Diagnostic Data Acquisition Strategies

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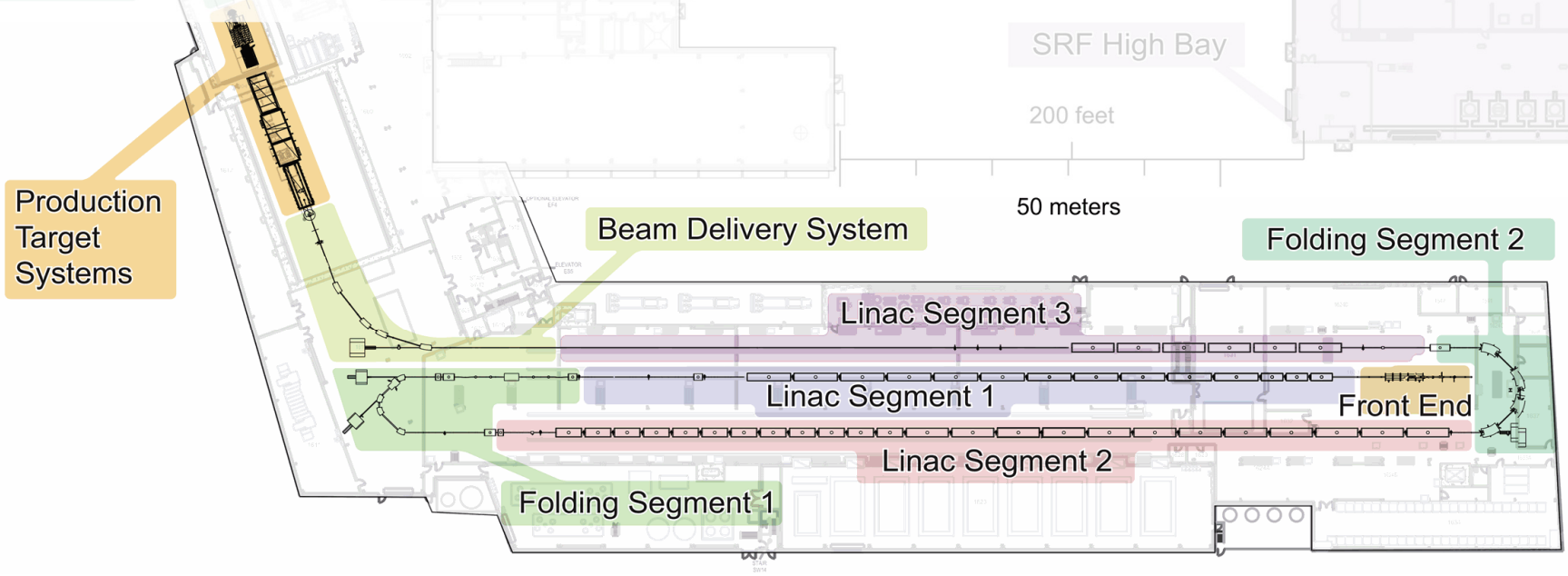
U.S. DEPARTMENT OF ENERGY | Office of Science

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. 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.

Facility for Rare Isotope Beams

… a new scientific user facility for nuclear science, funded by the Department of Energy Office of Science (DOE-SC), Michigan State University (MSU), and the State of Michigan. Under construction on campus and operated by MSU, FRIB will provide intense beams of rare isotopes.

- Accelerate ion species Ar to U (simultaneous multi charge states)
- Energies of no less than 200 MeV/u
- Provide beam power up to 400 kW

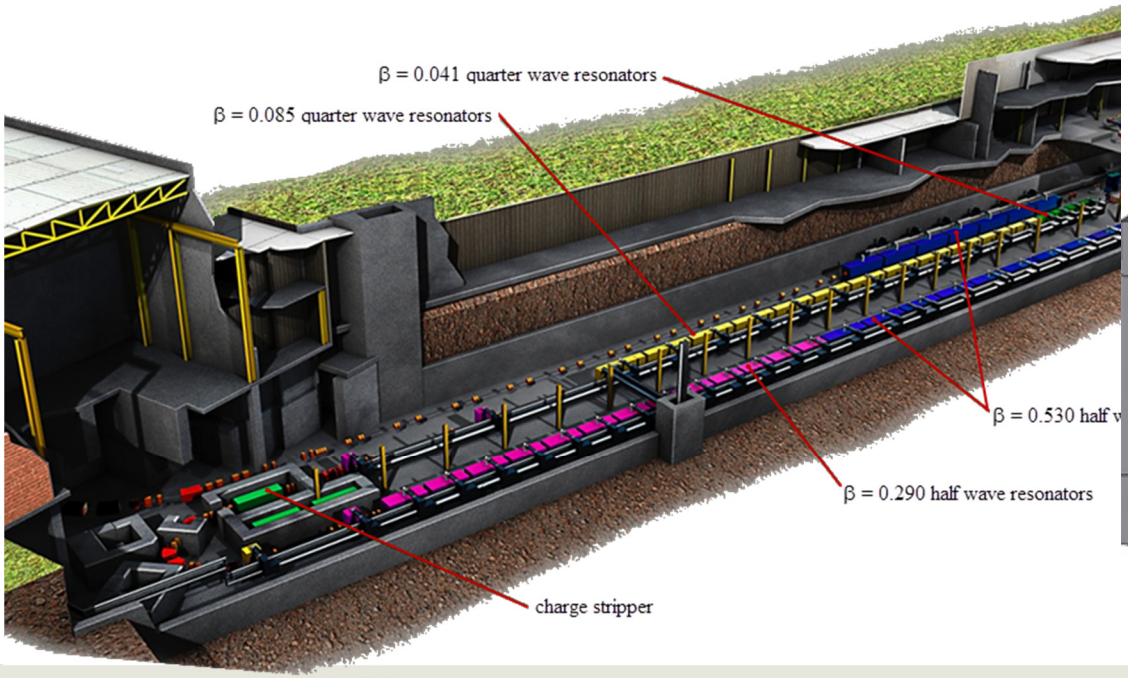


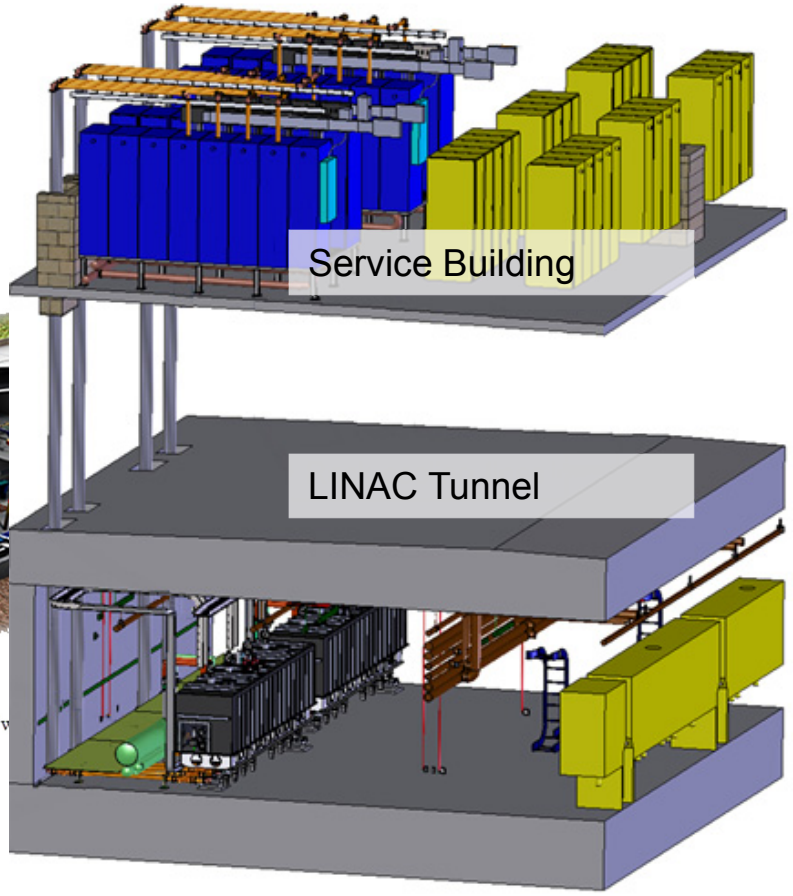
Diagnostic Data Acquisition Strategies

- … focus to ***accelerate development*** and ***simplify maintenance***
- FRIB diagnostic environment
  - Beam modes
  - Machine protection
  - Global timing
- Selecting electronics platform
- Data acquisition hardware
- Data reporting

Service Building and Tunnel Interface

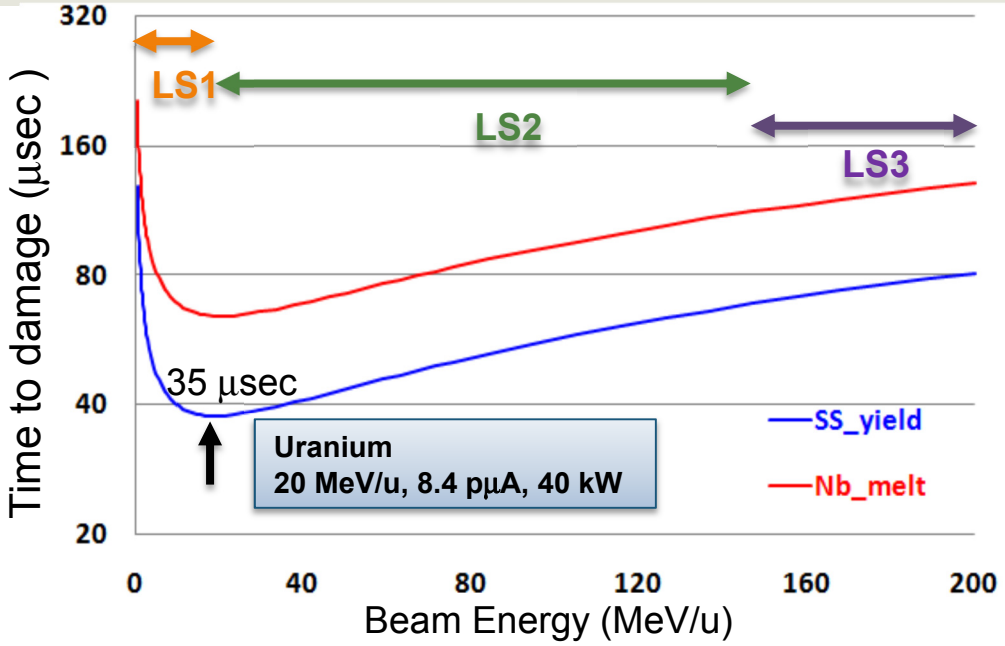
- **No electronics in the tunnel!**
- Penetration conduits and racks are laid out for instrumentation
  - Cable runs about 100 ft

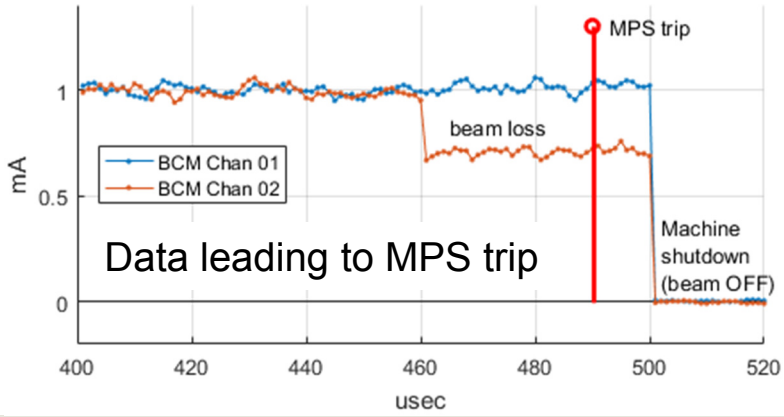




Machine Protection System (MPS)

- Diagnostics requirements primarily driven by MPS
  - Avoid accelerator component damage
  - Minimize residual activation
- Detect beam loss and respond
  - 35 μsec total time (worst case)
  - 15 μsec to detect 100% beam loss
  - Chronic small losses of 1 W/m or less
- 15 μsec → real-time decision
  - Custom firmware integrated (FPGA)
  - Fast sampling data, >= 1 MS/s
  - Response time <= 5 usec (35 kHz)
  - Post-mortem data analysis → timestamp synchronization
- Key MPS diagnostic devices
  - BCM: Beam current monitor (differential)
  - BLM: Beam loss monitors (halo ring, ion chamber, neutron detector)
  - BPM: Beam position monitor





Diagnostic Devices, Front End to Target

Accelerator Systems - Diagnostics	TOTAL	FE	LS1	FS1	LS2	FS2	LS3	BDS
*Beam Position Monitor **	149	4	39 + 20	18	24	12	22	10
*Beam Current Monitor (ACCT) **	12	3		5		2		2
*BLM - Halo Monitor Ring **	66		17	8	24	4	13	
*BLM - Ion Chamber **	47						15	12
*BLM - Neutron Detector **	24	1					1	
*BLM – Fast Thermometry System**	240							
Profile Monitor (Lg., Sm. Flapper)	41	7L/3S/3F					4S	2L/5S
Bunch Shape Monitor	1			1				
Allison Emittance Scanner (2 axis)	2	2						
Pepper pot emittance meter	1	1						
Wire Slit Emittance Scanner (2 axis)	1	1						
Faraday Cup	7	7						
Fast Faraday Cup	2	2						
Viewer Plate	5	5						
Selecting Slits System - 300 W	5	5 axes						
Collimating Apertures - 100 W	2	2						
Intensity Reducing Screen System	2	2						

Continuously acquiring fast devices (MPS)

Intermittent use waveform data acquisition

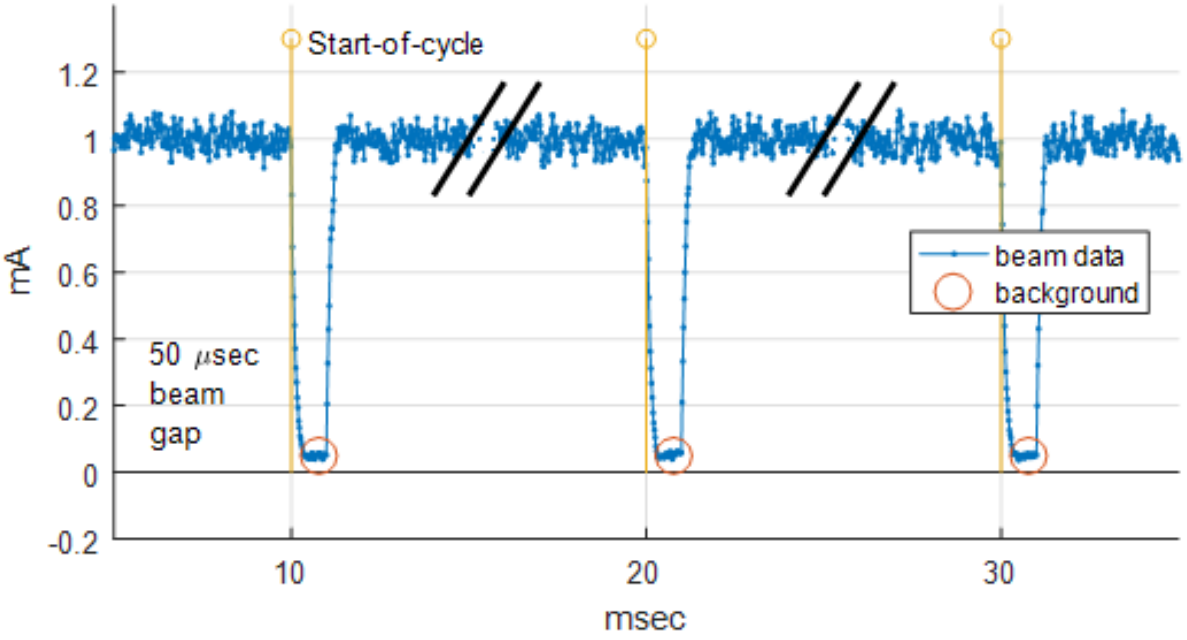
606 total diagnostic devices

** Machine Protection, Fast Response*

Beam Structure and Timing System

- CW Beam Operation
  - 50 μsec beam gap introduced ~100 Hz
    - » reset AC-coupled current transformer readings
    - » sampling of signal background
  - 99.5% active duty factor
  - 10 msec machine cycle period

- Global Timing System (GTS)
  - Distribute timing events to all fast devices
  - Events include:
    - » Start-of-cycle (every 10 msec)
    - » Beam ON / OFF
    - » Global timestamp (synchronization)

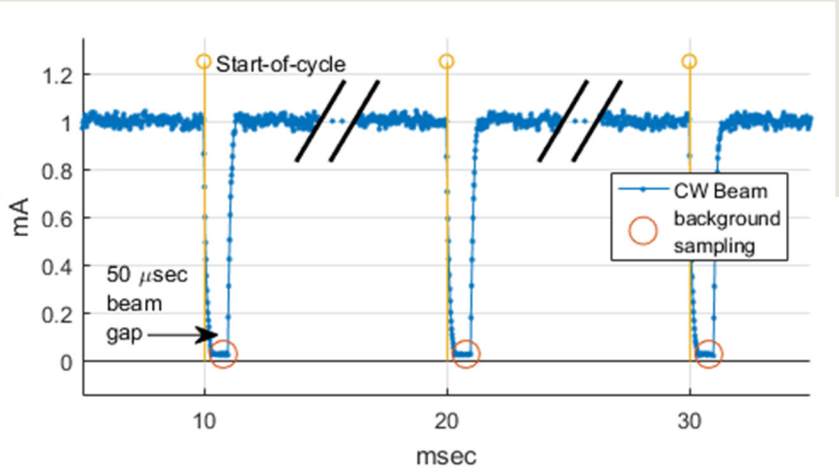


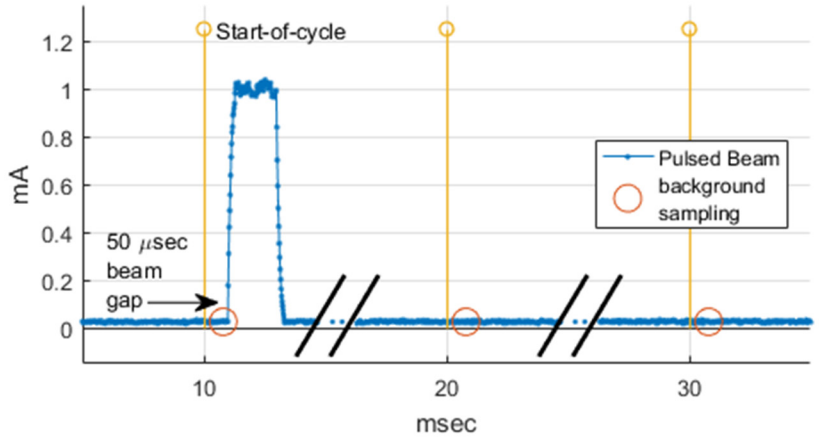
All diagnostics DAQ systems need beam state & timing.

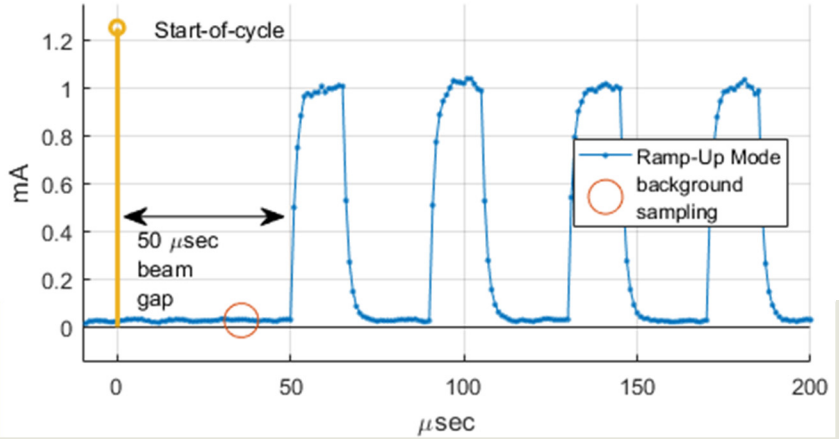
Beam Modes

- Continuous beam (CW)
  - 99.5% active duty factor
- Pulsed modes
  - Low duty factor for commissioning and tuning
- Ramp-up modes
  - Slowly heat target, avoid thermal shock
  - Duty factor ramps from 0% to 99.5%

All modes utilize 10 msec period structure, with 50 μsec beam gap at beginning of each cycle.

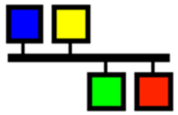




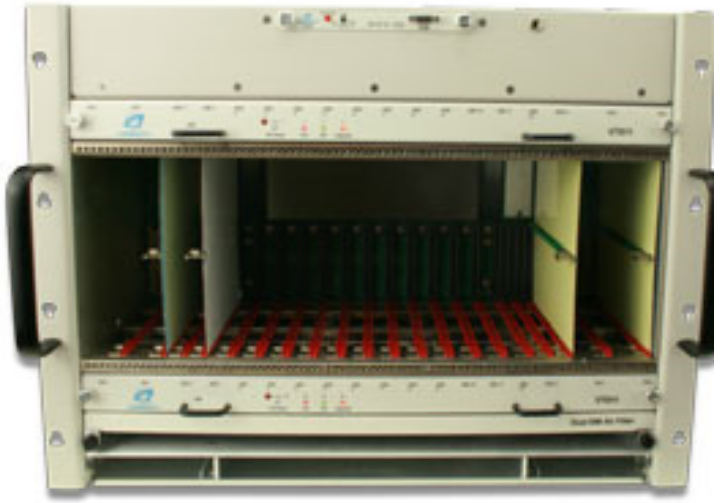


Choosing Scalable Electronics Platform

- Hundreds of diagnostic devices, which …
  - Fast data acquisition (>= 1 MSPS)
  - Interface with Machine Protection System (MPS)
  - Interface with Global Timing System (GTS)
  - Get data to EPICS network (Ethernet)



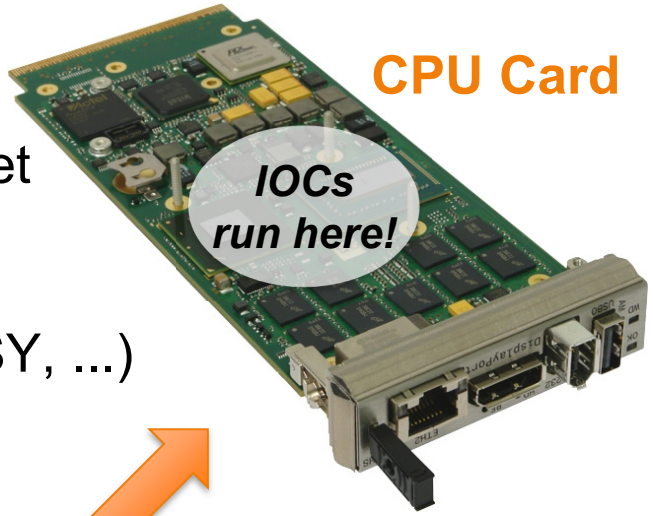
- Considered “pizza box”
  - Enclosed system for each device type



- Chassis-based system (VME, MicroTCA)
  - Allows consolidation of MPS, GTS and Ethernet
  - Distribute signals along backplane
  - Multiple cards share CPU, power module, etc
  - Commercial off-the-shelf modules

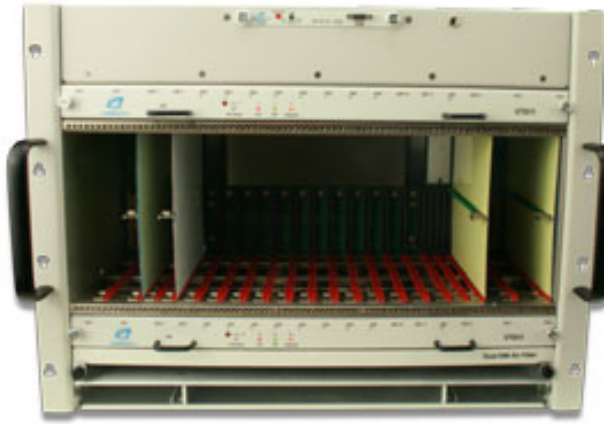
MicroTCA.4 for Diagnostics Platform

- MTCA.4 compelling features
  - Modular, 12 payload cards
  - Fast data busses on backplane, PCIe and Ethernet
  - Remote management & monitoring
  - EPICS IOC drivers centralized to single CPU
  - Industry support (PICMG), community users (DESY, ...)

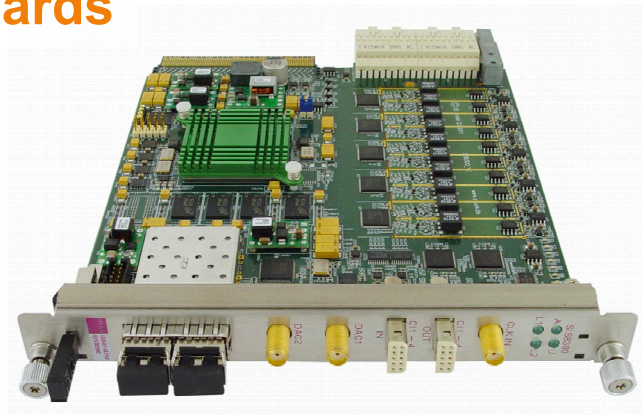


CPU Card

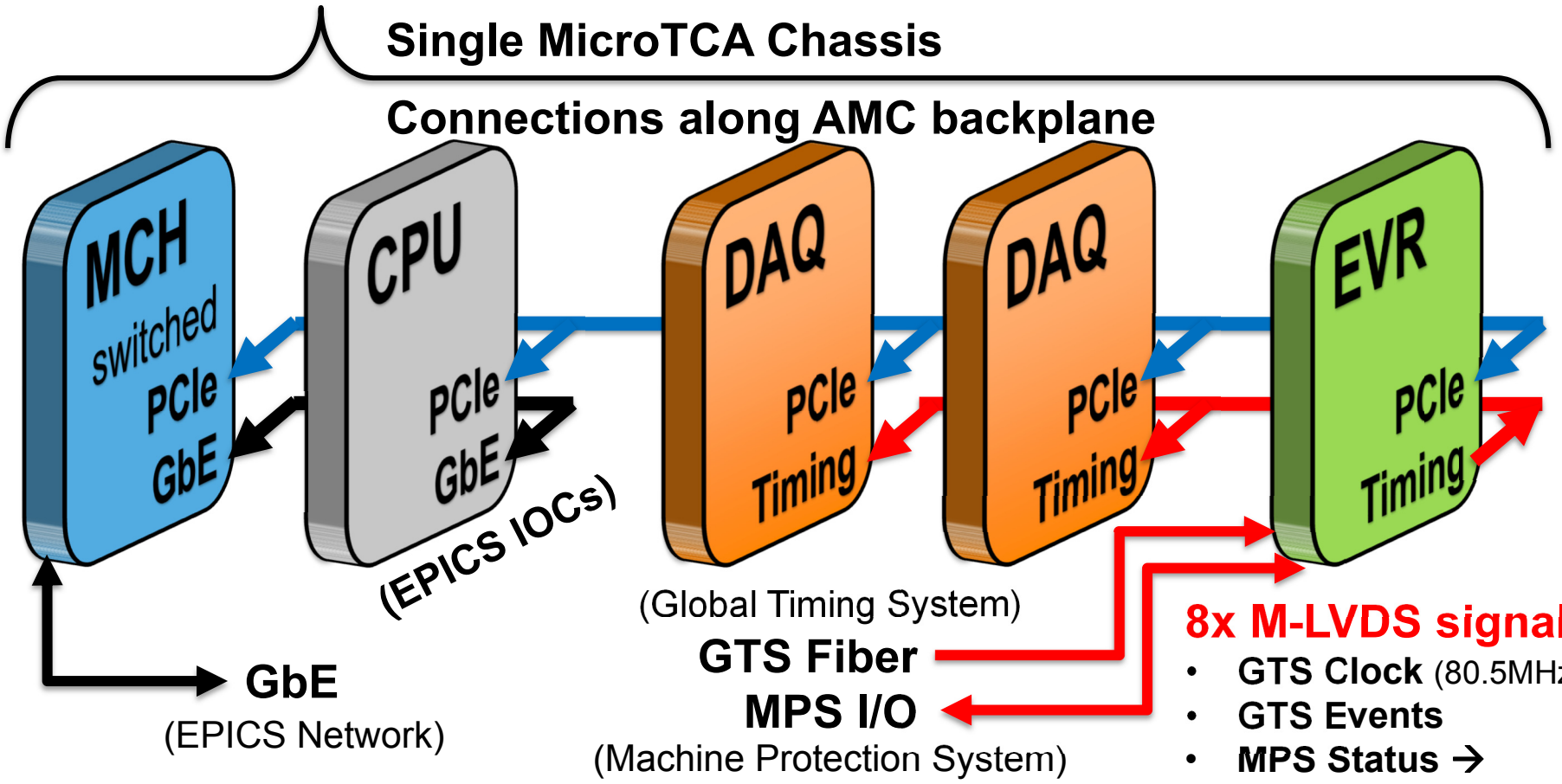
12-slot Chassis



DAQ Cards



MicroTCA Backplane Reduces Cabling

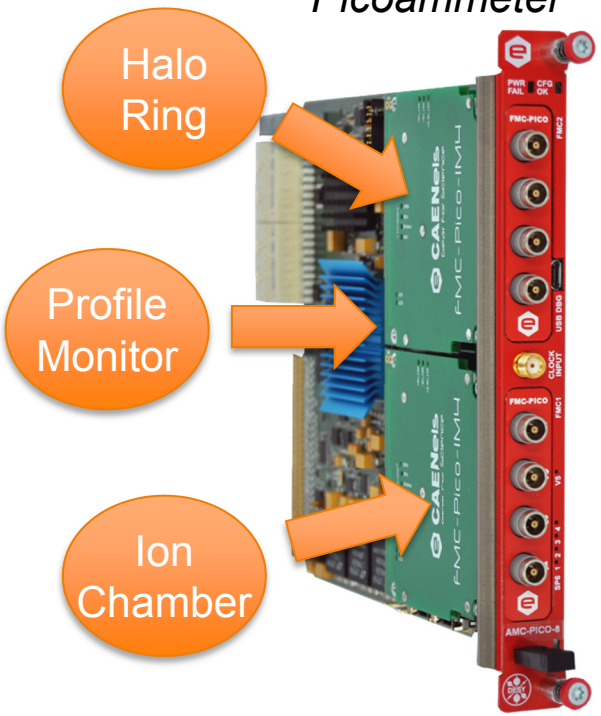


Simplified cabling and signal distribution.

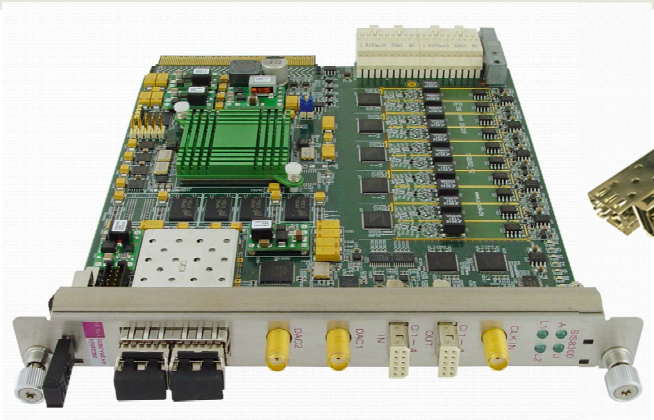
Leveraging Commonality Accelerates Development

- Benefits of devices using common DAQ hardware
  - Fewer systems to learn, develop, and maintain
  - Common hardware → common firmware → common software
- Many different diagnostic devices
  - Continuous vs. intermittent
  - Machine protection requirements
  - Varied response time requirements
  - Varied dynamic ranges (noise requirements)
- Plan ahead to consolidate DAQ solutions
  - Implications for hardware, firmware, and software design
- At FRIB, about 75% of devices fall into 3 categories
  - Full current measurement (BCM)
  - Low current measurement (BLM)
  - Fast voltage measurements (BPM)

Picoammeter



FRIB Uses Three Primary DAQ Cards



CAENels AMC-PICO-8

8 chan @ 1MS (35kHz BW)

- **65x 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 (Differential BCM)**

Not required for MPS, but shared DAQ system

FRIB Digital Board

General purpose

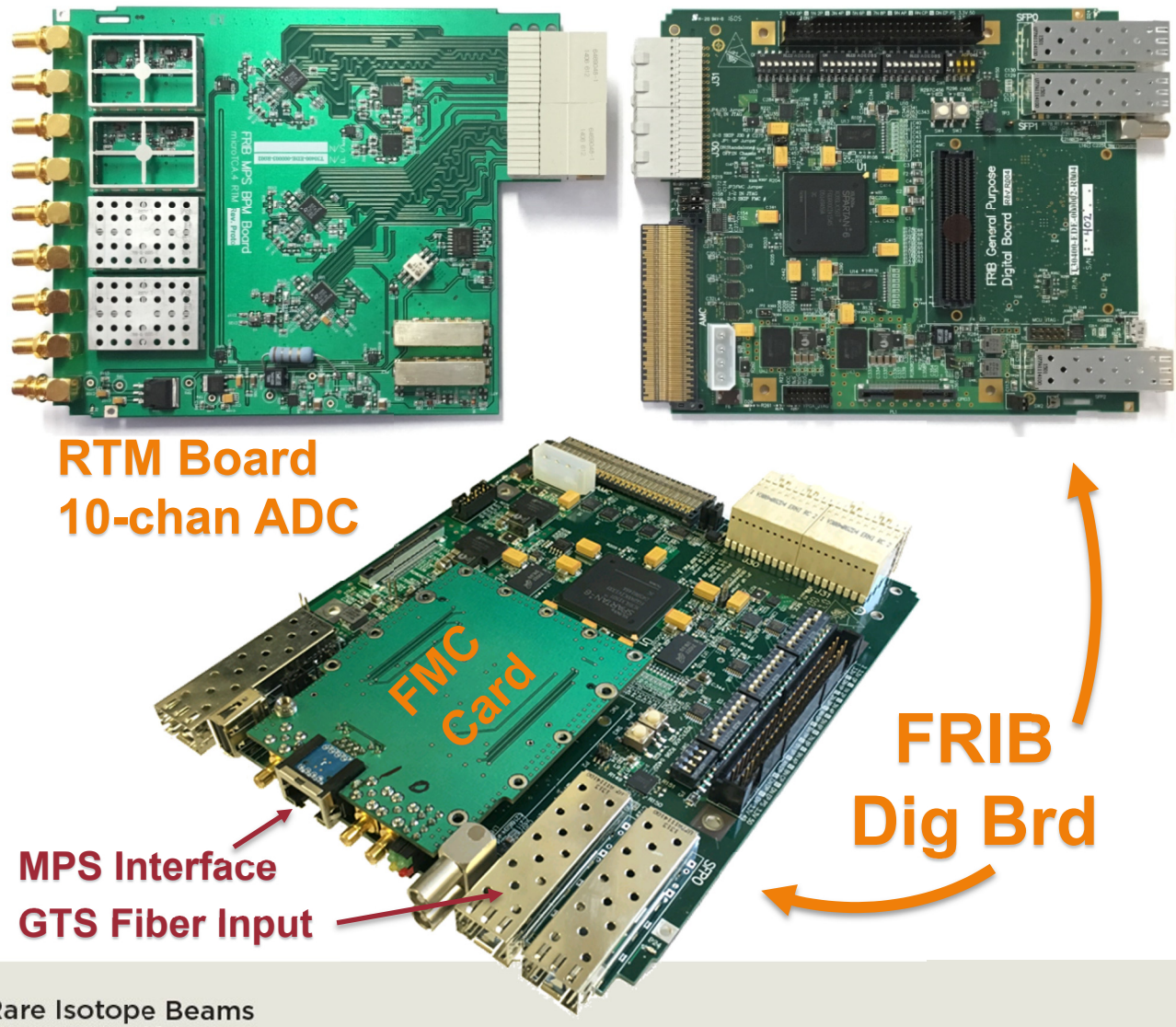
- **147x Beam Position (BPM)**
- 20x Event Receiver & Machine Protect System

Developed at FRIB, used by Diagnostics, LLRF, and Controls

All utilize FPGA for real-time signal processing and Machine Protection (MPS)

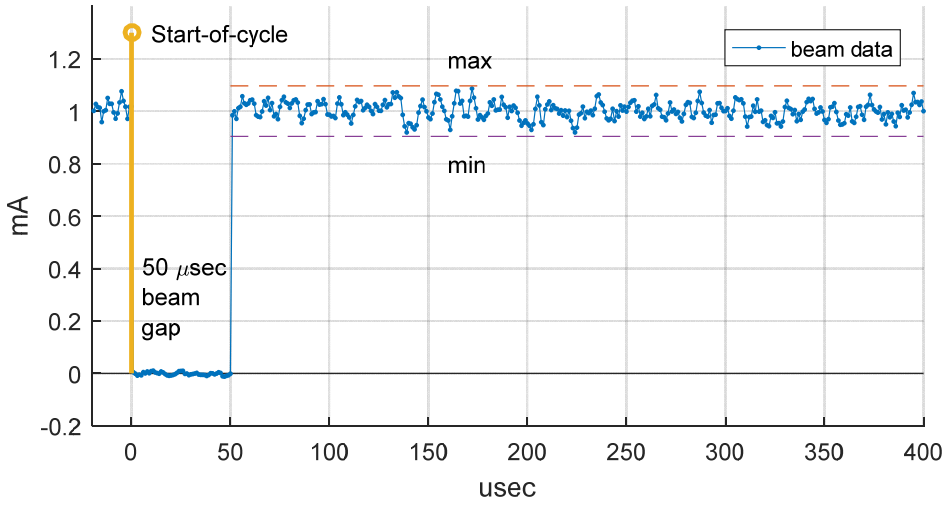
FRIB Digital Board Supports Multiple Applications

- In-house board design
  - LLRF
  - Controls
  - … and now Diagnostics
- Beam Position Monitor
  - Rear Transition Module with 10-channel ADC, sampling up to 125MHz
- Event Receiver (EVR)
  - Single interface to Global Timing System (GTS) and Machine Protection System (MPS)
  - Consolidates and distributes signal from MPS and GTS to/from other cards



Standardized Beam Data Reporting
Common to all Fast Acquisition Devices

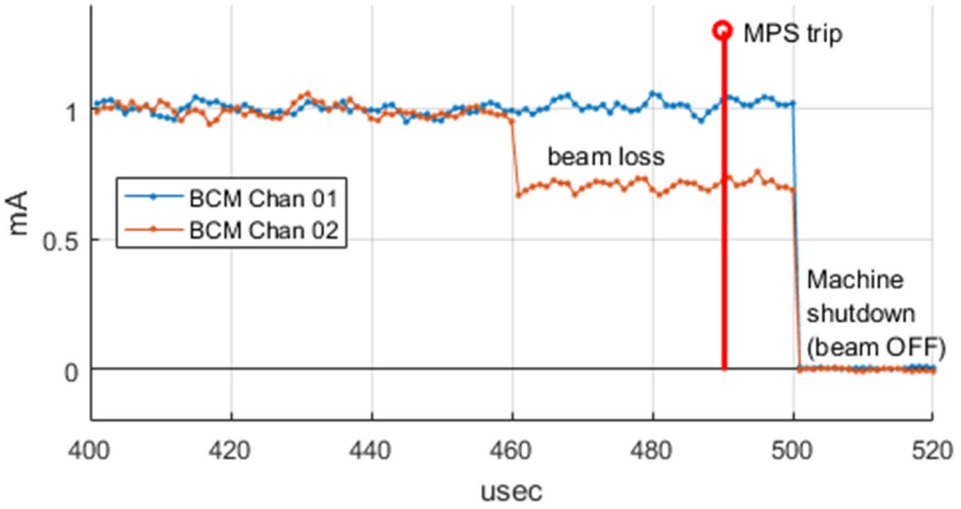
- 100-Hz data measurements
  - Summarize data from each 10 msec cycle
  - Natural time period, synchronized by GTS
  - Consolidated by EPICS IOC software



Per-Cycle Record (10 ms)
• Total Charge (TC)
• Average Beam
• Min / Max
• Time ON
• Timestamp

x100 per second

- MPS ring buffer (post-mortem)
  - 1 sec history (per channel), @ 1MS
  - Always running (freeze when MPS trips)
  - Acquired upon MPS trip interrupt



Supports ***all beam modes*** and ***all fast devices*** with standard reporting scheme.

Summary

- Reducing the number of independent hardware/firmware/software developments is accelerating diagnostics system development.
- Achieved a high degree of commonality for DAQ hardware
  - Three primary DAQ boards
  - Leveraged in-house hardware design (FRIB digital board)
  - Supported by industry partners for custom firmware development
- MicroTCA
  - Simplified cabling
  - Modular electronics
  - Remote management
- Standardized diagnostic data reporting → simplified high-level SW
  - 100-Hz data measurements / statistics
  - Ring buffer data, @ 1MS/s
- Small electronics team is making fast progress!