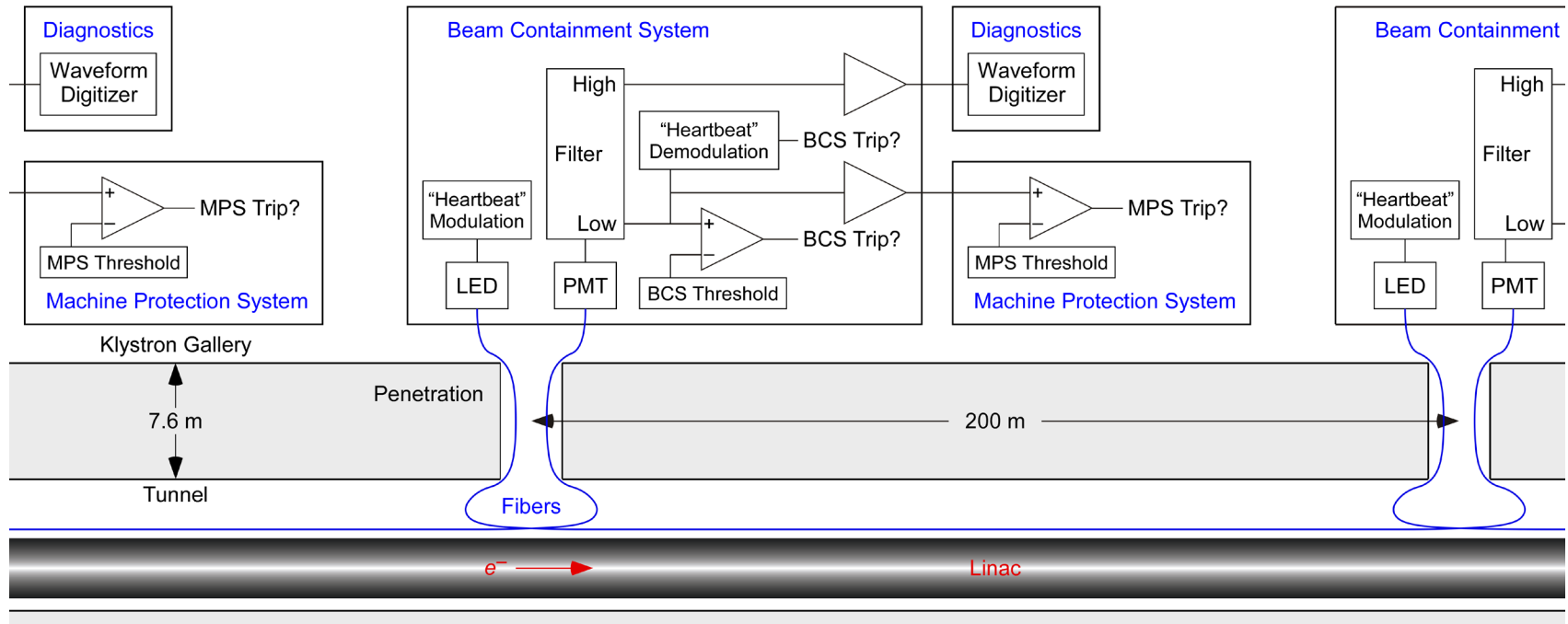


# Commissioning of the Superconducting Linac and New BLMs



- 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
- Shuttters photocathode laser, stops RF to cryomodule 1

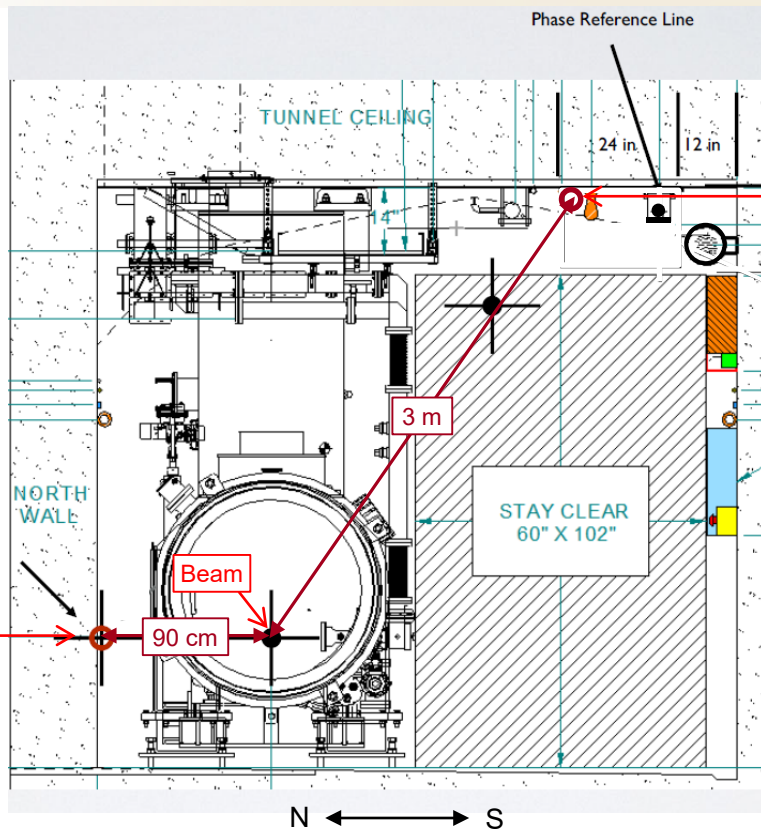
**MPS** = Machine Protection System

- 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

**LBLM Status Details**  
LBLM:HTR:167:B

Temp Ctrl Home Screen... Exit

**BLM Controller Info**

- Firmware Version: 000a
- Firmware SHA: 807c9803
- Hardware Revision: 0C01
- Connection Status: PRESENT

**Uptime**

Counter	Days	Hrs	Min	Sec
Counter	4	0	17	43
Apx Time Since Last Fault	4	0	17	43

**PMT and Cooling Status Registers**

Raw Value	Now	Latched
—PMT Power	ON	ON
—PMT Health	OK	OK
—Peltier Power	ON	ON
—Peltier Health	OK	OK
—Abnormality Detect	OK	OK
—Chassis TEC Alarm	OK	OK

**Analog**

- DSP Temperature: 30.0 degC
- Trip Threshold: 274.0 mV
- HV Readback: 680.3 V
- HV Setting: 798.2 V
- Self-Check Freq: 0.000 Hz
- Input Amp Gain: 6.02
- ADC Offset: 2.1 mV
- ADC P-P Amplitude: 12.9 mV
- DAC Modulation Offset: 6.8 mV
- AC Modulation Amplitude: 0.6 mV
- AC Line Phase Det: 359.7 deg
- Self-Check High Limit: 20.0 mV
- Self-Check Low Limit: 5.0 mV
- Self-Check Stage 1 Ampl: 8.25 mV
- Self-Check Stage 2 Ampl: 8.41 mV
- Self-Check Stage 3 Ampl: 8.41 mV
- Self-Check After Gain: 1064.0 uV
- Self-Check Stage 1 Phase: -175.7 deg
- Self-Check Stage 2 Phase: -176.5 deg
- Self-Check Stage 3 Phase: -176.2 deg

**Common Status Register**

Value at Last Trip	Live
Raw Value: 0x018	0x000
Test Request: NO	OK
Comparator Trip: OK	OK
Input Overrange: OK	OK
Power Monitor: OK	OK
Sensor Self-Check: OK	OK
Bypass Switch: OFF	OK
Gain S1-1: X2	NO
Gain S1-2: X3	NO
Gain S1-3: NO	NO
Gain S1-4: NO	NO
Debug Port In Use: NO	NO

Latched Fault: OK

Asyn Diag

# “Heartbeat” for Continuous Self-Checking

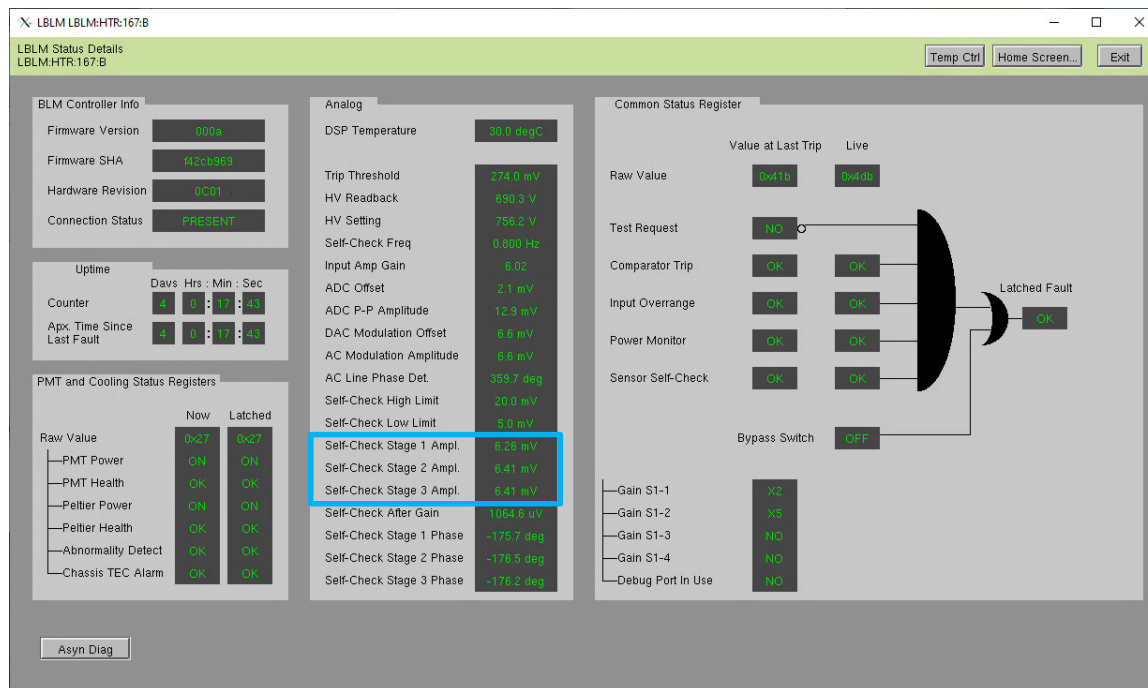
- LED modulated at 0.8 Hz sends weak light to the PMT through the fiber

The screenshot displays the 'LBLM Status Details' window for unit LBLM:HTR:167:B. The interface is organized into several sections:

- BLM Controller Info:** Shows Firmware Version (90%), Firmware SHA (807c980), Hardware Revision (9001), and Connection Status (PRESENT).
- Uptime:** A digital display showing 4 days, 9 hours, 17 minutes, and 43 seconds.
- PMT and Cooling Status Registers:** A table with columns for 'Now' and 'Latched' status. All indicators (PMT Power, PMT Health, Peltier Power, Peltier Health, Abnormality Detect, Chassis TEC Alarm) are currently 'OK'.
- Analog:** Lists various sensor readings such as DSP Temperature (93.0 degC), Trip Threshold (274.0 mV), HV Readback (680.3 V), and Self-Check Freq (0.800 Hz, highlighted in blue). Other highlighted values include DAC Modulation Offset (0.8 mV) and AC Modulation Amplitude (0.8 mV).
- Common Status Register:** A logic diagram showing 'Value at Last Trip' and 'Live' status for several parameters: Raw Value (Raw16), Test Request (NO), Comparator Trip (OK), Input Overrange (OK), Power Monitor (OK), and Sensor Self-Check (OK). These inputs feed into an AND gate, which outputs to a 'Latched Fault' indicator (OK). A 'Bypass Switch' is currently set to 'OFF'.

# “Heartbeat” for Continuous Self-Checking

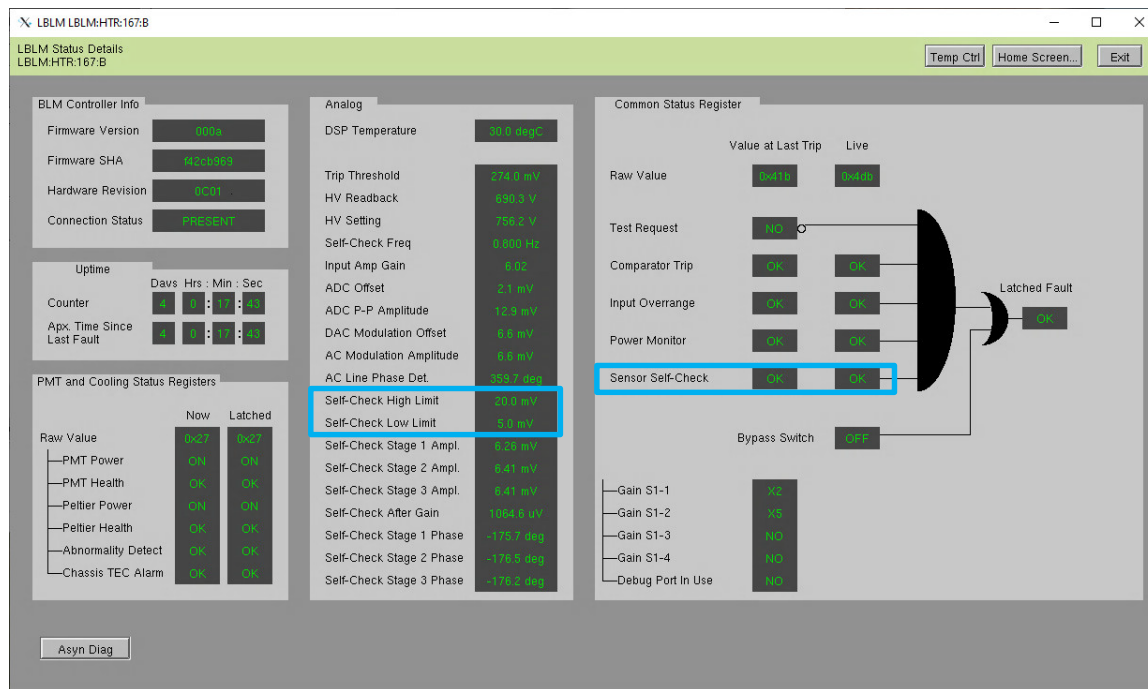
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- DSP demodulates using the algorithm of a digital lock-in amplifier





# “Heartbeat” for Continuous Self-Checking

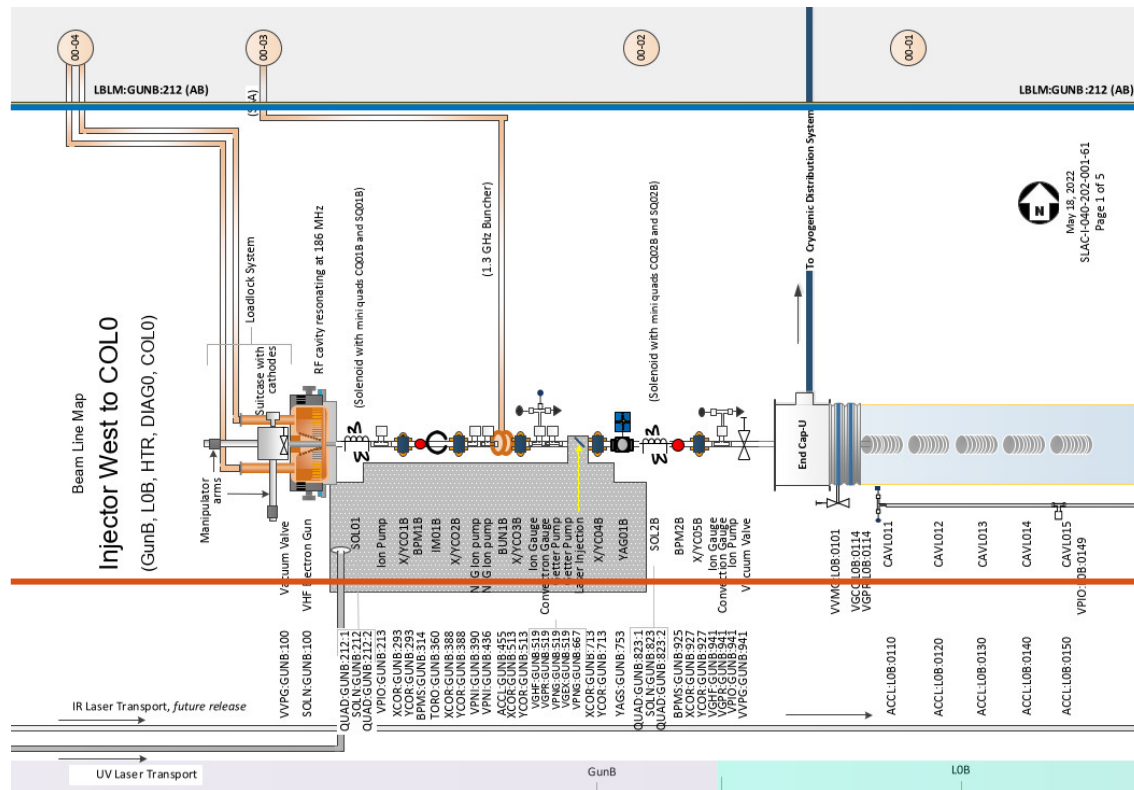
- LED modulated at 0.8 Hz sends weak light to the PMT through the fiber
- DSP demodulates using the algorithm of a digital lock-in amplifier
- Beam will trip if the fiber breaks, the HV for the PMT fails, radiation raises fiber attenuation...
  - Trips in about 3 minutes



# 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,  
3 m from beam

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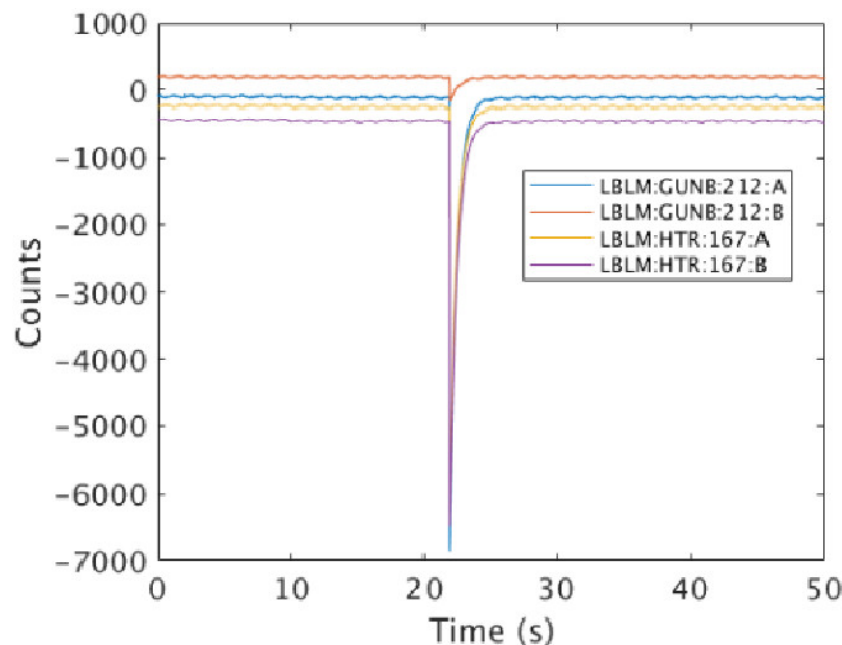






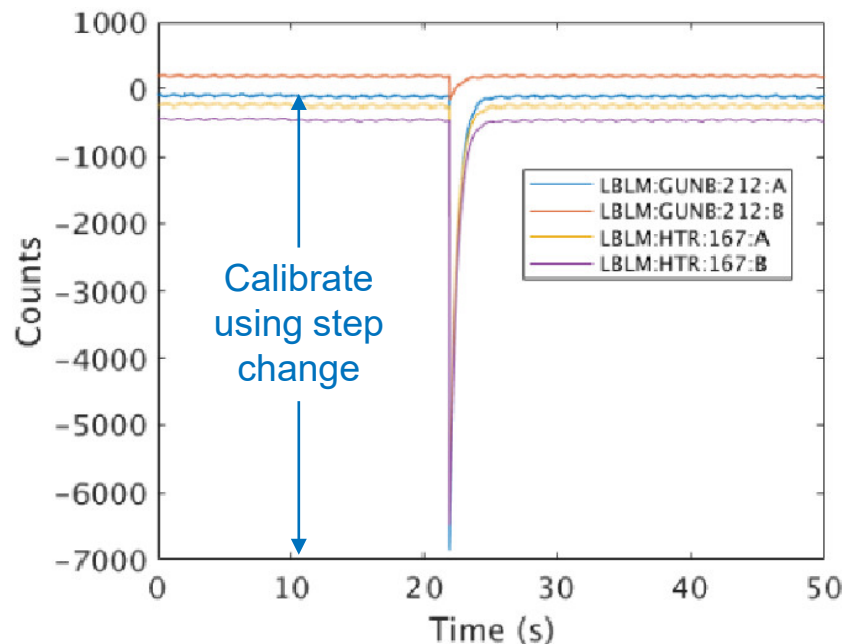
# Response to a Burst of Bunches

- Each bunch 220 pC, 80 MeV  $\rightarrow$  17.6 mJ
- 500 bunches with 2- $\mu$ s spacing  $\rightarrow$  8.8 J
  - Abrupt start, 500-ms RC decay



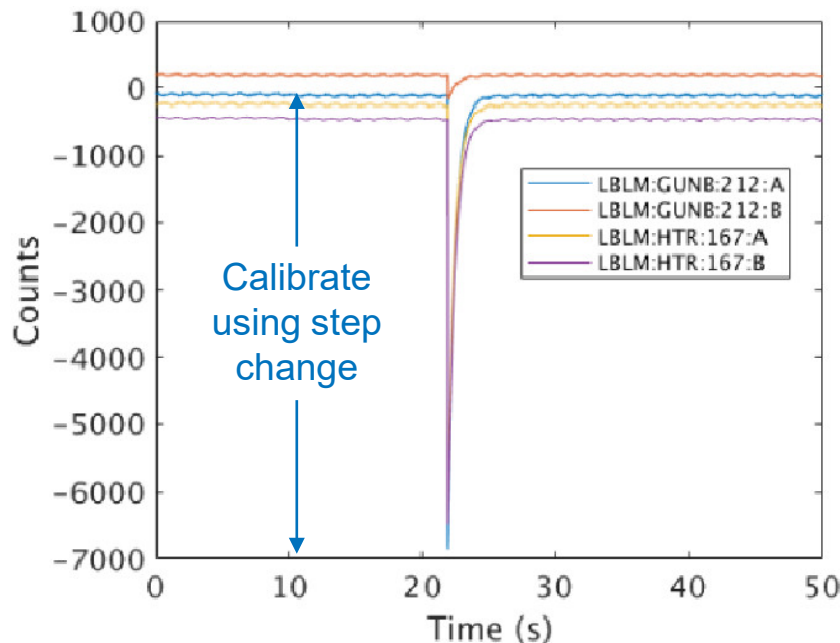
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  - Abrupt start, 500-ms RC decay
  - Calibrate with the step change from baseline to peak
- Baseline consists of:
  - Constant BCS self-check at 0.8 Hz
  - Offset of each ADC channel
    - ADC acquires data for MPS and EPICS
    - BCS does not use the digitizer
    - MPS will soon measure offsets and subtract
  - Dark current (largely from the gun)
    - Often strong, depending on settings...



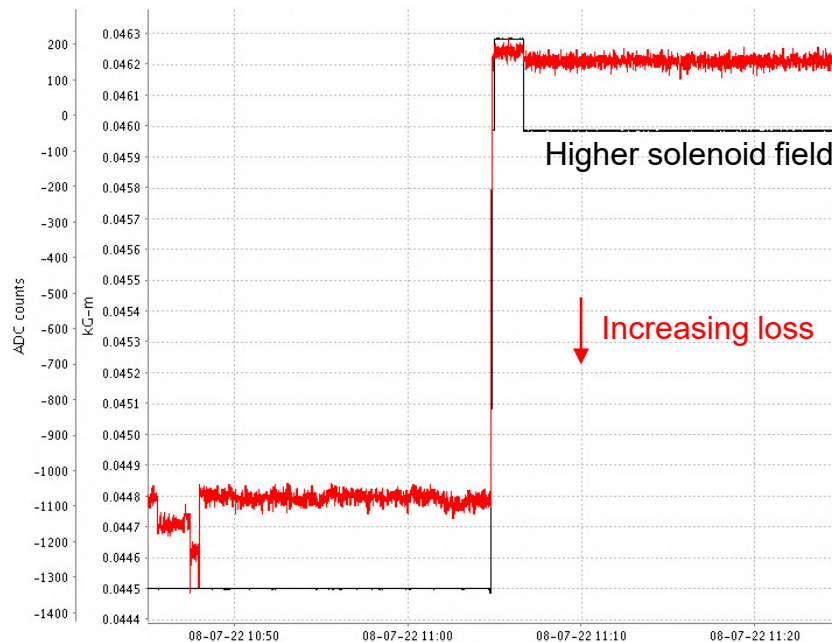
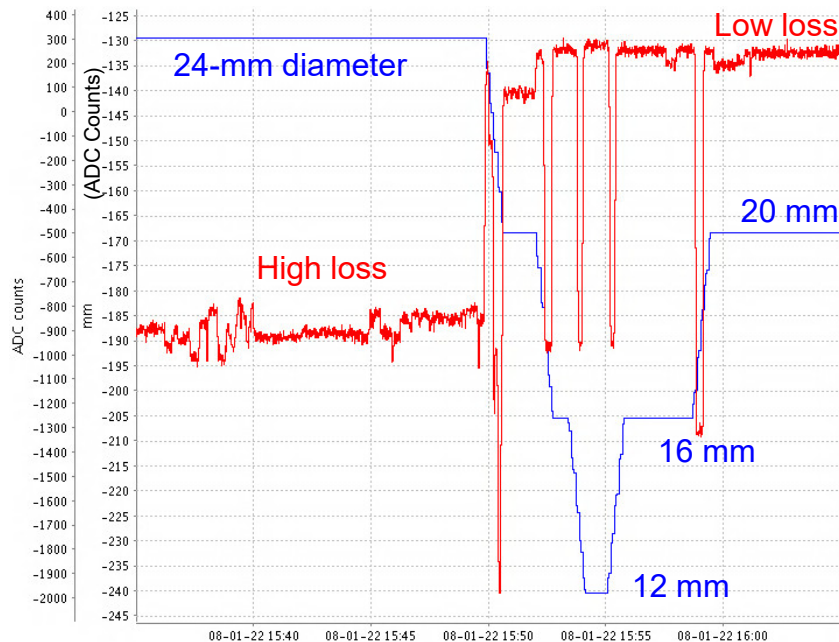


# LBLM Responds to Gun Dark Current

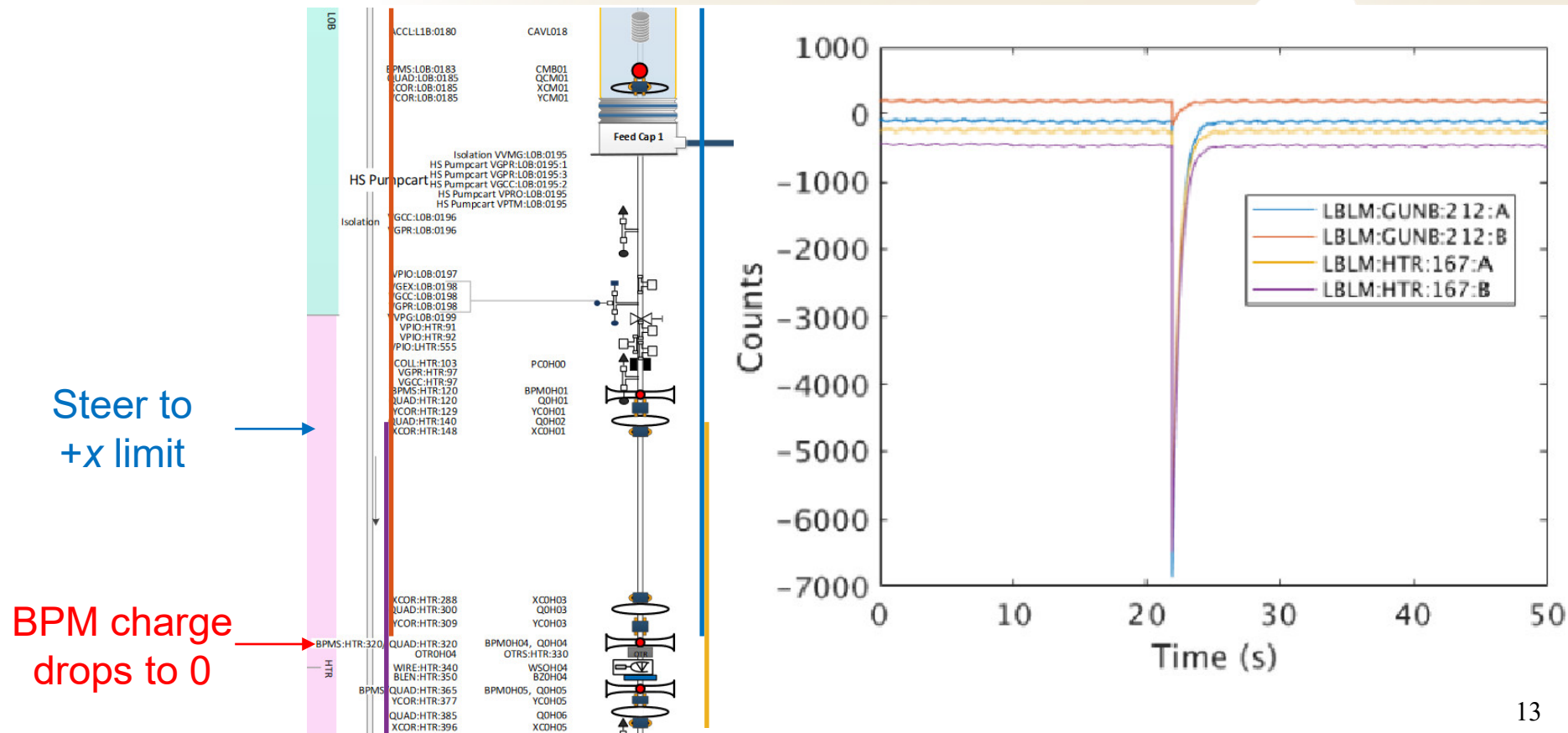
Collimating apertures before CM01  
(motor position)

LBLM:HTR:167:B

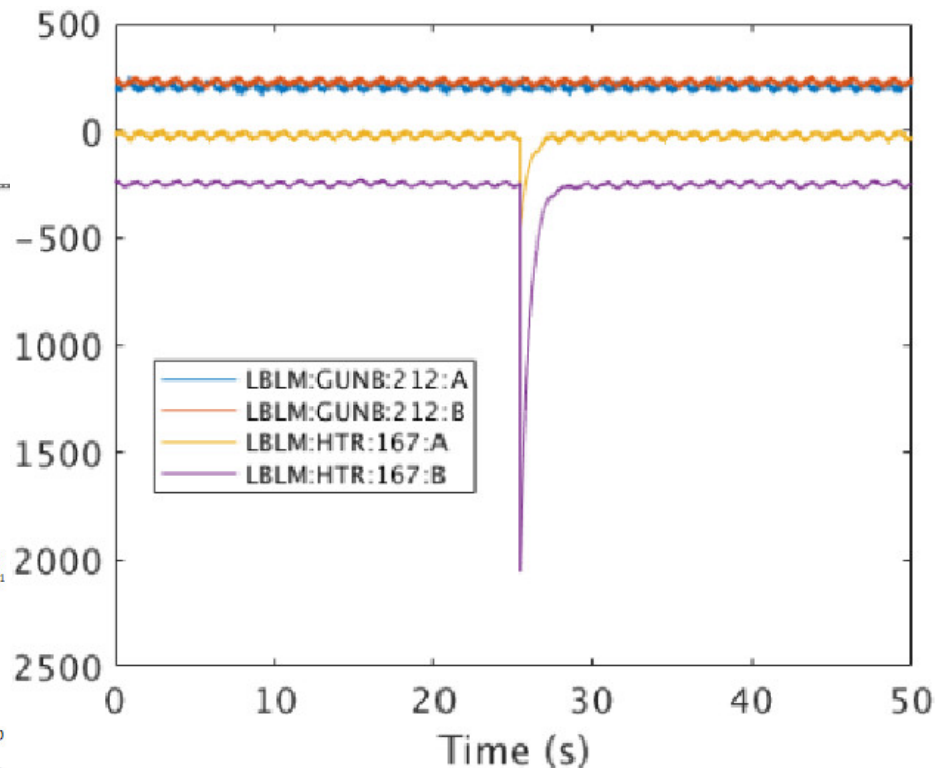
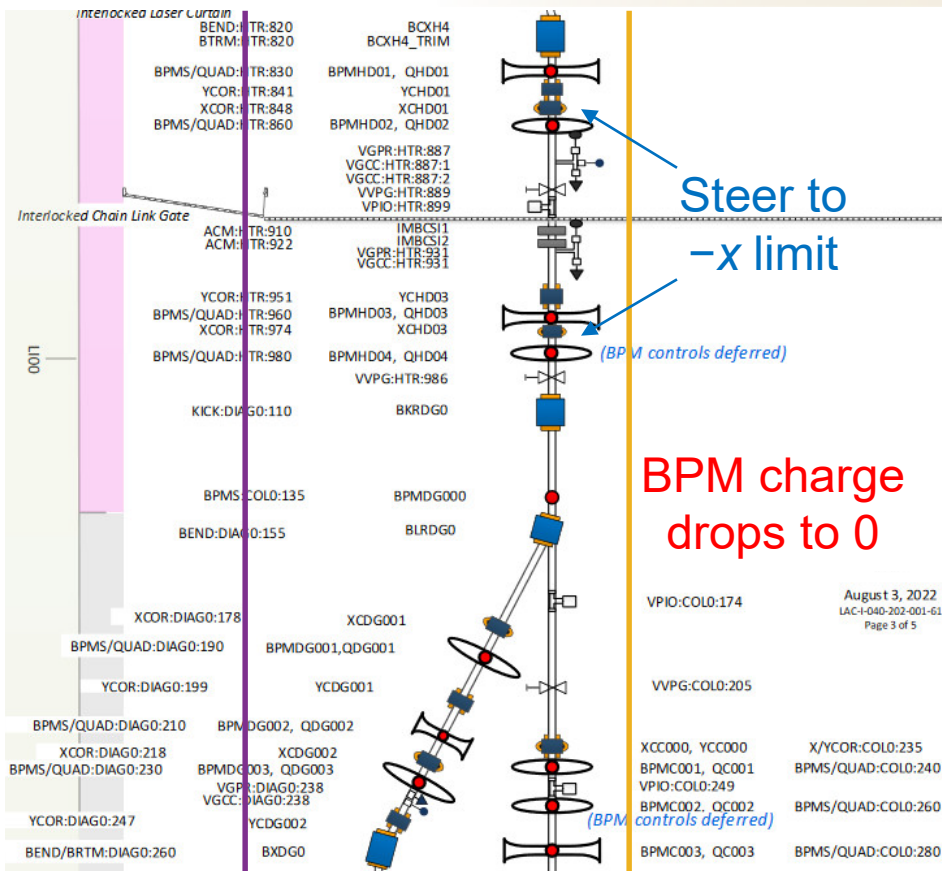
Focusing  
solenoid at gun



# Loss at Grazing Incidence on the Beampipe: Location 1

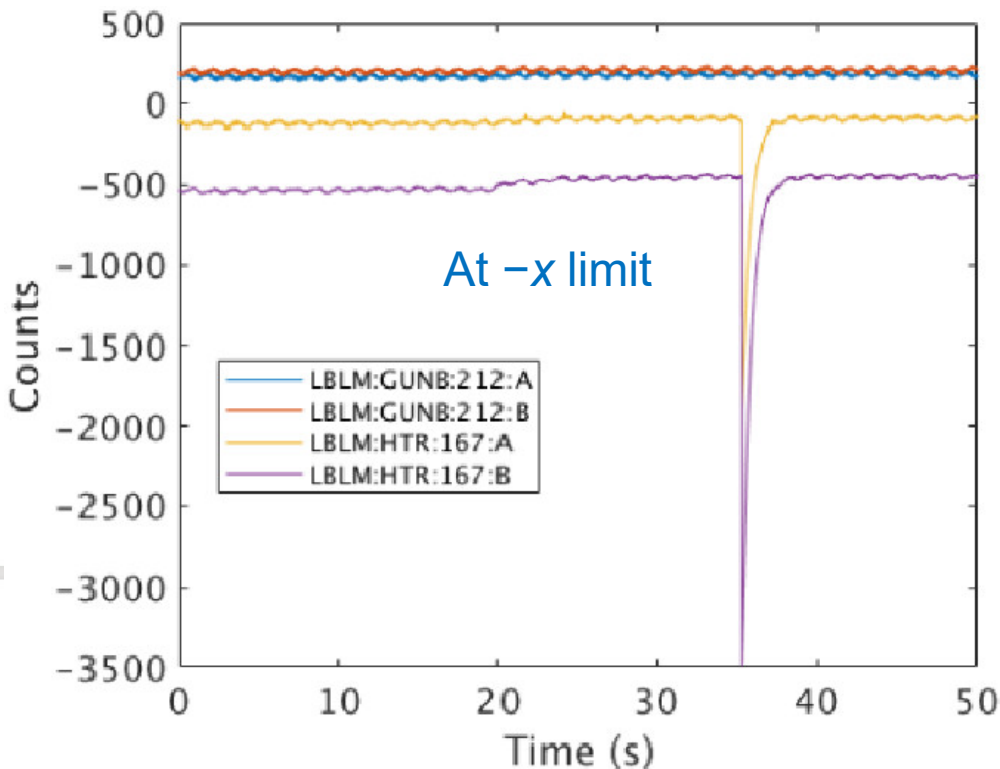
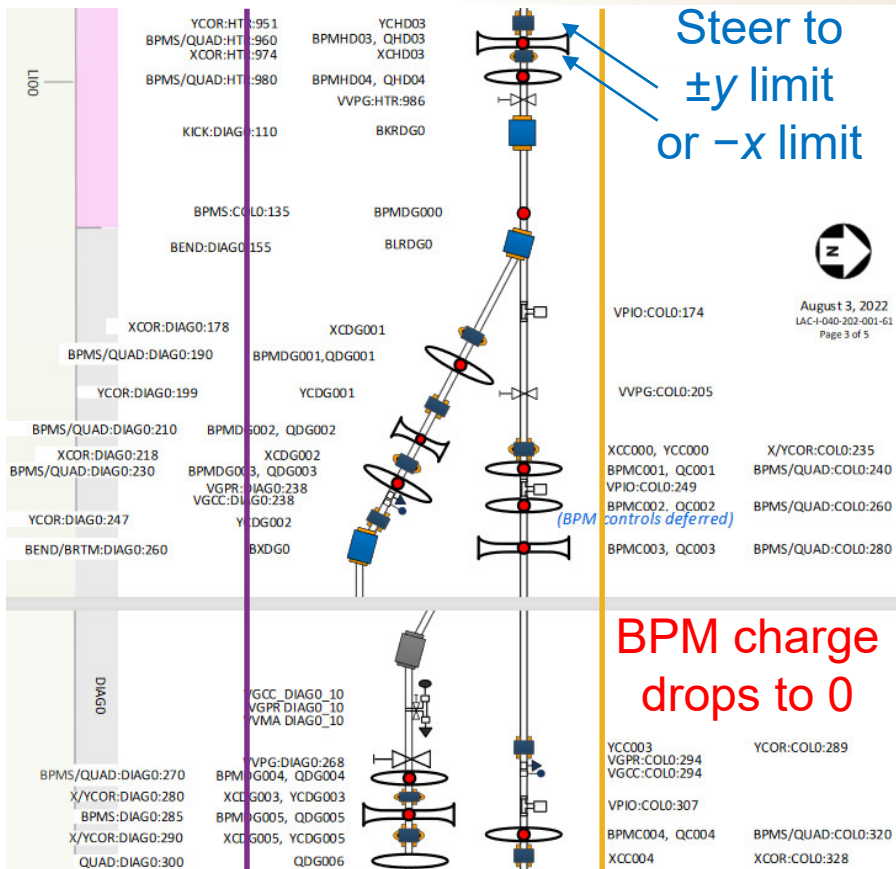


# Loss Location 2

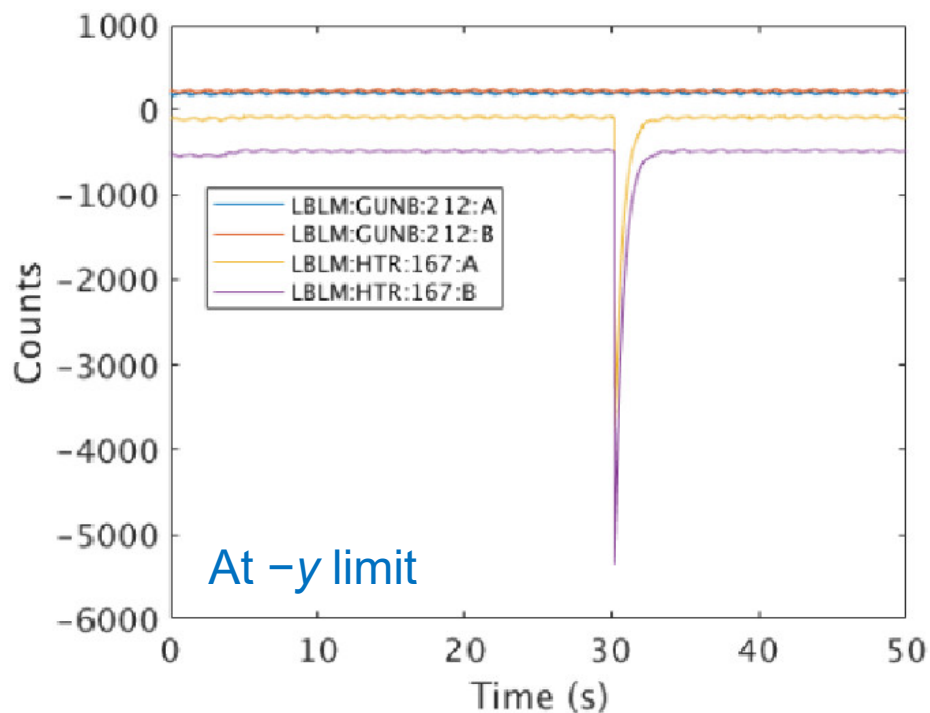
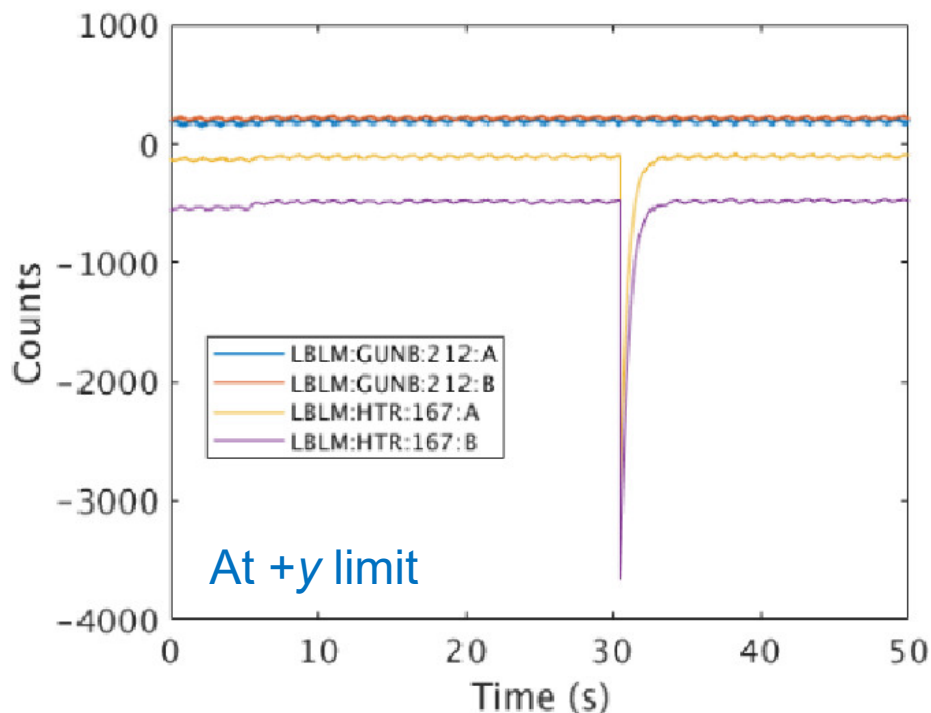


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# Loss Location 3

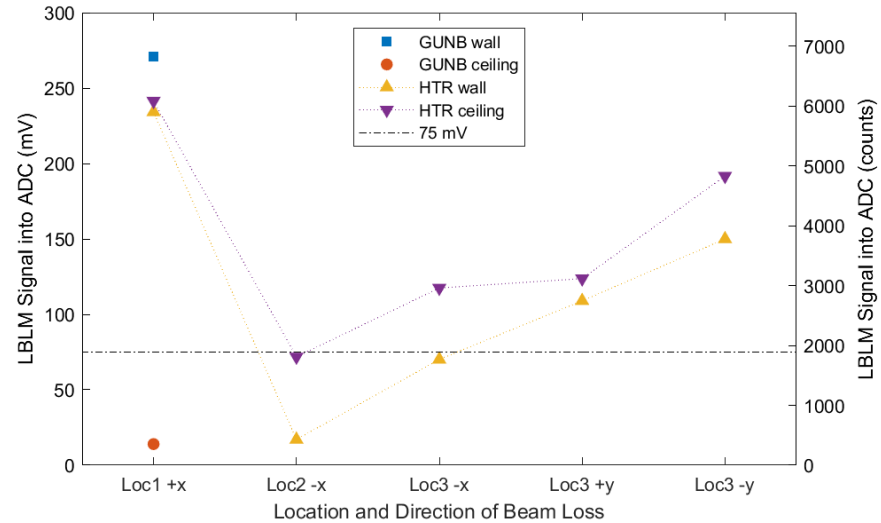


# Loss Location 3: Vertical Loss

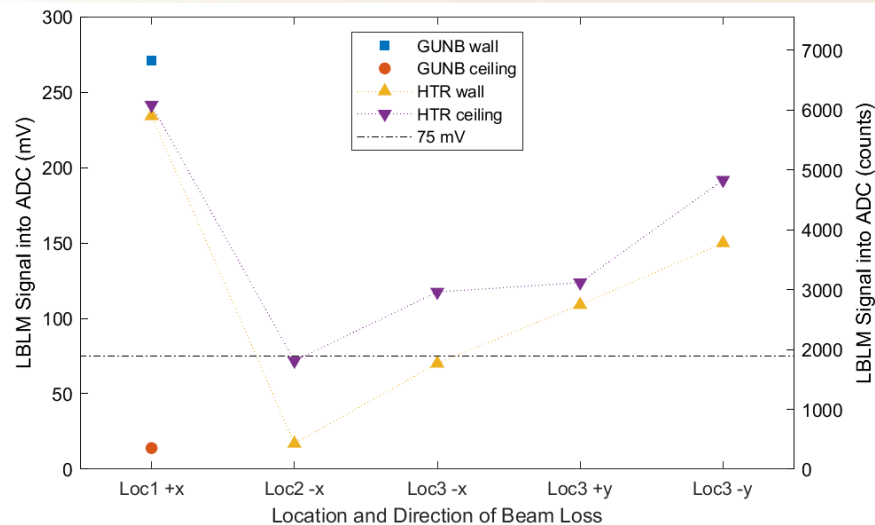


Steering *down* gives a *larger* signal on the ceiling: Local shielding means more than loss direction

# LBLM Response along the Beamline

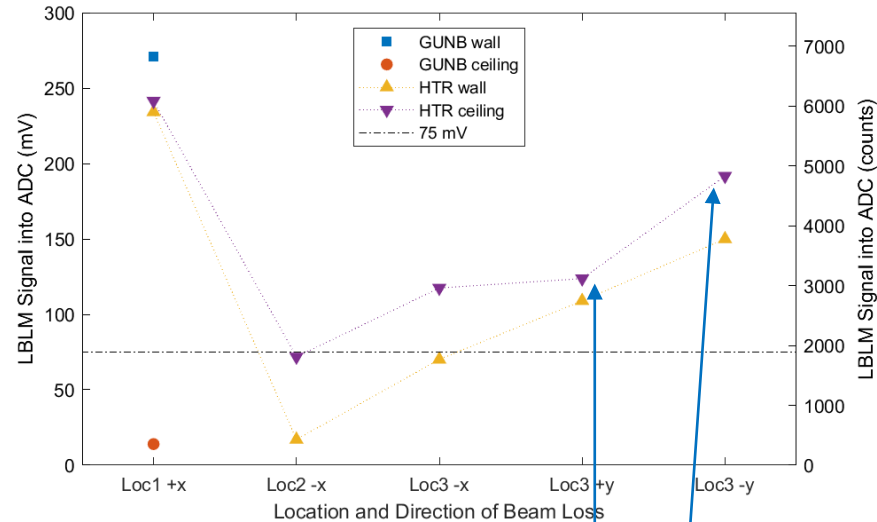


# LBLM Response along the Beamline



- Response varies along each fiber due to local shielding.

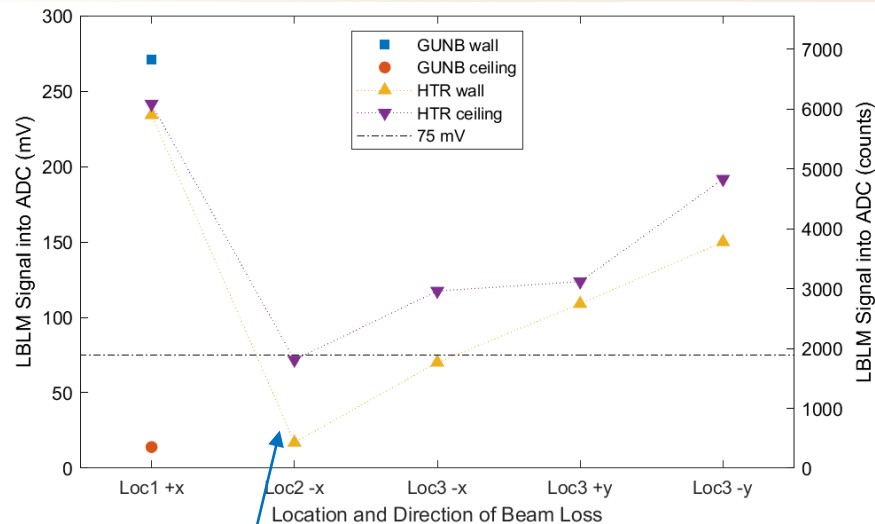
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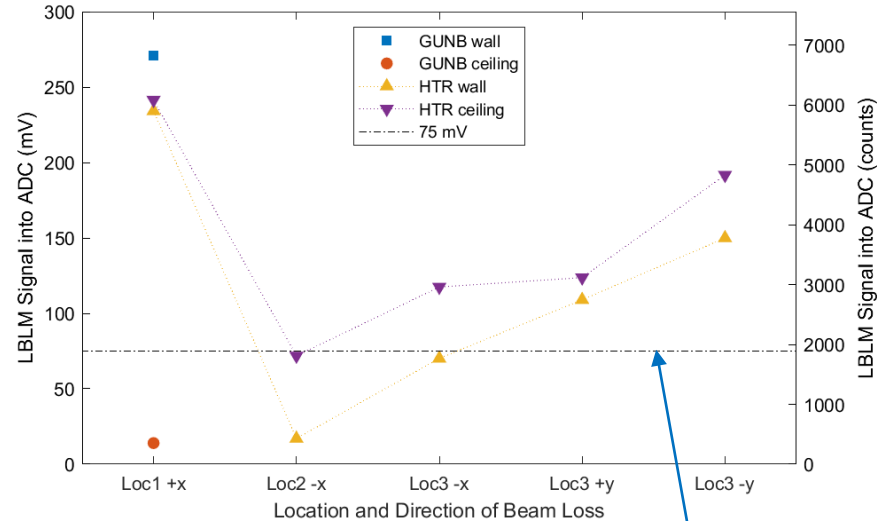


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- Loss signal does not seem to be directional: Compare  $+y$  to  $-y$  for the ceiling (HTR:B) fiber
- One fiber in a pair can compensate for shielding that blocks the other: A benefit of two views
- Calibrate using a typical or lower response (not maximum): 75 mV for the 8.8 J lost.

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# Calibration Example

- Begin with the burst measurement of the fiber:  $8.8 \text{ J} \rightarrow 75 \text{ mV}$
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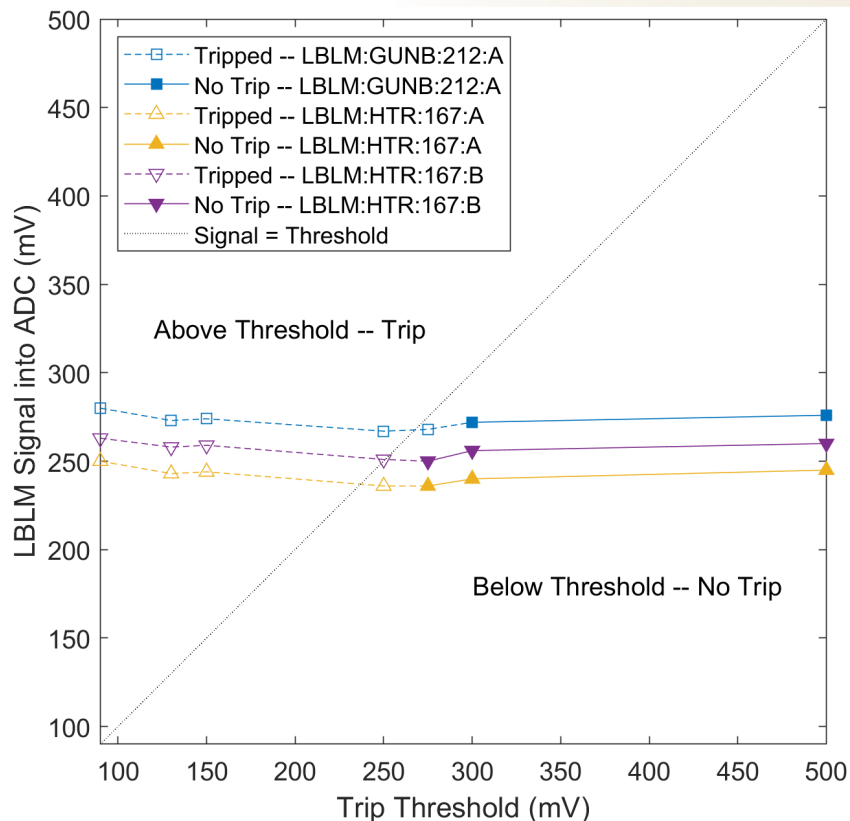
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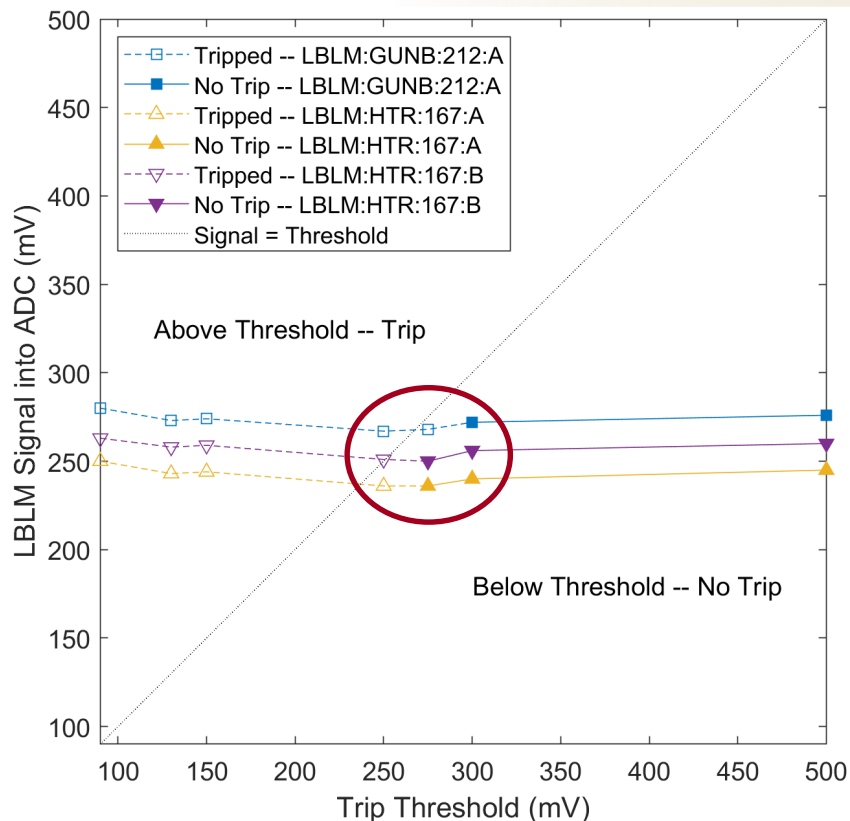
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  - Stops photocurrent *and* RF to CM01: slower recovery and so a higher threshold
- But we haven't yet measured the response to thick targets (*e.g.*, collimators)
- Use a cautious, low threshold until we complete calibrations up to  $4 \text{ GeV}$

# LBLM BCS Trip Verification at Loss Location 1



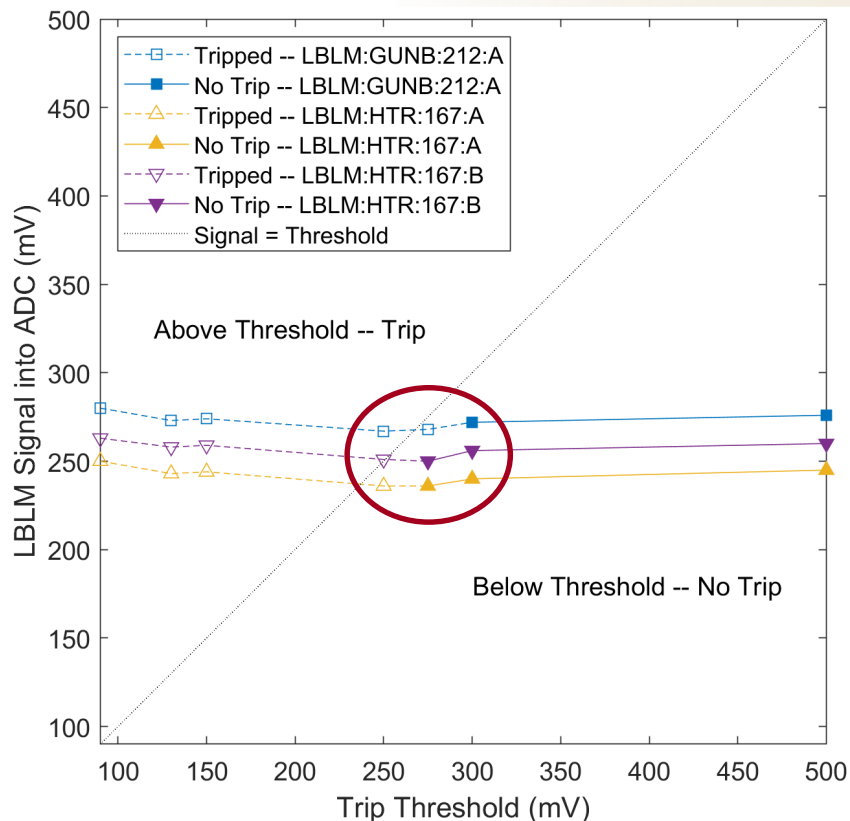
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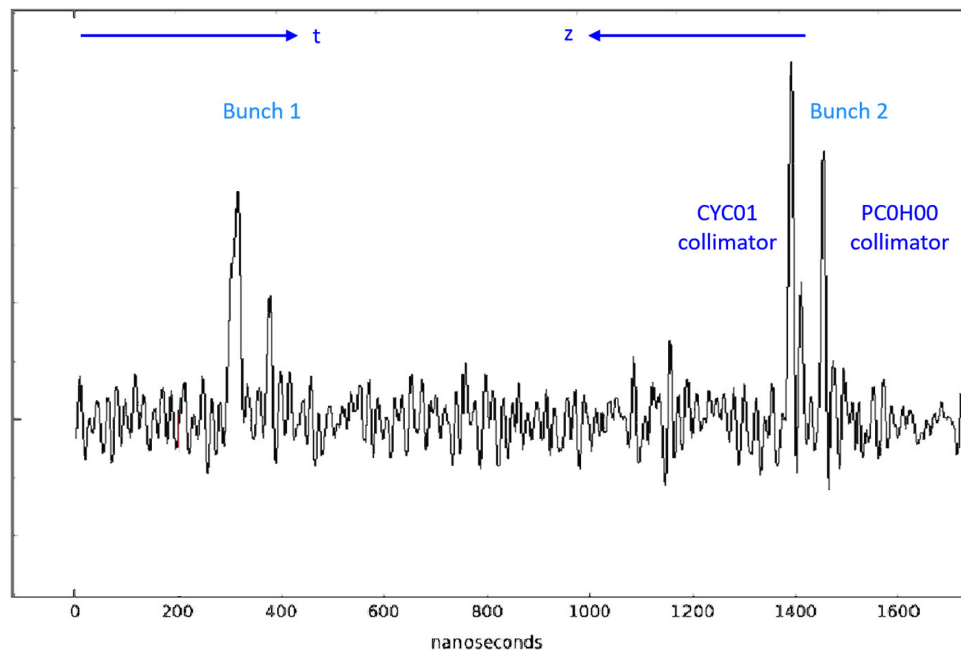
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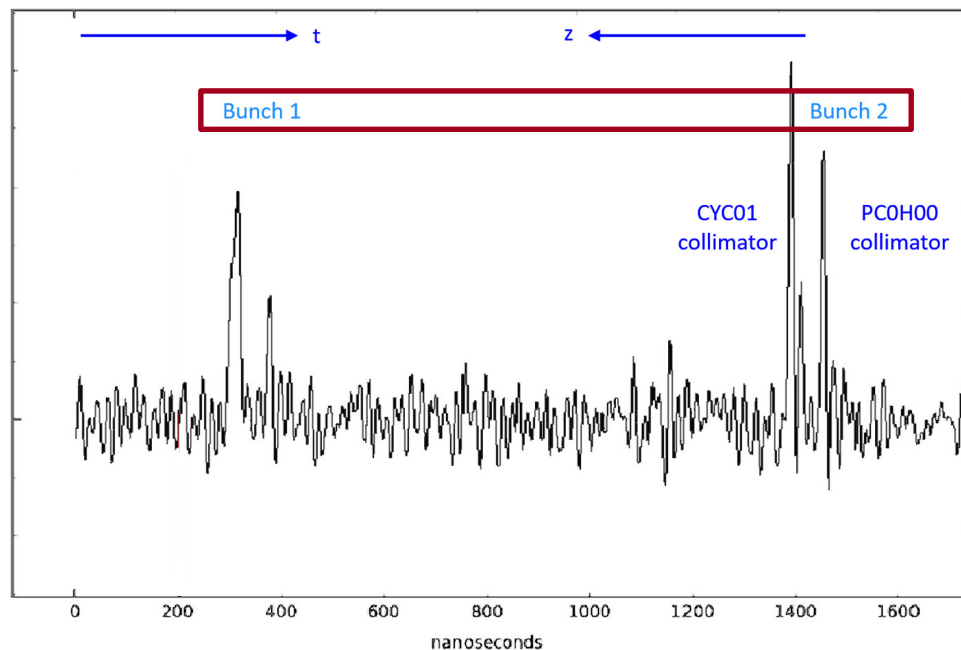
- Bursts with various trip thresholds
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- Some trips appear to happen slightly below the threshold: Readout offset
- MPS software combines dark current and the channel's digitizer offset
- Dark current contributes to BCS and MPS trips, but not included 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



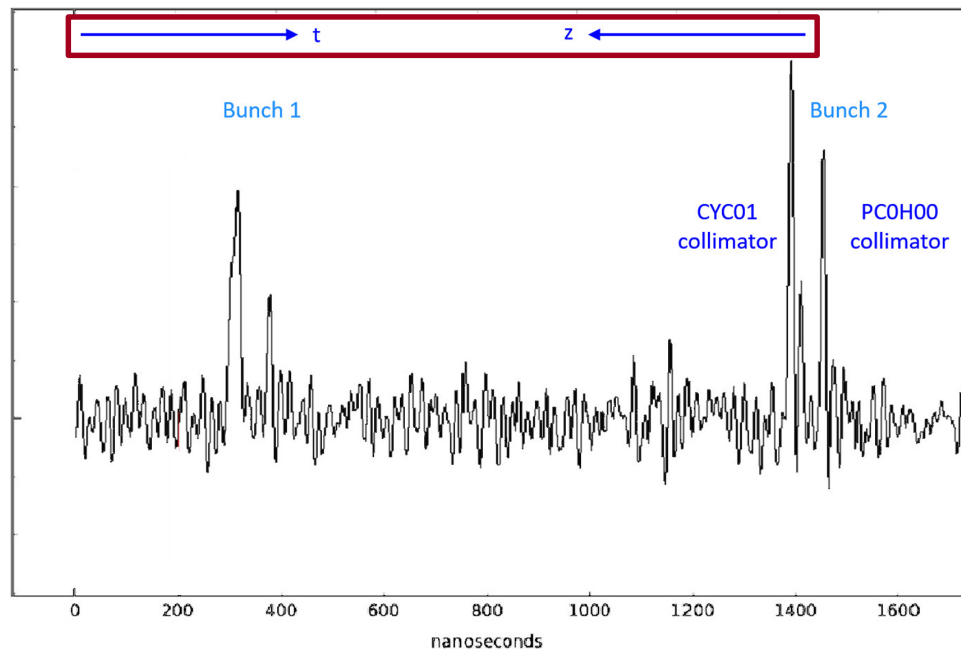
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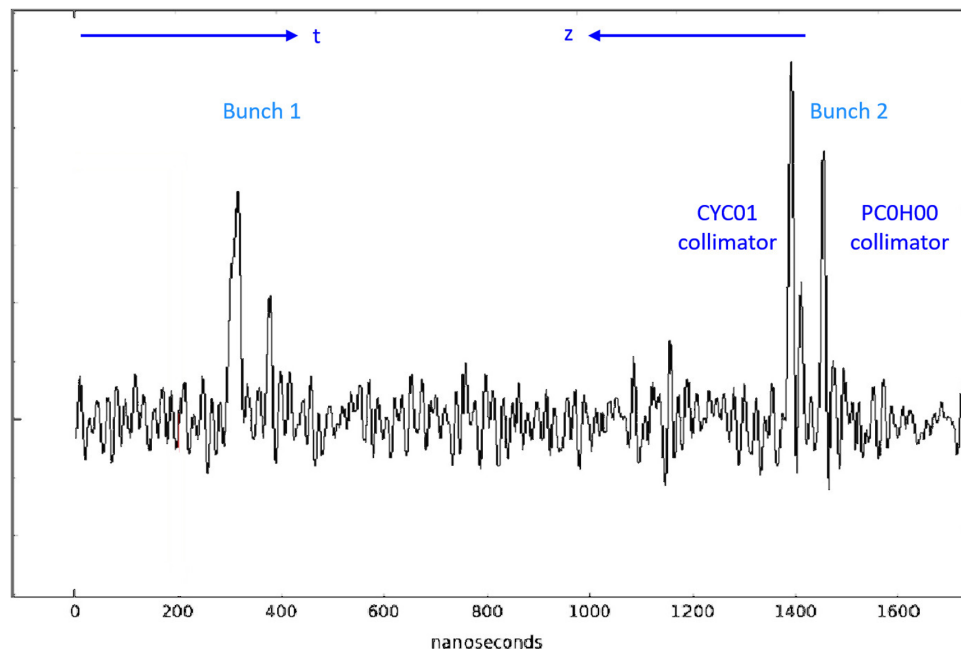
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- $t$  and  $z$  coordinates are reversed: Upstream loss signal arrives later
- 2 collimators, 38 m apart:
  - Beam first scraped on PC0H00
  - Then it hit CYC01

# 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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*Thank you!*