WEPM8X01

Collimation Design and Beam Loss Detection at FRIB

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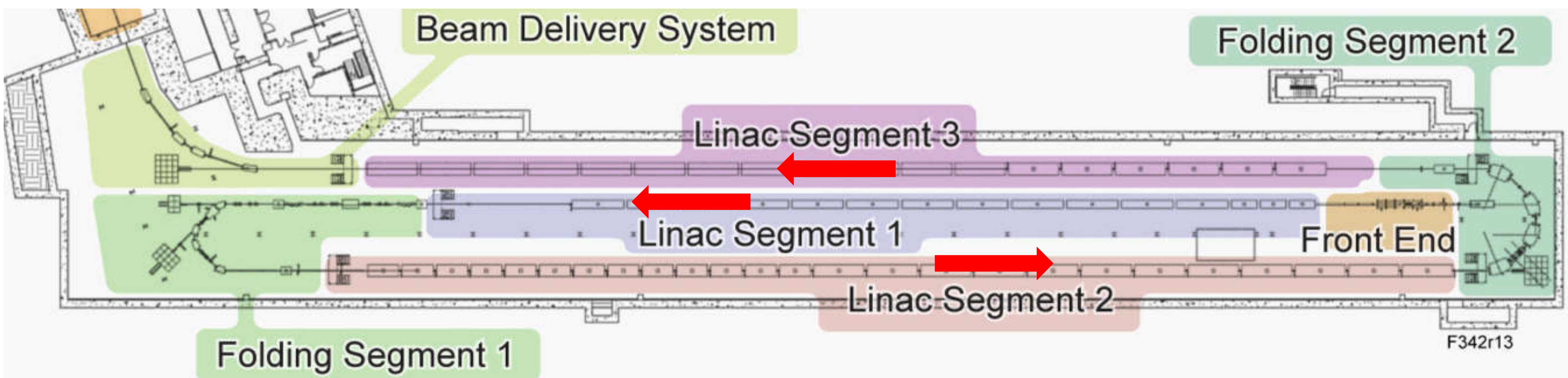
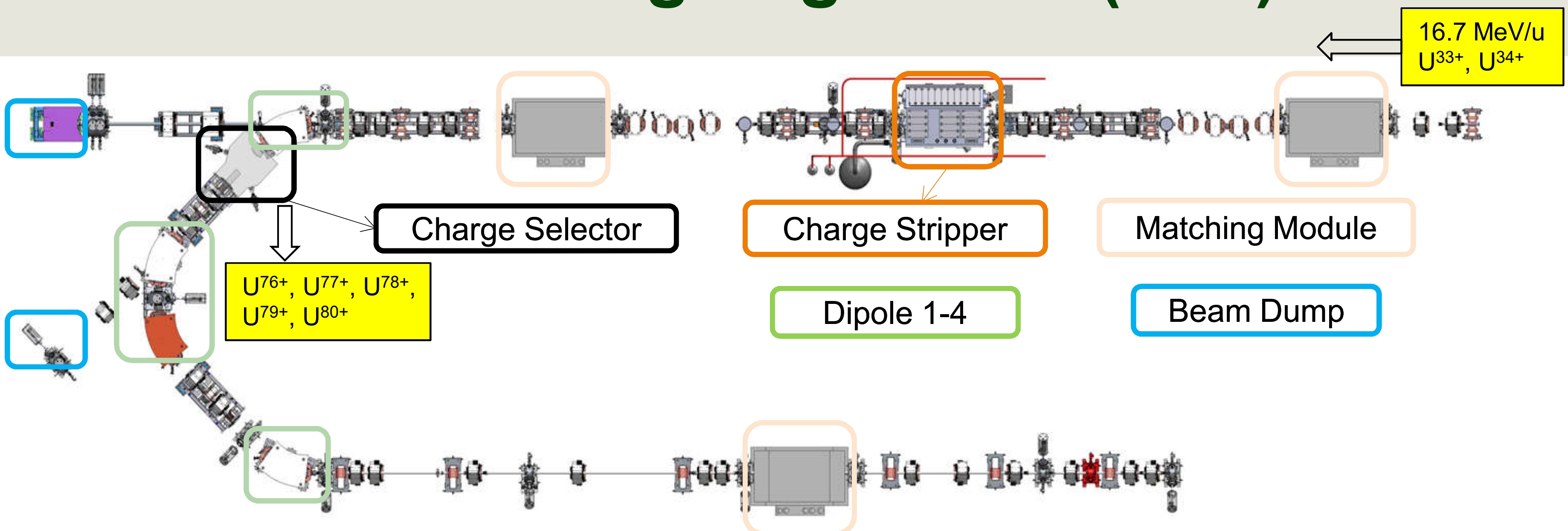
Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Outline

- Collimation design in FRIB Folding Segment 1
  - Collimation for losses due to contaminants from ECR source
  - Collimation for losses due to beam halo induced at charge stripper
  - Collimation for losses due to charge exchange with residual gas
- FRIB Beam Loss Monitor Network
  - Multi-layer loss monitor network to satisfy MPS requirements
  - Beam loss detectors and DAQ cards
  - Challenge of loss detection at Folding Segment 1
- Summary



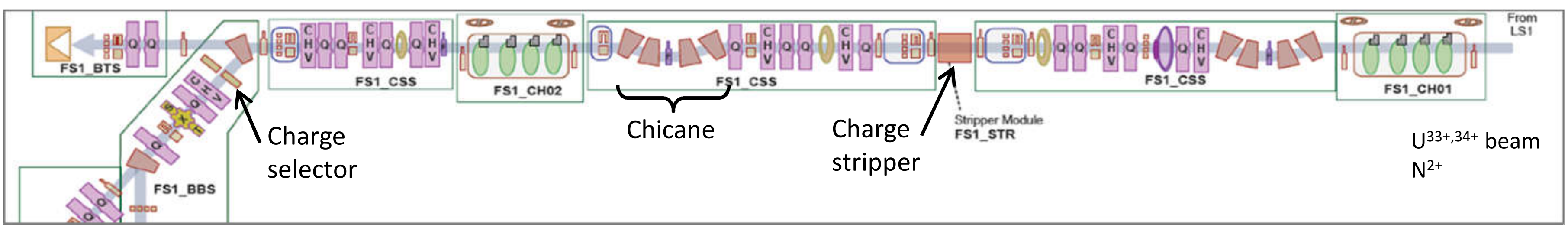
FRIB Folding Segment 1 (FS1)



- Particular Challenges of Beam Losses in Folding Segment 1
  - Contaminants from ECR source separated from beam after charge stripper
  - Beam halo induced at charge stripper or mistuned bending arc
  - Charge exchange with residual gas due to higher pressure in Folding Segment 1

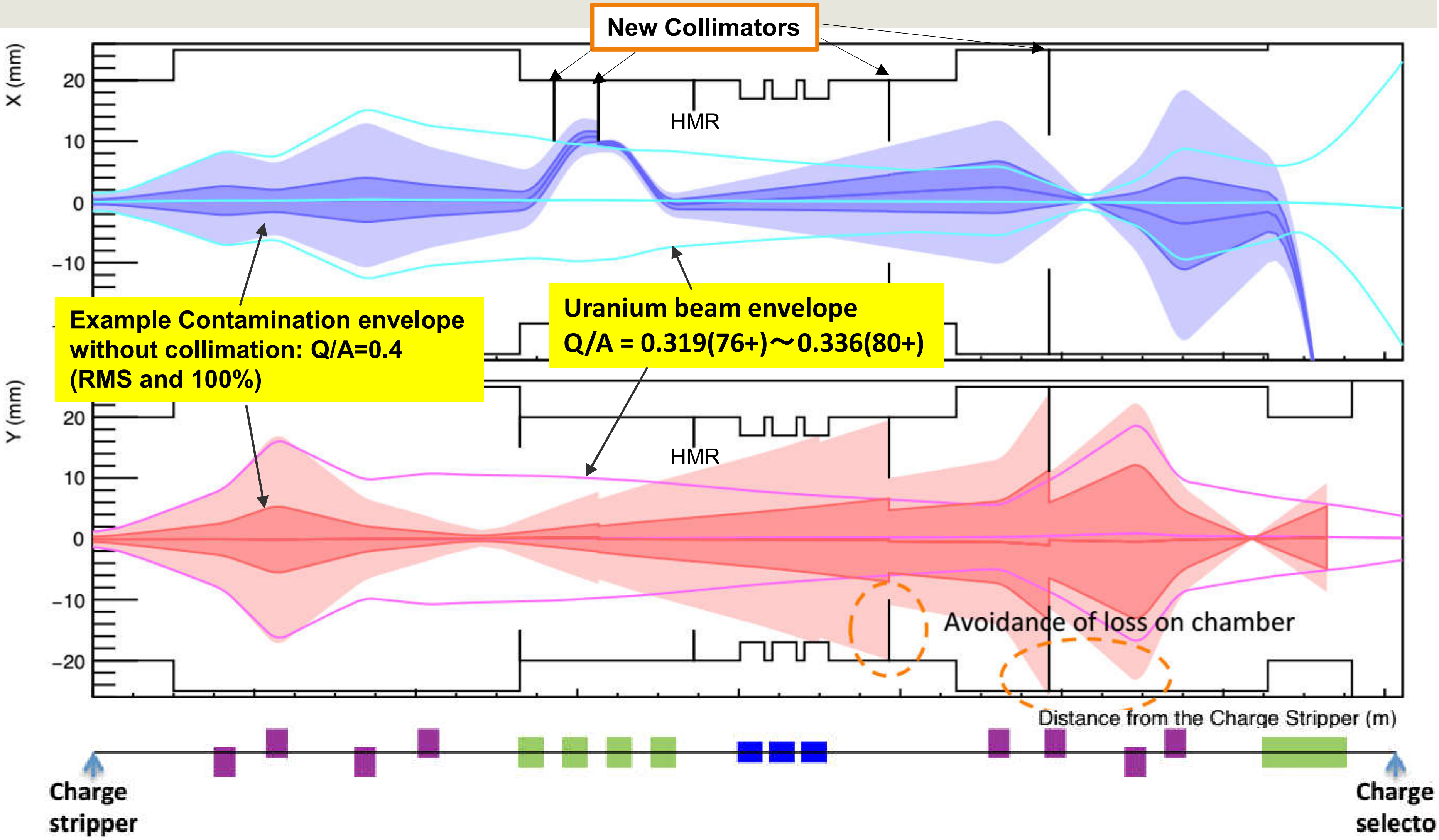
Beam Losses Due to Contaminants from ECR Source

- FRIB's high intensity requirement pushes higher microwave power of the ECR source, thus generating more outgassing particles (up to 5%)
- The most common contaminants are oxygen, nitrogen, carbon particles
- Contaminants that have the same Q/A could be accelerated in LS1
  - e.g. U^{34+} (Q/A = 0.143) ⇔ N^{2+} (Q/A = 0.143)
- After charge stripper, the contaminant has larger Q/A than the beam and different focusing and bending paths.
  - e.g. $U^{76+\sim80+}$ (Q/A = 0.319 ∼ 0.336) ⇔ N^{7+} (Q/A = 0.500)
- A chicane designed to prevent direct line of sight between the charge stripper and the SRF cavities bends differentially the contaminants, but only a fraction is stopped there



Courtesy T. Maruta

Collimator Locations for ECR Contaminants



Courtesy T. Maruta

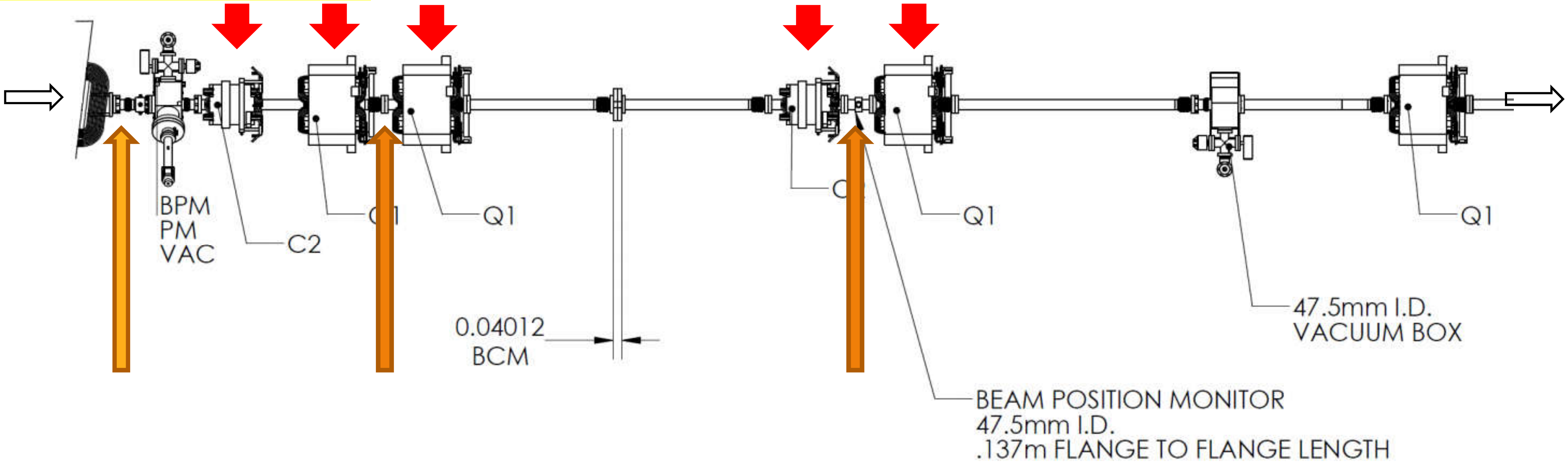
Halo-Collimation System After FS1

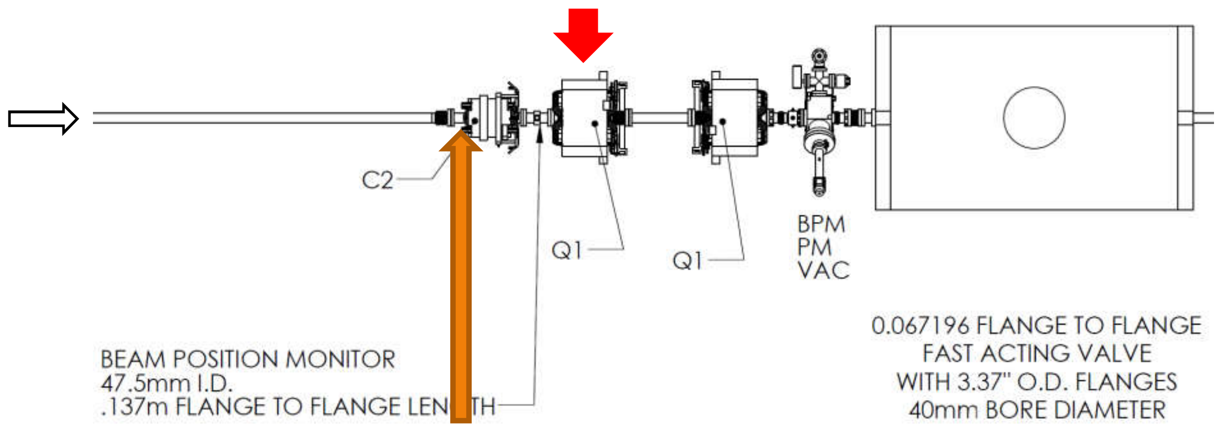
- Halo-collimation system should be planned after FS1 to protect critical equipment such as superconducting cavities
- Method:
  1) Artificially increasing the nominal beam size and tracking the locations of beam losses (MAD-X)
  2) Placing the collimators to protect critical equipment:
     » Magnets
     » SC cavities
     » Bellows
  3) Checking if the collimators intercept losses in case of bigger beams (MAD-X)
  4) Simulating energy deposition in the collimators (FLUKA)
  5) Simulating the projectiles (primaries and fragments) escaping from the collimators (FLUKA)

Courtesy V. Chetvertkova

Collimator Locations for Beam Halo

Lattice after arc in FS1





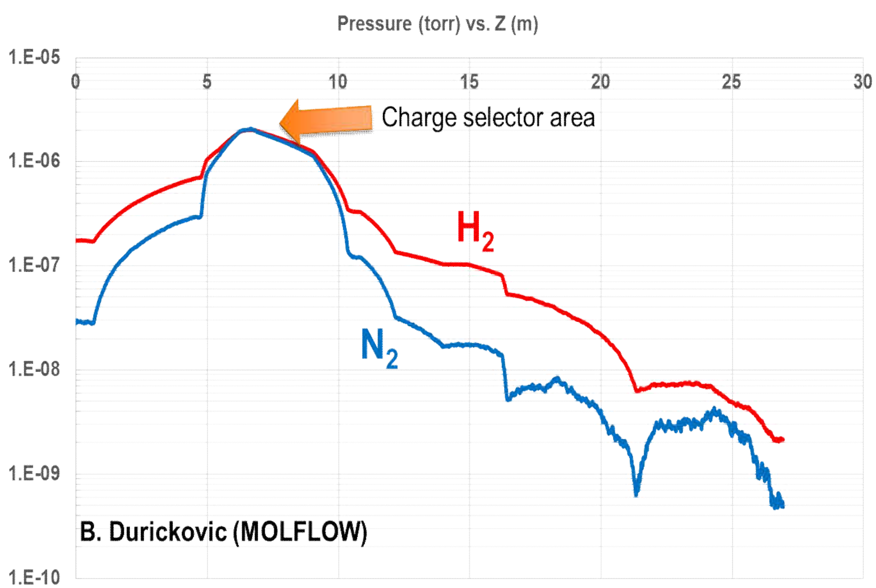
Locations of losses without collimators

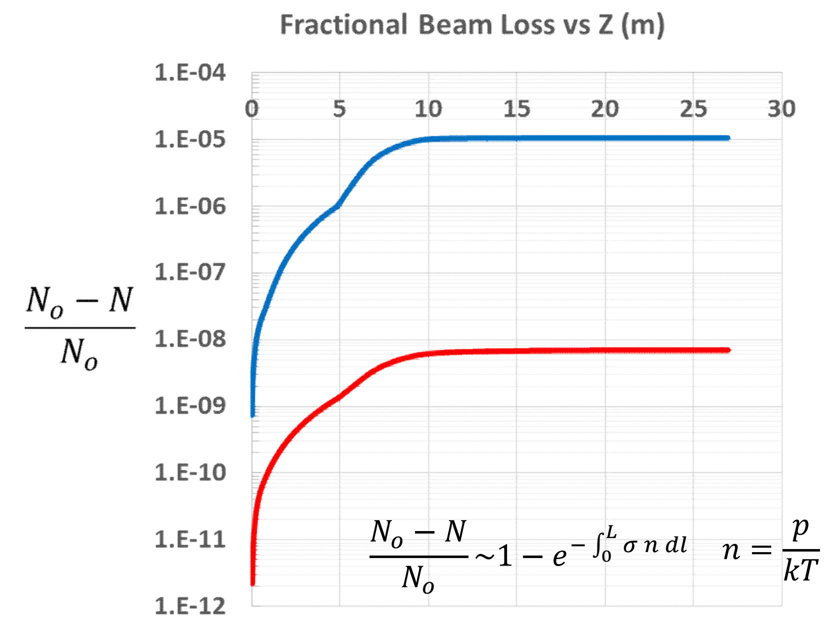
Locations of collimators

Courtesy V. Chetvertkova

Estimate of Charge Exchange Rate in FS1

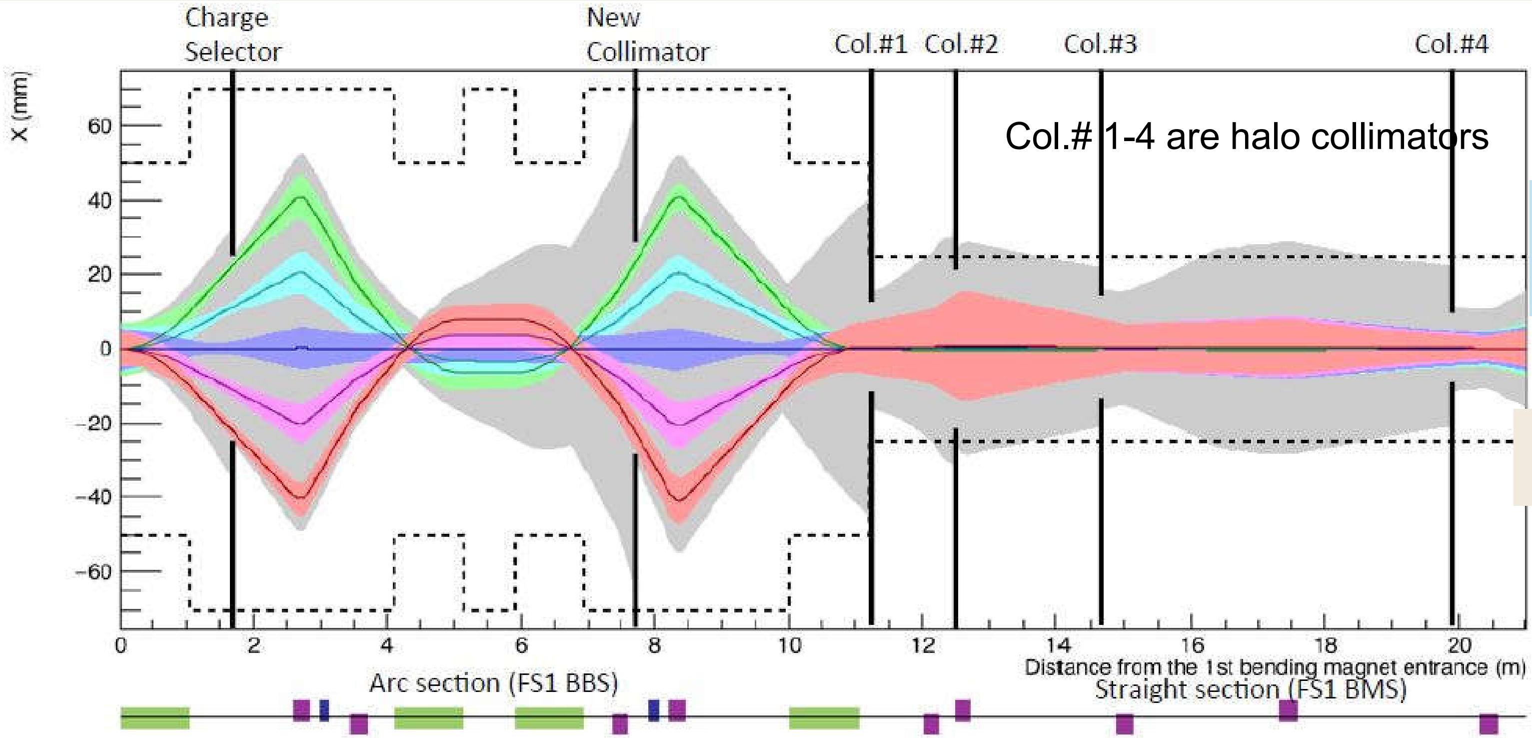
- According to the vacuum simulation in FS1, most charge exchange events occur at charge selector area
  - Fractional charge exchange rate for H_2 → 7 ppb
  - Fractional charge exchange rate for N_2 → 10 ppm





σ is electron capture cross section for U^{73+}

Location of New Collimator
(Assume Uniform Charge Exchange Over Whole Length)



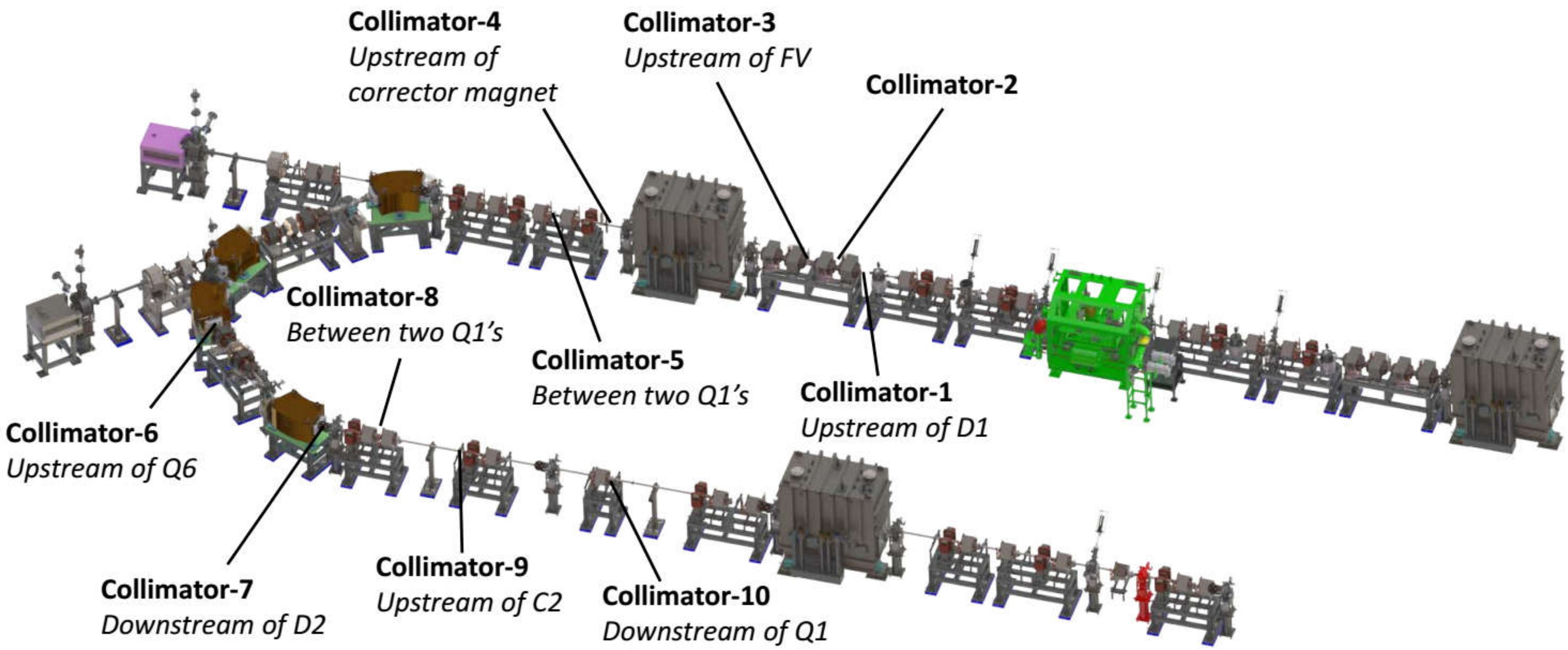
Color: primary beam (5 charge states)

Gray: Charge exchange particles

- **The charge exchanged particles generated around the charge selector are completely scraped by new and original collimators**
- If assume uniform charge exchange probability over the whole length of FS1:
  - ~80% are scraped by collimators in FS1
  - ~4% become beam loss in FS1
  - ~6% escape the collimators and lost in LS2. They could be blocked by HMR before cryo.

Courtesy T. Maruta

Summary of Collimator Locations in FS1



FRIB Challenges Conventional Loss Detection Approach

- The conventional BLM, i.e., ion chamber, does not work for significant part of FRIB Linac because
  - » Heavy ions produce less radiation
  - » Cavity X-ray background is high compare with low energy beam loss signal
  - » Significant radiation cross talk due to FRIB folding structure
- FRIB MPS requirement:
  - » BLM shall report large fractional beam losses to MPS in 15 μs
  - » BLM shall detect chronic small fractional beam loss of 1 W/m
- A multiple layer protection system to keep low-energy loss in a tolerable level:
  - » Differential BCM features large fractional beam loss detection
  - » Halo Monitor Ring (HMR) installed before cryomodules features direct loss measurement with high sensitivity
  - » Fast Thermometry System (FTS) installed before/after solenoid features in-cryomodule chronic small loss detection

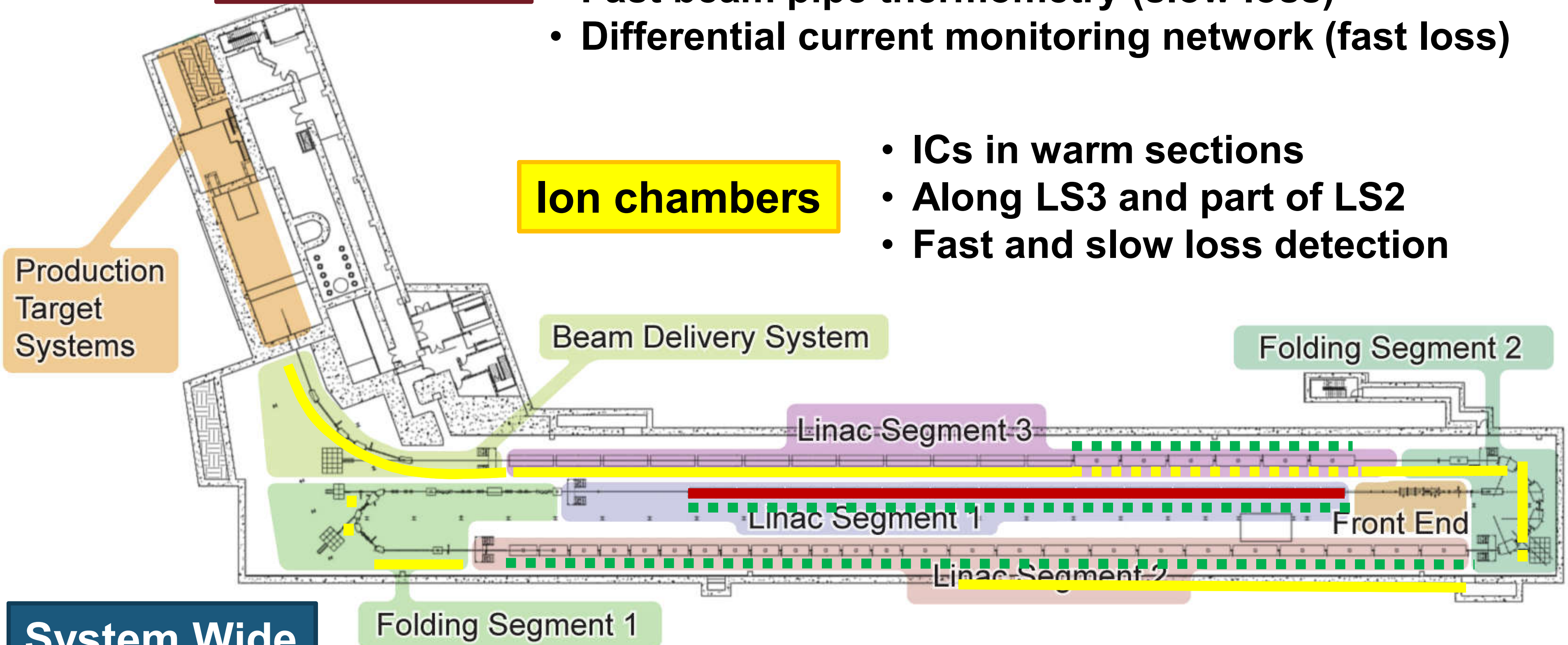
FRIB Beam Loss Monitoring Network

LS1 monitors

- Halo monitor rings (fast/slow loss)
- Fast beam pipe thermometry (slow loss)
- Differential current monitoring network (fast loss)

Ion chambers

- ICs in warm sections
- Along LS3 and part of LS2
- Fast and slow loss detection



System Wide

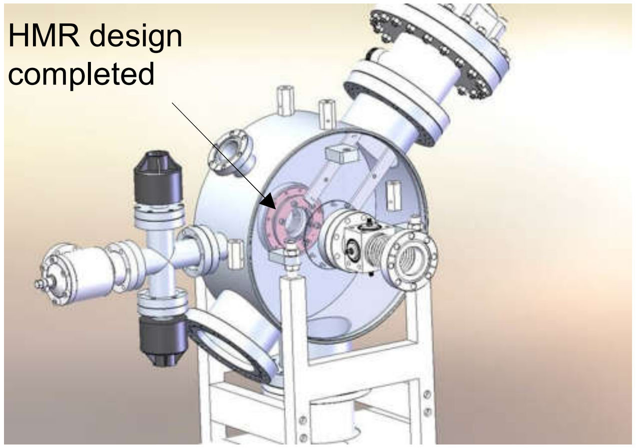
- DBCM
- HMR

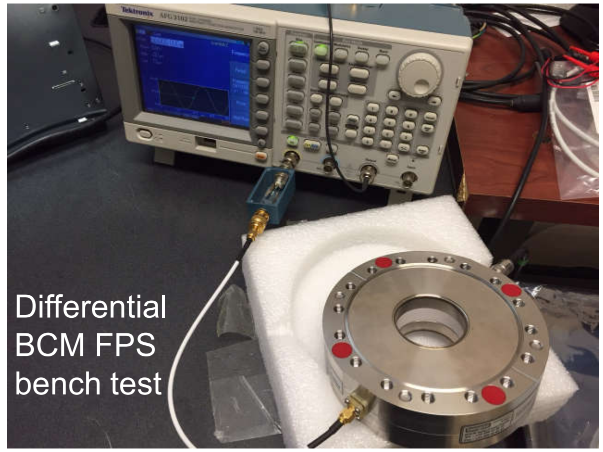
not shown here

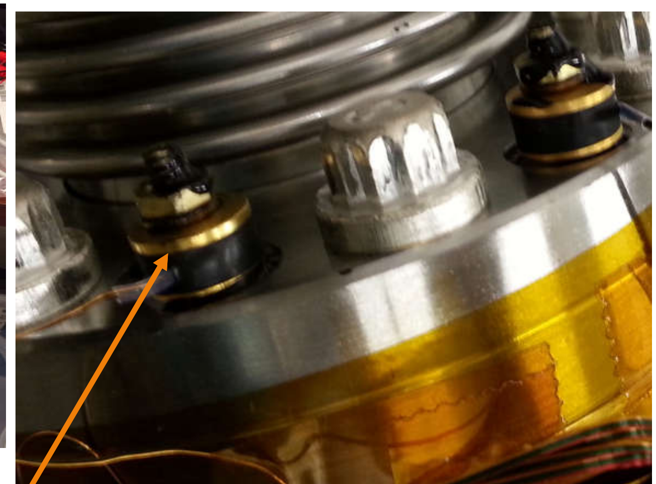
Neutron detectors

- Bkgd, LS1 (tuning only)
- Slow detection

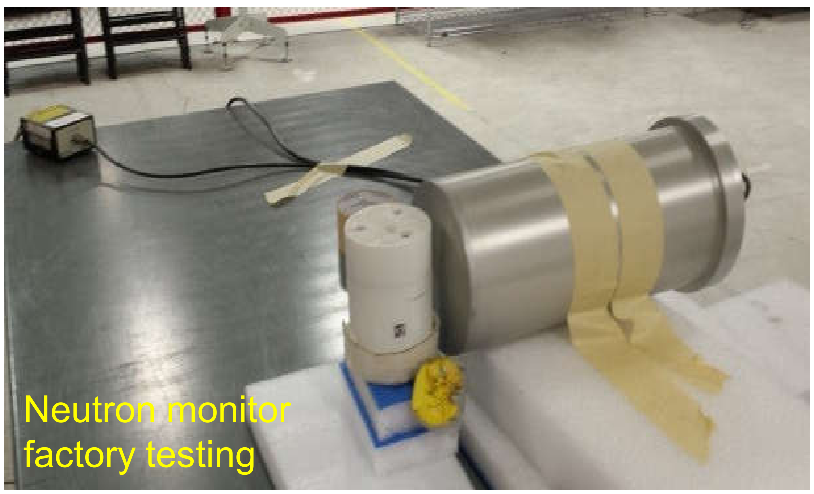
FRIB Beam Loss Detectors



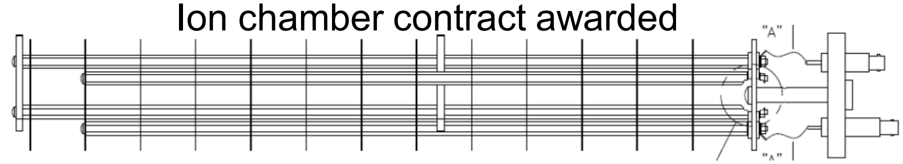




Cernox sensors and temp. sensor for FTS



Ion chamber contract awarded



Detector Signal Amplitudes and Acquisition Times are Defined

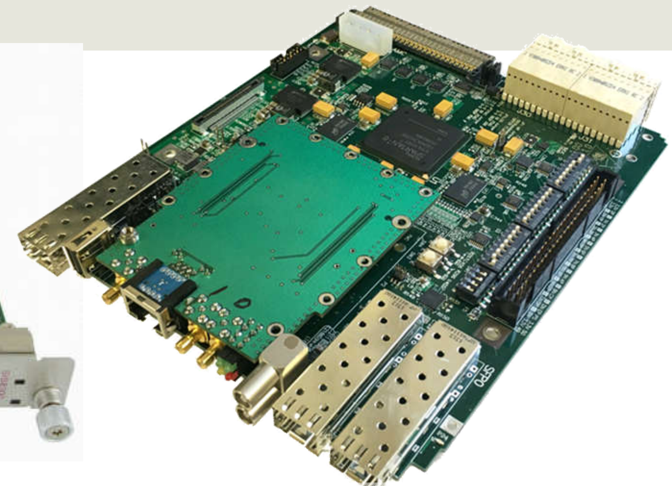
- Per MPS requirements, we have defined the minimum signal amplitudes with acquisition times for beam loss detectors, which requires certain noise levels, dynamic ranges and integration windows on the DAQ
- Example: Ion chamber imposes stringent requirement on DAQ card noise (10% of 350pA in 150µs)

Ion chamber's signal estimation based on minimum sensitivity requirement

	LS2&FS2 70MeV/u	**LS3** 200MeV/u	**Time Window**	**Correspondence to beam power loss level in watt/meter**
Ion Chamber (minimum sensitivity requirement 1.5nA/R/hr)	3pA	42pA	1.5sec	0.1 W/m loss
	35pA	420pA	15ms	1 W/m loss
	350pA	4nA	150µs	10 W/m Loss
	3.5nA	42nA	15µs	100 W/m loss

3pA to 10uA		Dynamic range window 1 (for normal operation)
1nA to 100µA		Dynamic range window 2 (for beam dump area)

MicroTCA DAQ Cards for Loss Detectors



CAENels AMC-PICO-8
8 chan @ 1MS (35kHz BW)

- 66x Halo Ring Monitors
- 42x Ion Chambers
- 24x Neutron Detectors
- 8x Faraday Cups
- 2x Allison Scanner
- 41x Profile Monitors

Struck SIS8300-L2
10 chan @ 125MS

- 12x Beam Current Monitors (Differential BCM)

FRIB Digital Board
General purpose to 125MS

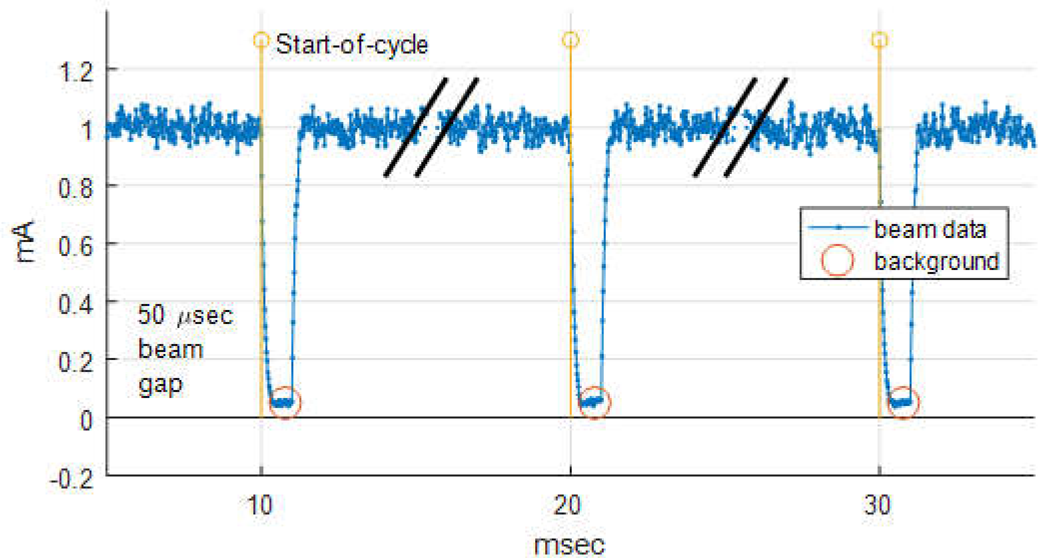
- 147x Beam Position (BPM)
- 20x Event Receiver (EVR)
- 20x Fast Protect System (FPS)

75% of devices covered by these three MicroTCA cards

All support fast response for Machine Protection System (MPS and FPS)

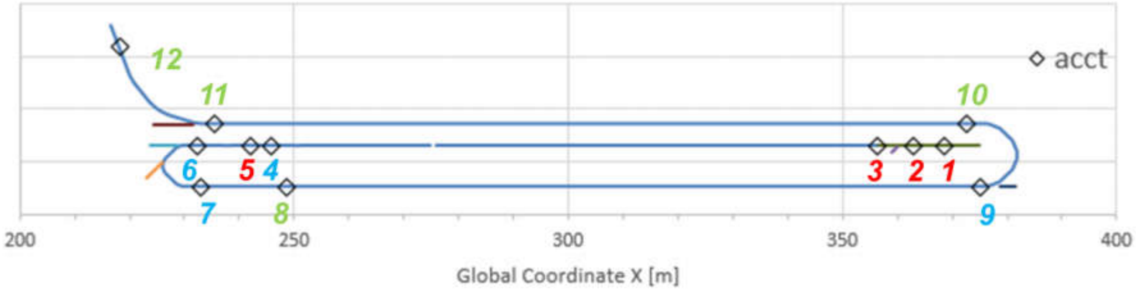
Background Signal Subtraction

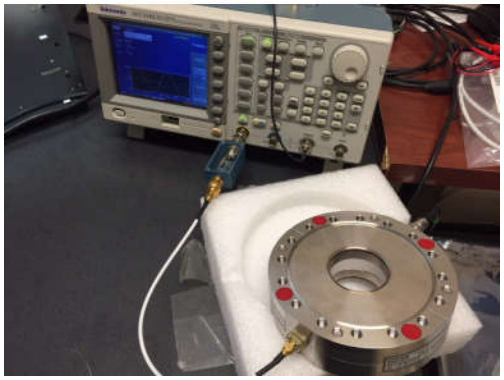
- All three fast DAQ cards are capable to do background signal subtraction during the 50 μs beam gap period. This implies that all DAQ electronics have fast enough response time (at least 35 kHz signal bandwidth)
- Depending on the signal, background sampling may be used to remove electrical measurement offsets or background signal (e.g. ion chamber signal due to cavity X-ray background)

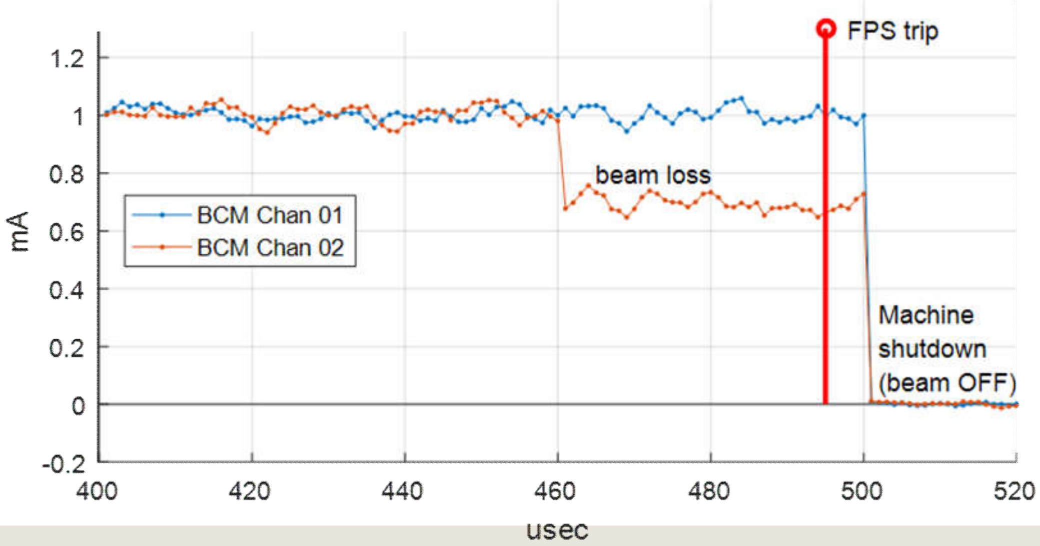


Differential BCM FPS Validation

- Differential BCM signals demonstrated using function generator
- Custom firmware developed and FPS trip on differential loss is verified
- We plan to sample power line harmonics (60 Hz, 180 Hz) and subtract this power line noise signal prior to differential BCM







Feasibility Study of FTS for In-Cryomodule Slow Losses

- ~12% of in-cryomodule loss power will be distributed right before solenoid
- Cernox sensors are installed upstream of solenoid
- The FTS is experimentally proved to be able to detect 5mW loss power in a minute

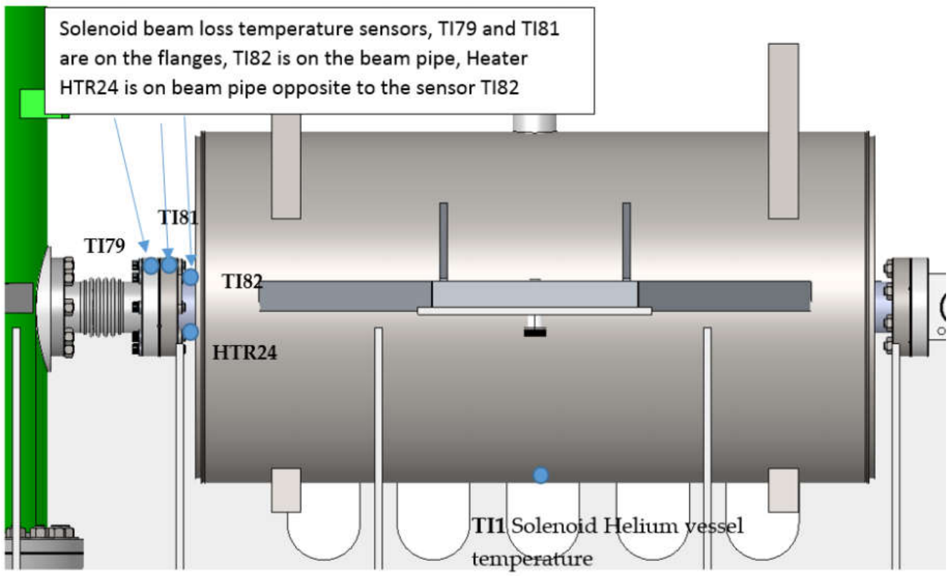


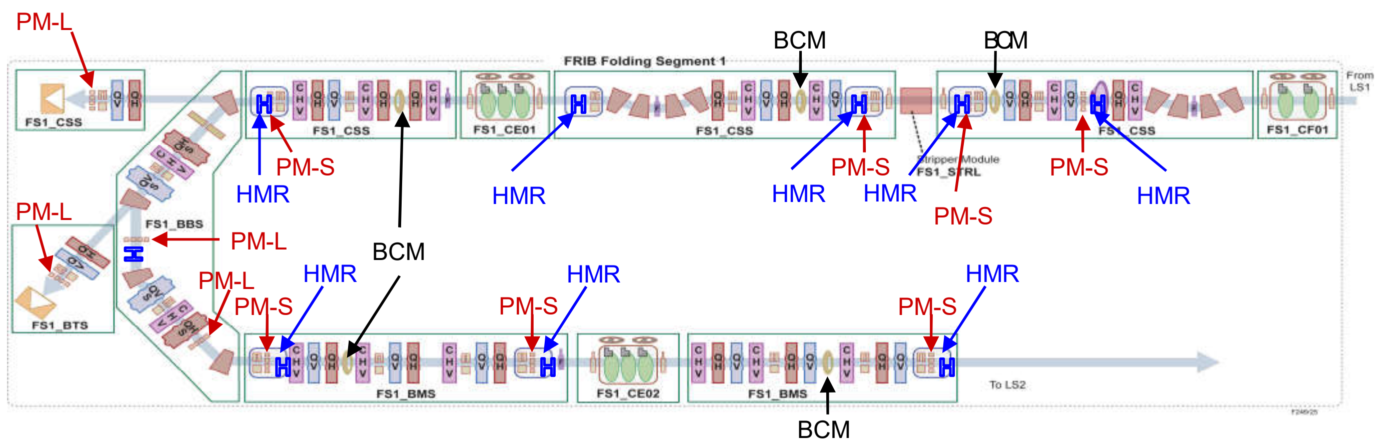
Table 1: Summary of TI82 Measurement Data

Heat Load	Delay	$t_{response}$ for 10mK change
2 mW	83 s	303 s
4.5 mW	17 s	107 s
12.5 mW	14 s	50 s
32 mW	11 s	29 s
50 mW	10 s	21 s
98 mW	11 s	17 s
1013 mW	10 s	11 s

Z. Zheng et al, "Cryogenic thermometers as slow beam loss detectors", Proceeding of IBIC2015

Challenge of Loss Detection in FS1

- Large intentional beam losses at stripper, charge selector and collimators will make it difficult to detect uncontrolled losses in FS1
- We will measure beam current at different locations. Changes in the ratio will be interpreted as unexpected changes in the losses
- If the intentional loss is stable on the time scale of slow loss monitoring, small uncontrolled loss detection is feasible:
  - DBCM: sensitive to few μAs; PM: easy to detect 10^{-3}; HMR: sensitive to few nAs
  - Considering to instrument collimators in arc for differential monitoring there



Summary

- Collimation systems are particularly designed for
  - ECR contaminants that are separated from primary beam after stripper
  - beam halo induced by stripper or bending arc
  - potential charge exchange with residual gas due to higher pressure in FS1
- Due to FRIB folded structure, linac faces big challenges on loss detection. A loss monitor network is designed to fulfill MPS requirements (15μs for large losses and 1 W/m slow losses)
- Large intentional losses in FS1 make loss detection very difficult there. If the intentional losses are stable on the time scale of slow loss monitoring, we should be able to detect small uncontrolled losses

THANK YOU