Beam Loss in the First Segment of the FRIB Linac

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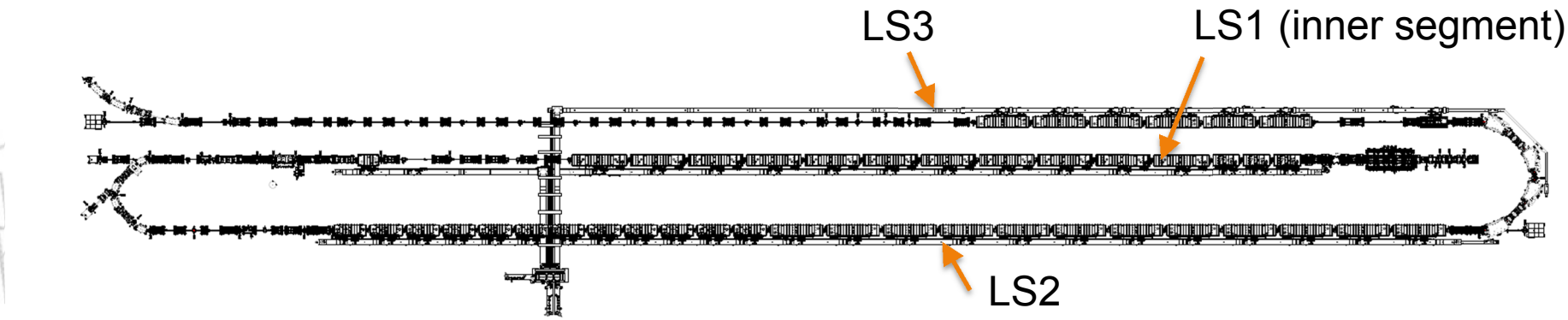
Motivation for Loss Monitoring

- Objectives:
  - Assist with tuning
  - Minimize component activation
  - Extend machine lifetime
  - Avoid beam damage
- Slow loss (~ seconds)
  - Machine background losses are small and typically change very gradually
  - Controlling regular background losses saves wear on machine
- Fast loss (~ microseconds)
  - Losses from part failure arise quickly and are often large
  - Fast identification of large losses is essential to prevent major damage

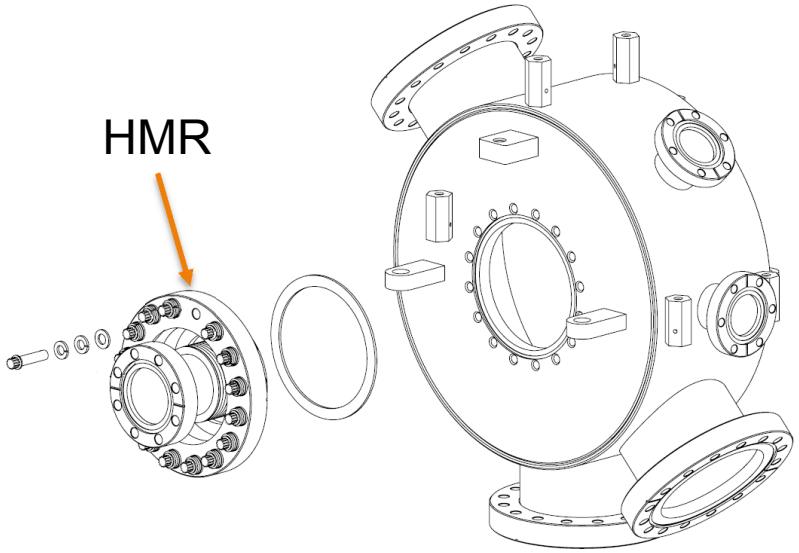
FRIB Faces Unique Challenges…

- High beam intensity
  - Intercepting devices must withstand up to 400 kW
  - Significant damage from misdirected beam is possible quickly
- Folded geometry
  - Only 1.5% of dose detected at LS1 is from LS1 losses
  - Cross talk from LS3 dominates low-energy half of LS2
  - Radiation cross-talk limits usefulness of standard radiation detectors
- Superconducting components
  - Radiative heating creates risk of magnet quenching



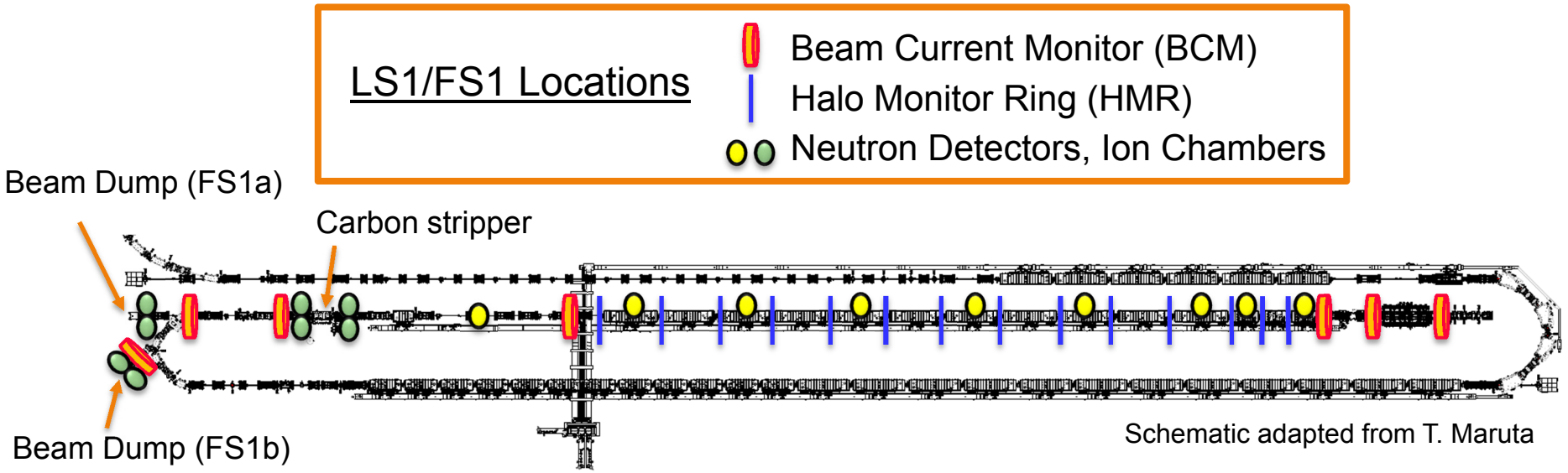
…Which Require Novel Solutions

- A variety of detectors and techniques are necessary
- Beam Measurements
  - Halo monitor rings (HMR)
  - Beam current monitors (DBCM)
- Temperature Measurements
  - Resistive temperature devices (RTD)
- Radiation Measurements
  - Neutron detectors (ND)
  - Ionization chambers (IC)



…And Thoughtful Deployment

- BCM distributed throughout accelerator
- HMR/Temp important for slow losses in LS1
  - HMR in boxes between cryomodules, RTDs within cryomodules
- BLM important for slow losses in rest of linac
  - ND primarily mounted to outside of cryomodules
  - IC mounted to magnet stands below beamline in folding segments (pairs)



First Segment Has Been Commissioned

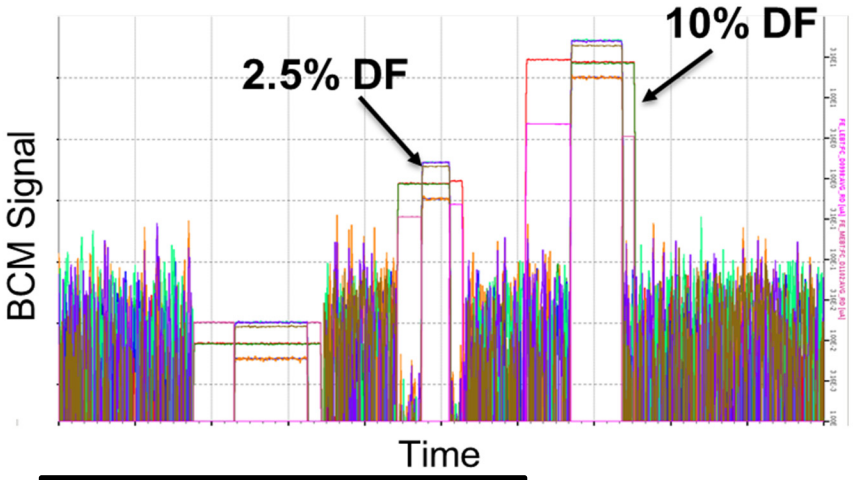
Commissioned →

		LS1	FS1	LS2 low energy	LS2 high energy	FS2	LS3	BDS
Fast Loss ~ 50 μs	**Primary**	DBCM	DBCM	DBCM	DBCM	DBCM	DBCM	DBCM
	Secondary	HMR	BLM	BLM	BLM	BLM	BLM	BLM
Slow loss ~ 1 s	**Primary**	HMR/Temp	BLM	BLM	BLM	BLM	BLM	BLM
	Secondary	HMR/Temp		Temp	DBCM	DBCM	DBCM	DBCM

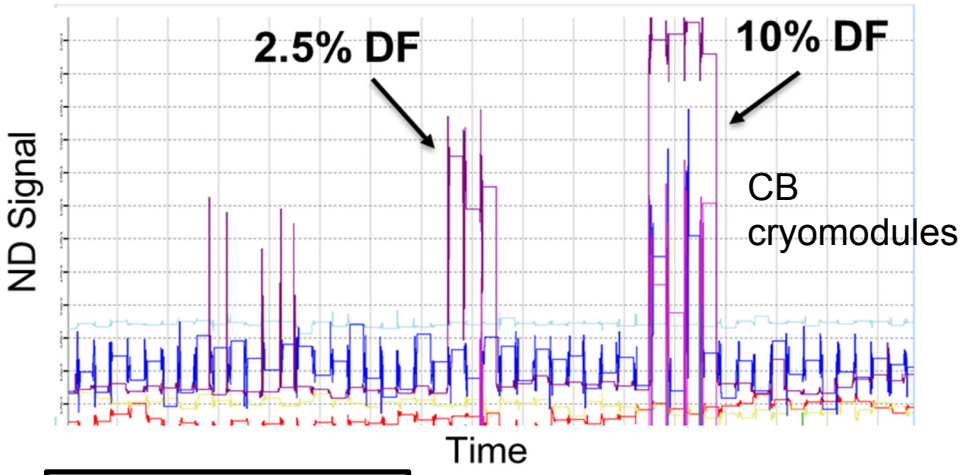
- BCMs and HMRs proved very useful in beam tuning
  - HMRs quiet after tuning, indicator of good beam focusing
- IC only saw losses from high-power tests
  - Data for pair of devices (same location, different pressures)
  - Signal ratio consistent with pressure ratio
- Neutron detector saw both low and high power beam
  - Signal spikes seen during profile monitor scans, use to calibrate

Beam Loss Observed in Suite of Detectors

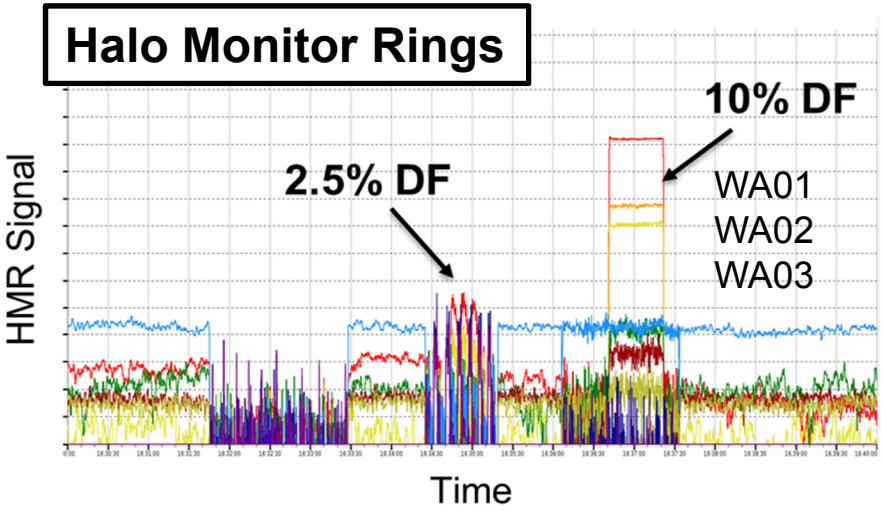
Beam Current Monitors



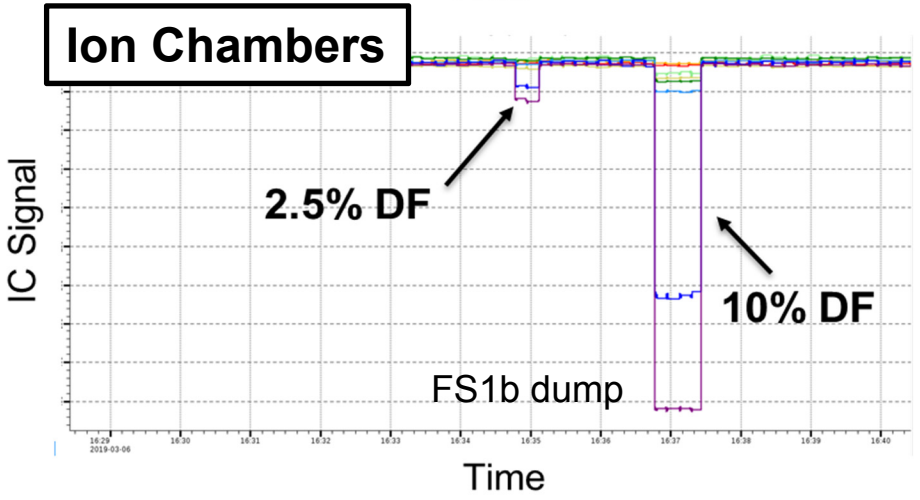
Neutron Detectors



Halo Monitor Rings



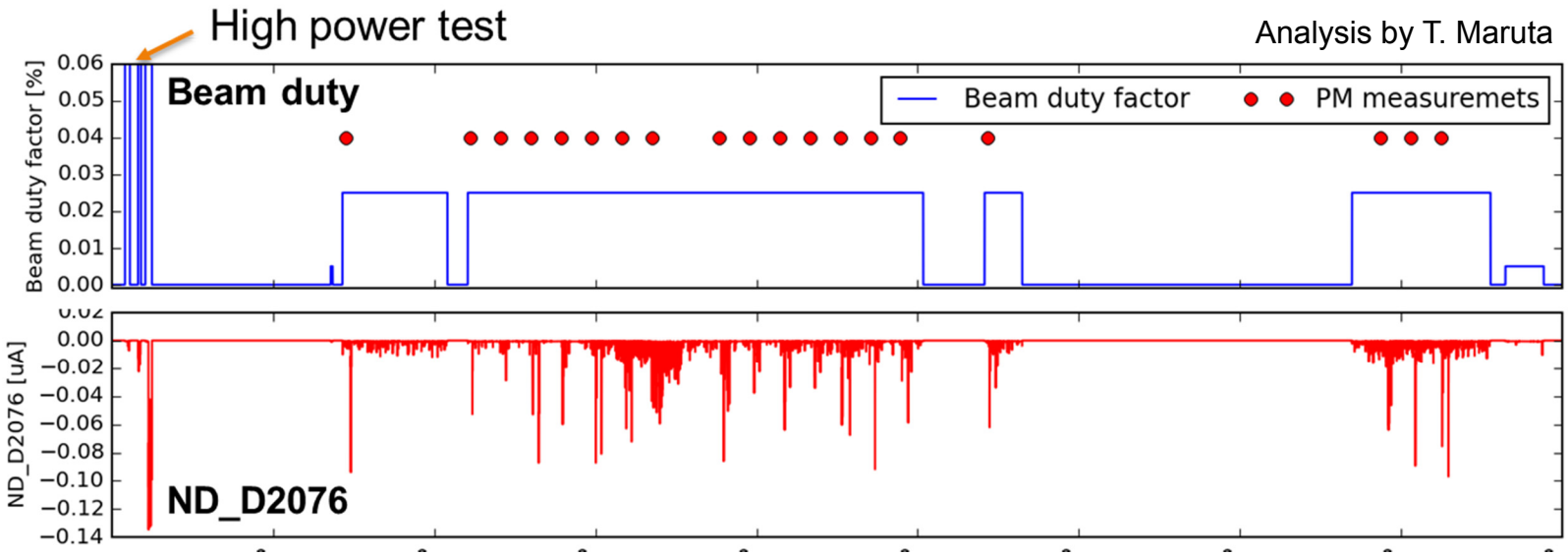
Ion Chambers



5 Hz averaged signals

Leverage Intercepting Devices to Calibrate

- Signal spikes seen in adjacent ND during profile monitor scans
- 19 scans with profile monitor PM_D2056 on March 6th
  - $^{40}Ar^{9+}$, 34 euA, beam duty 0.025% (5 Hz x 50 usec)
- Calibrate ND_2076 downstream of PM
  - Calculate loss due to PM wire moving through beam (0.5 W-sec per scan)
  - Integrate ND signal during PM measurement time period (Ave: -0.52 uA-sec)



Allows Estimate of Absolute Beam Loss

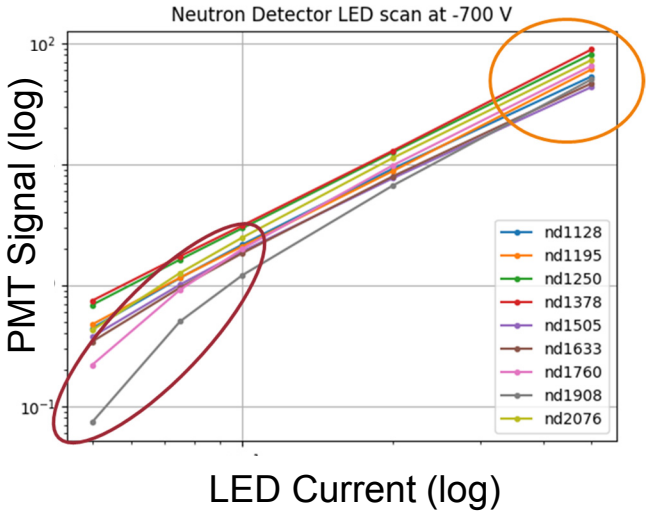
- Ratio of beam loss to ND signal is -0.96 [W/μA]
- Apply to low-power beam transport: ^{40}Ar beam @ 0.77 W
  - ND average signal: 0.00022 μA
  - 0.2 mW loss → 2.3E-4 fractional loss
- Apply to high-power losses:

	3/5		3/6	
Beam duty [%]	10%	2.5%	99.5%	10%
Beam peak current [euA]	34	34	3.2	3.1
Beam power [W]	308	74	288	28
Beam loss [mW]	47	12	76	10
Fraction	1.5E-4	1.6E-4	2.6E-4	3.6E-4

Analysis by T. Maruta

Maintaining Health and Performance

- Neutron Detector PMT
  - Built-in LED to monitor PMT performance
  - Track linearity of response (slope, intercept, R^2)
  - Linear up to saturation (signal >100 μA)
  - Two ND non-linear at low signal <1 μA



- Ion Chamber Pressure Monitoring
  - Pressure loss average <1% per month
  - Currently measure pressure manually
    - » Difficult and intermittent (check monthly)
    - » Imprecise and lose gas (open and close valve each time)
  - Switching to remotely-monitored strain gauge pressure sensor

- One IC found to be losing pressure
  - Reduced signal corresponding to pressure loss
  - Compared pair of adjacent (redundant) ICs

D2254/D2255	March	April
Pressure Ratio	1.5	1.0
Signal Ratio	1.4	1.1

Summary

- Geometry creates challenges for loss monitoring
  - Radiation cross talk mitigated by using novel devices, e.g. HMRs
- Loss Monitors in LS1 and FS1 segments were commissioned
  - HMRs and BCMs were very useful during tuning
  - ND saw loss at low and high power levels
  - IC responded to high-power tests → increase pressure for greater sensitivity
- One ND was calibrated using loss on PM wire
  - Beam losses on the order of 10^{-4} during both low and high power tests
- Performance evaluation and maintenance plans are underway