MicroTCA at FRIB

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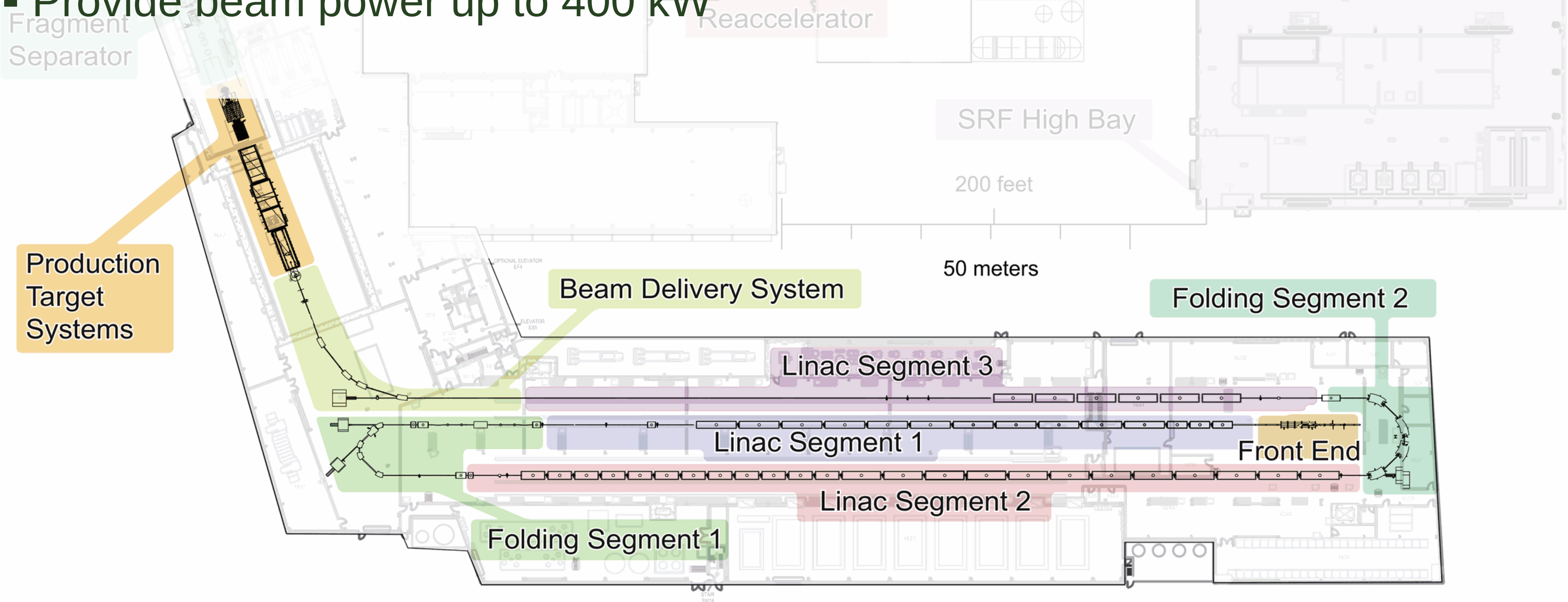
The Facility for Rare Isotope Beams

… at Michigan State University (MSU) is a world-class research, teaching and training center, hosting the most powerful rare isotope accelerator.

- 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

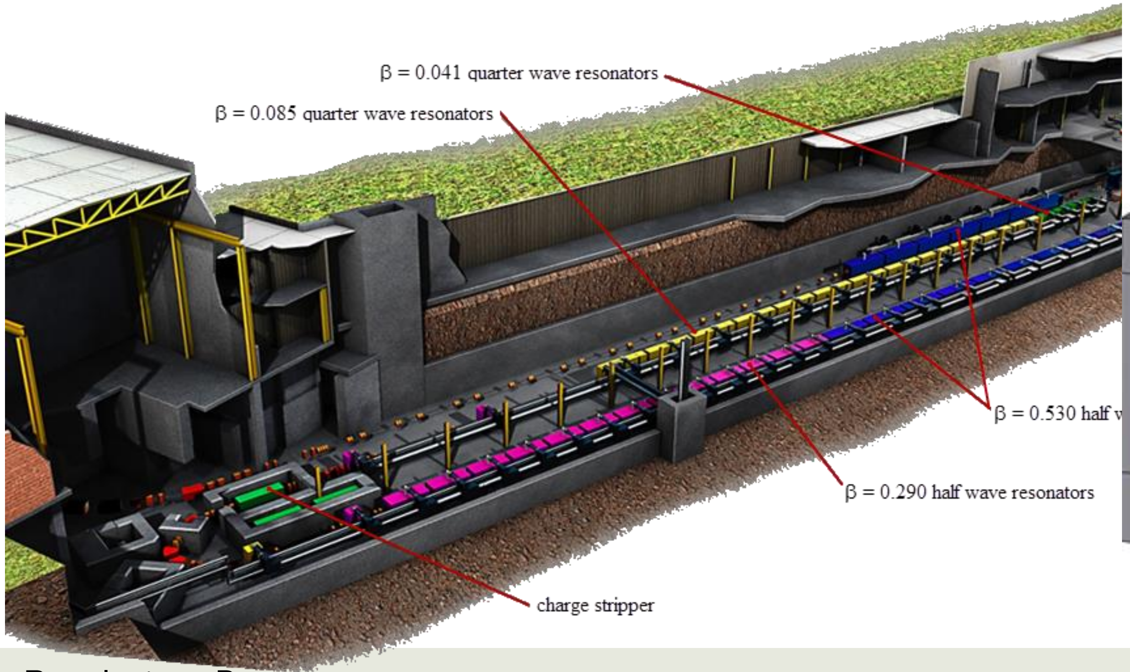


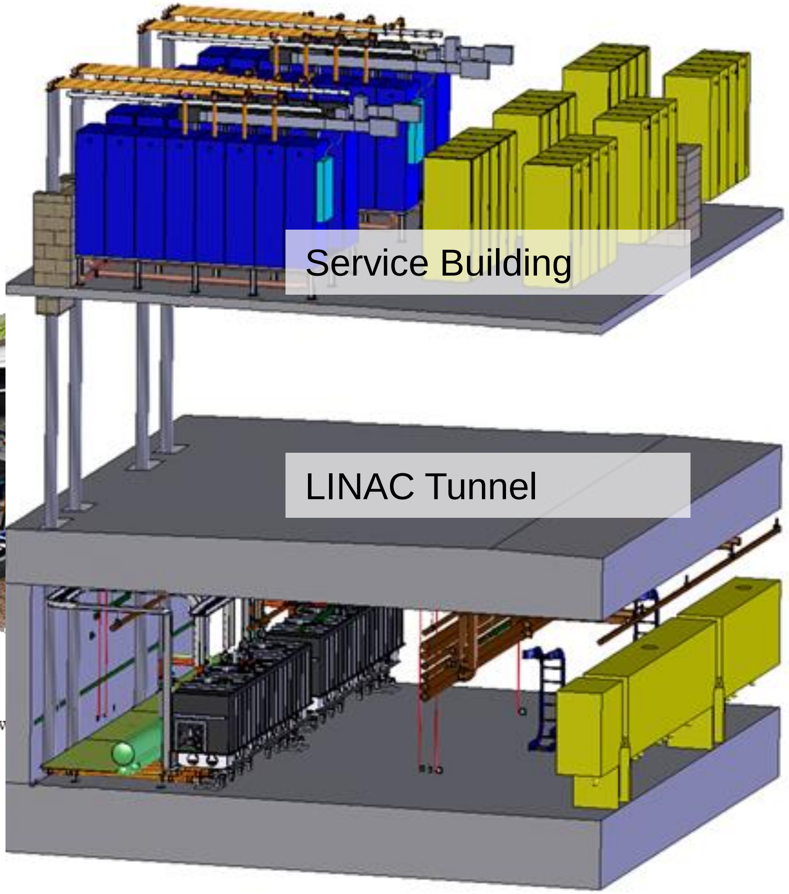
Talk Summary

- FRIB diagnostic environment
  - Beam modes
  - Machine protection
  - Global timing
- Selecting electronics platform
- Data acquisition hardware
- Data reporting

Service Building and Tunnel Interface

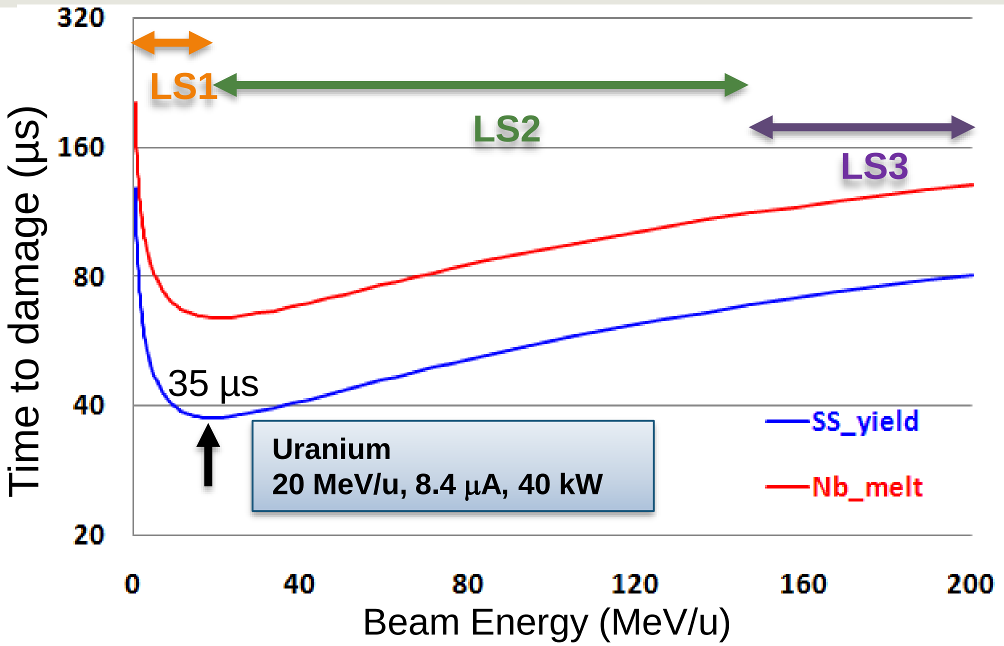
- **No electronics in the tunnel!**
- Penetration conduits and racks are laid out for instrumentation
  - Cable runs about 100 ft

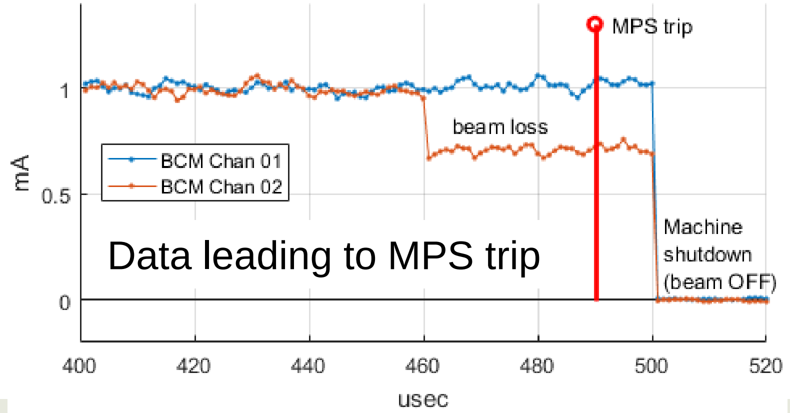




Machine Protection System (MPS)

- Diagnostics requirements primarily driven by MPS
  - Avoid accelerator component damage
  - Minimize residual activation
- Detect beam loss and respond
  - 35 μs total time (worst case)
  - 15 μs to detect 100% beam loss
  - Chronic small losses of 1 W/m or less
- 15 μs → real-time decision
  - Custom firmware integrated (FPGA)
  - Fast sampling data, ≥ 1 MS/s
  - 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)

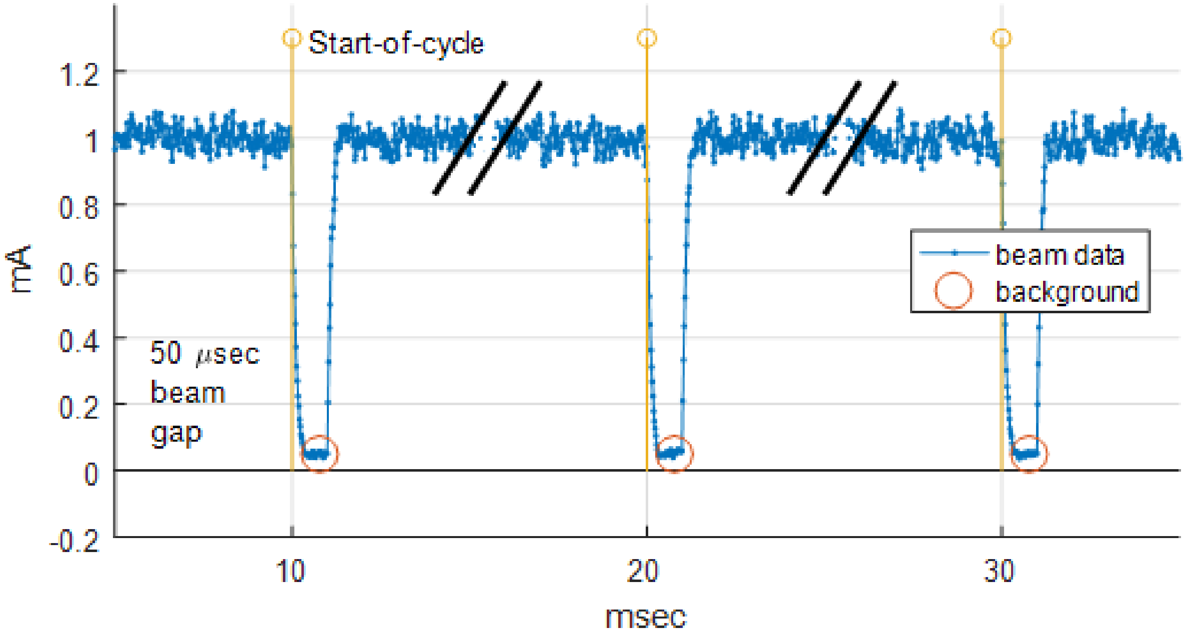
Intermittent use waveform data acquisition

606 total diagnostic devices

** Machine Protection, Fast Response*

Beam Structure and Timing System

- CW Beam Operation
  - 50 µs beam gap introduced @ 100 Hz
    - » reset AC-coupled current transformer readings
    - » sampling of signal background
  - 99.5% active duty factor
  - 10 ms machine cycle period
- Global Timing System (GTS)
  - Distribute timing events to all fast devices
  - Events include:
    - » Start-of-cycle (every 10 ms)
    - » Beam ON / OFF
    - » Global timestamp (synchronization)

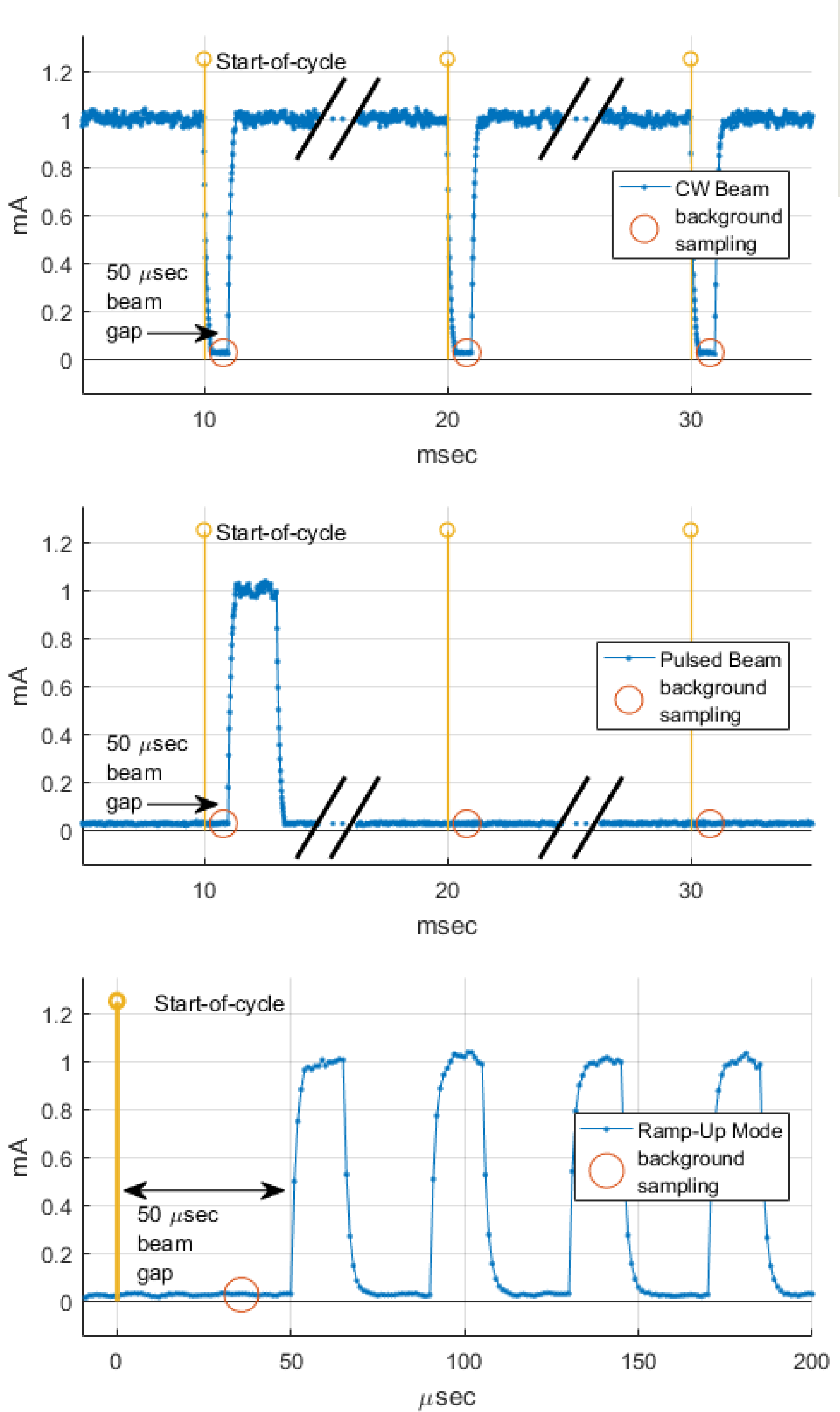


All diagnostics DAQ systems need beam state & timing.

Beam Modes

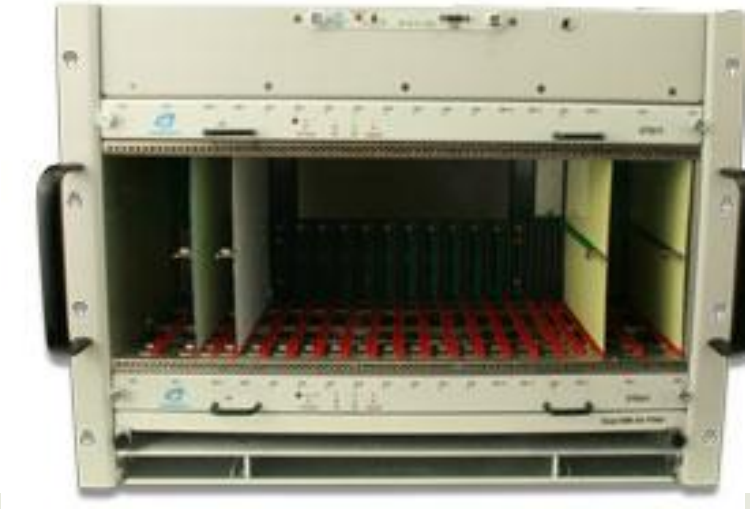
- Continuous beam (CW)
  - 99.5% active duty factor
- Pulsed modes
  - Low duty factor for commissioning and tuning
- Ramp-up modes
  - Slowly heat target, avoid thermal shock
  - Duty factor ramps from 0% to 99.5%

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



Choosing Scalable Electronics Platform

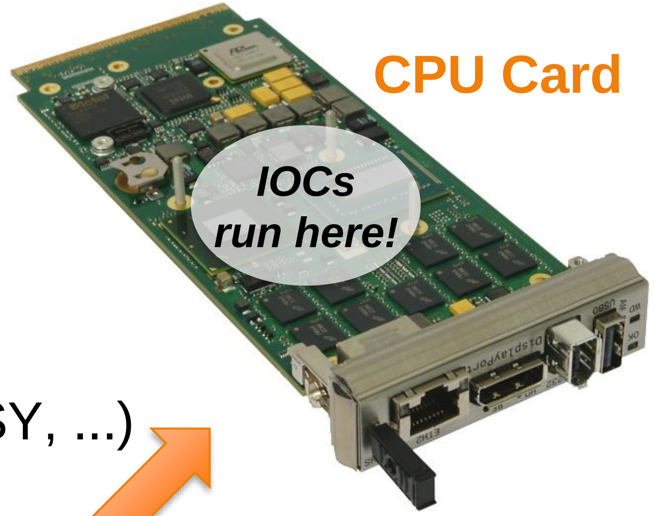
- Hundreds of diagnostic devices, with
  - Fast data acquisition (>= 1 MS/s)
  - Interface with Machine Protection System (MPS)
  - Interface with Global Timing System (GTS)
  - Get data to EPICS network (Ethernet)
- Considered “pizza box”
  - Enclosed system for each device type
- Chassis-based system (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

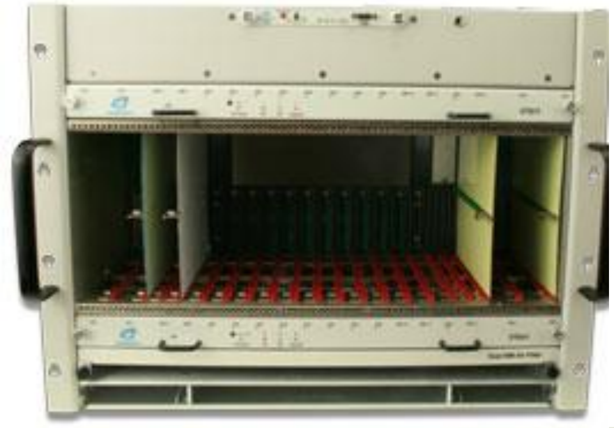
- MTCA.4 compelling features
  - Modular, 12 payload cards
  - Fast data buses on backplane for card-to-card communication
  - PCIe and Ethernet
  - Remote management & monitoring
  - EPICS IOC drivers centralized to single CPU
  - Industry support (PICMG), community users (DESY, ...)

CPU Card



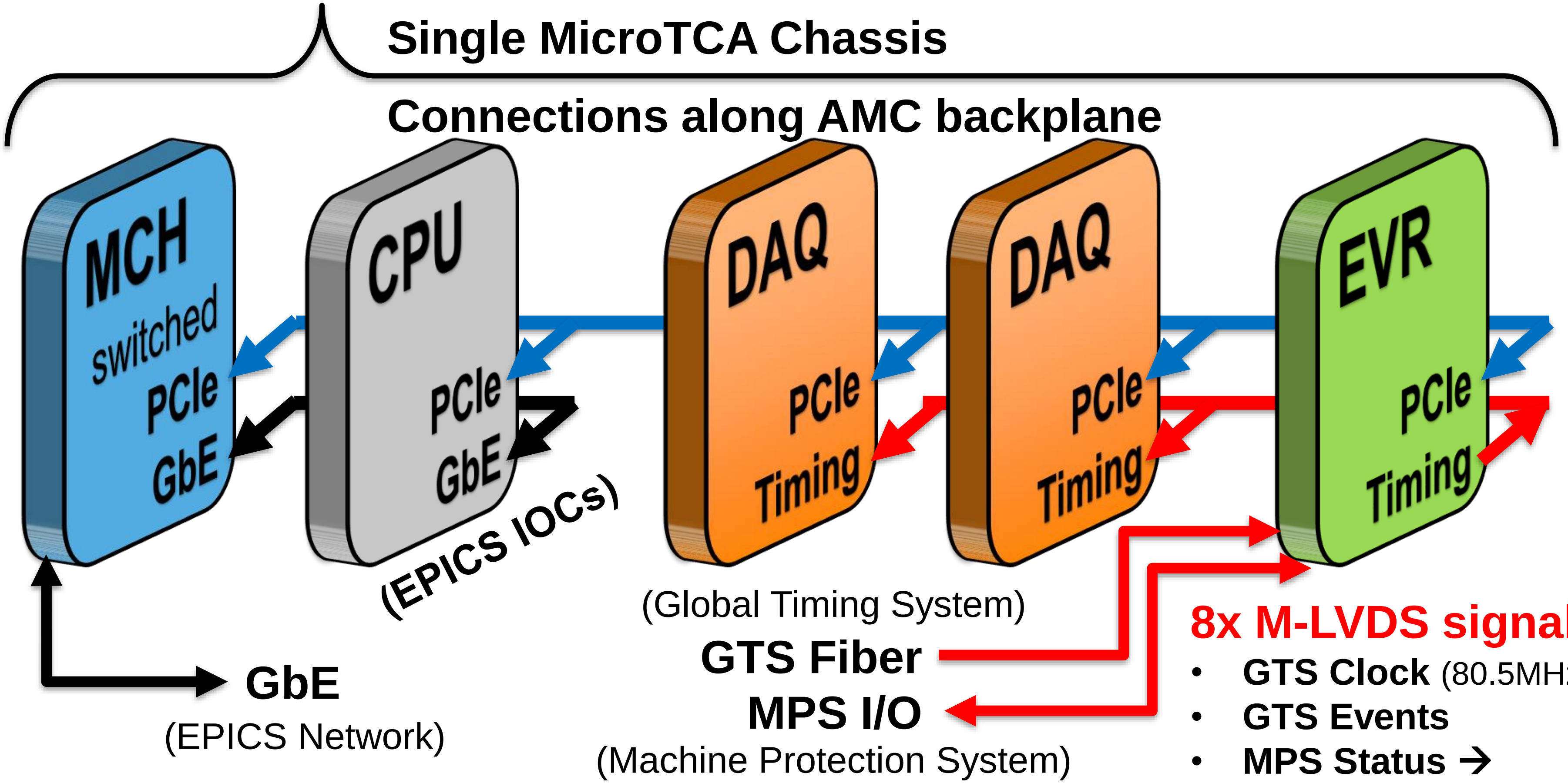
IOCs run here!

12-slot Chassis



DAQ Cards

MicroTCA Backplane Reduces Cabling



8x M-LVDS signals:

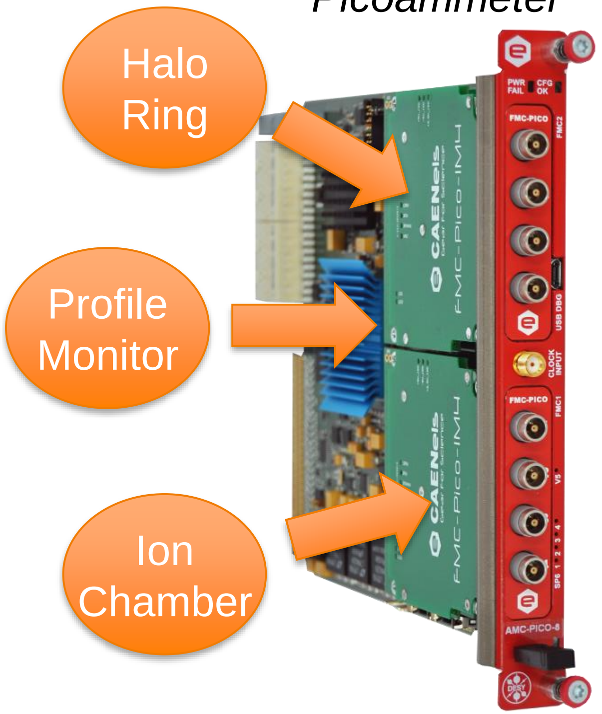
- **GTS Clock** (80.5MHz)
- **GTS Events**
- **MPS Status →**
- **MPS NOK ←**
  shared "emergency brake"

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 diagnostic 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/s (35kHz BW)

65x Halo Ring Monitors
42x Ion Chambers
24x Neutron Detectors

8x Faraday Cups
2x Allisson Scanner
41x Profile Monitors

Not required for MPS, but shared DAQ system

Struck SIS8300-L2
10 chan @ 125MS/s

12x Beam Current (Differential BCM)

FRIB General Purpose Digital Board
(FGPDB)

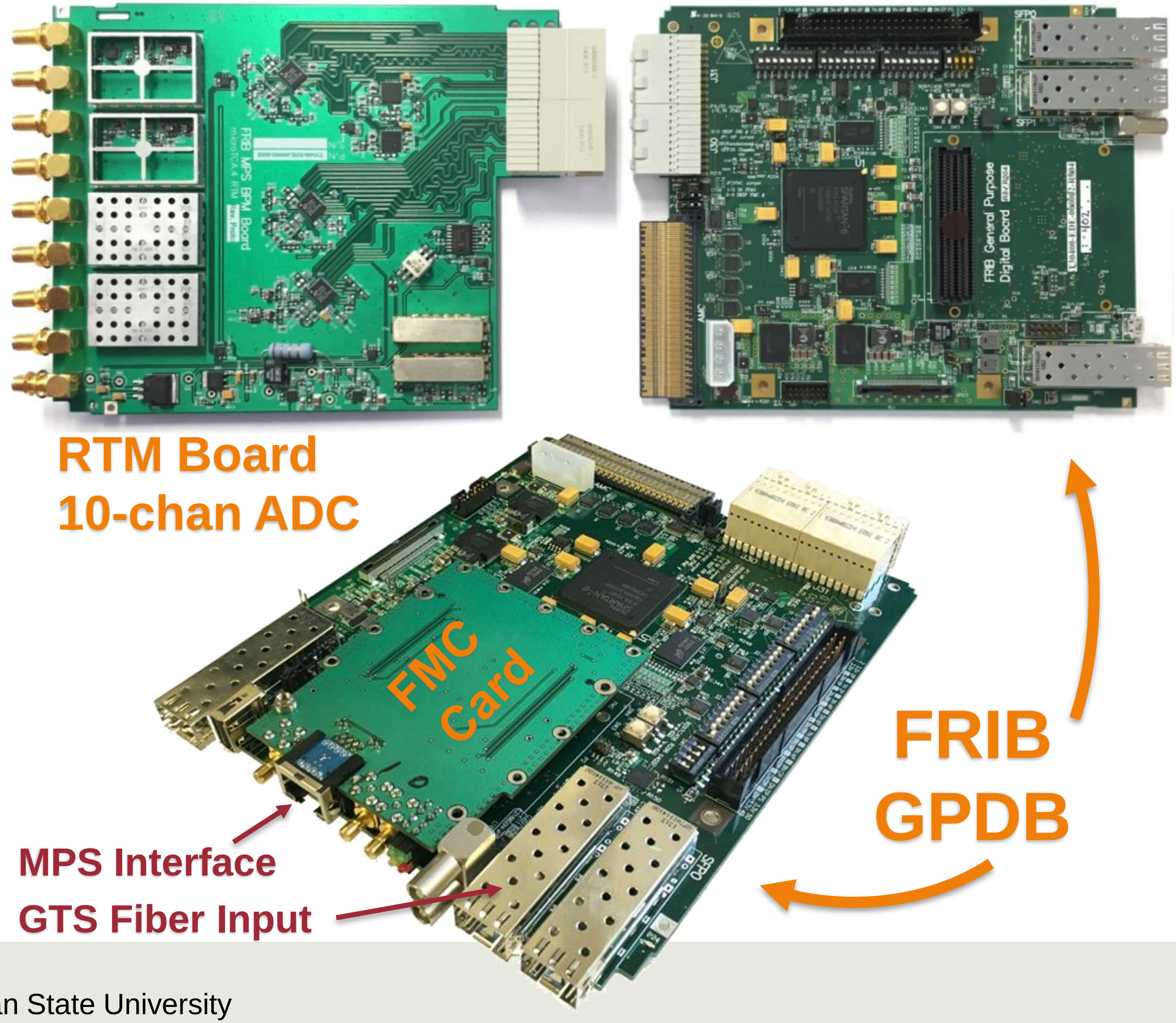
147x Beam Position (BPM)
20x Event Receiver & Machine Protect System

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

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

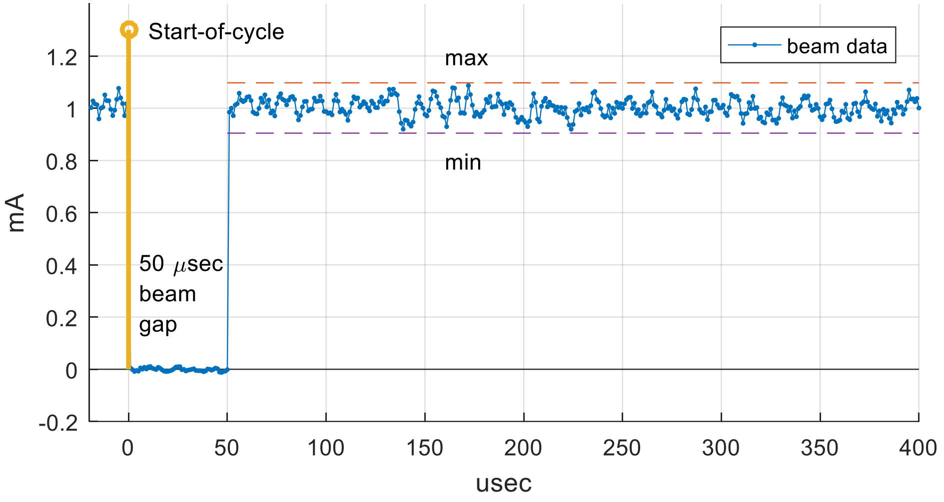
FRIB Digital Board Supports Multiple Applications

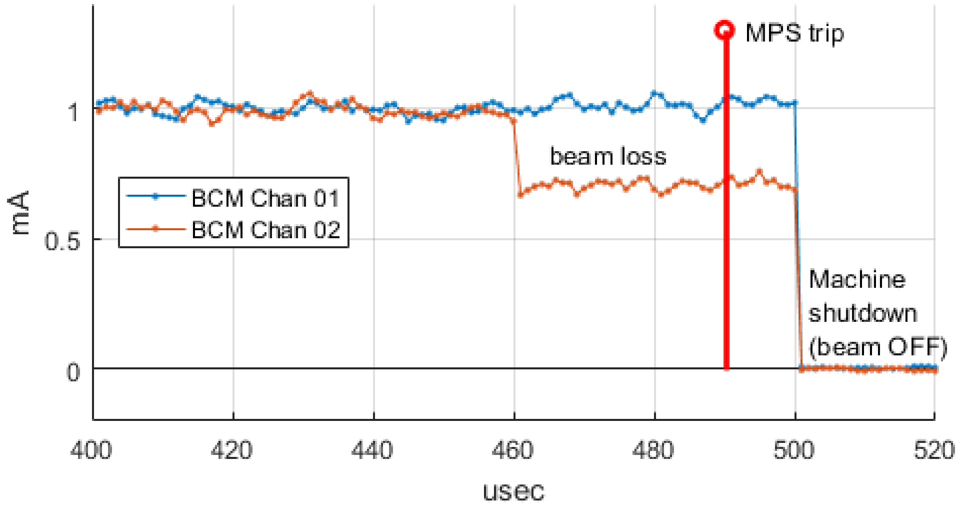
- In-house board design
  - LLRF
  - Controls
  - Diagnostics
- Beam Position Monitor
  - Rear Transition Module with 10-channel ADC, sampling up to 125MS/s
- Event Receiver (EVR)
  - Single interface to Global Timing System (GTS) and Machine Protection System (MPS)
  - Consolidates and distributes signal 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 ms cycle
  - Natural time period, synchronized by GTS
  - Consolidated by EPICS IOC software
- MPS ring buffer (post-mortem)
  - 1 sec history (per channel), @ 1MS
  - Always running (freeze when MPS trips)
  - Acquired upon MPS trip interrupt





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

x100 per second

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

Summary

- Reducing the number of independent hardware/firmware/software developments very valuable in 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
- Thank you!