PIP-II DAQ/XRM Final Design Review

ED0023842

Evan Milton
January 2025

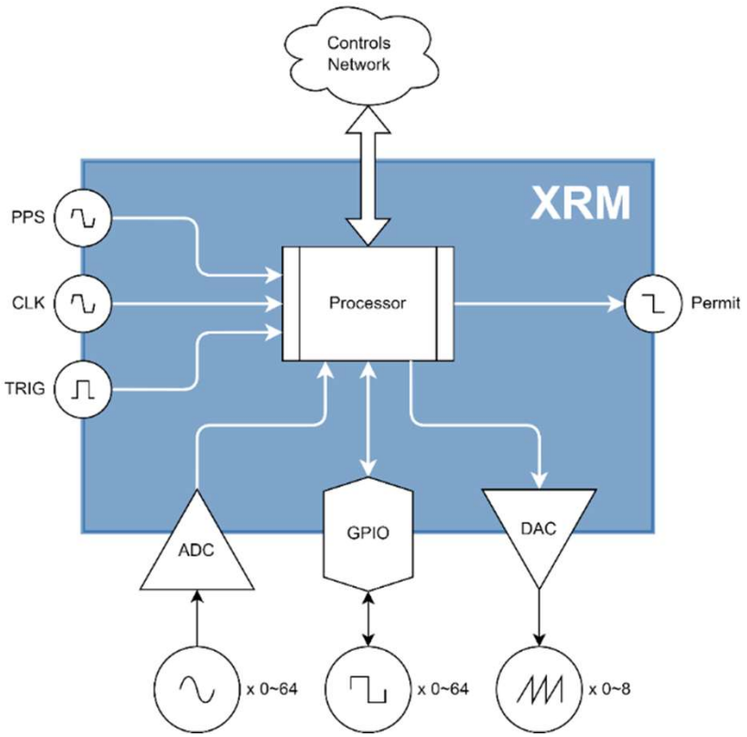
A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

Overview

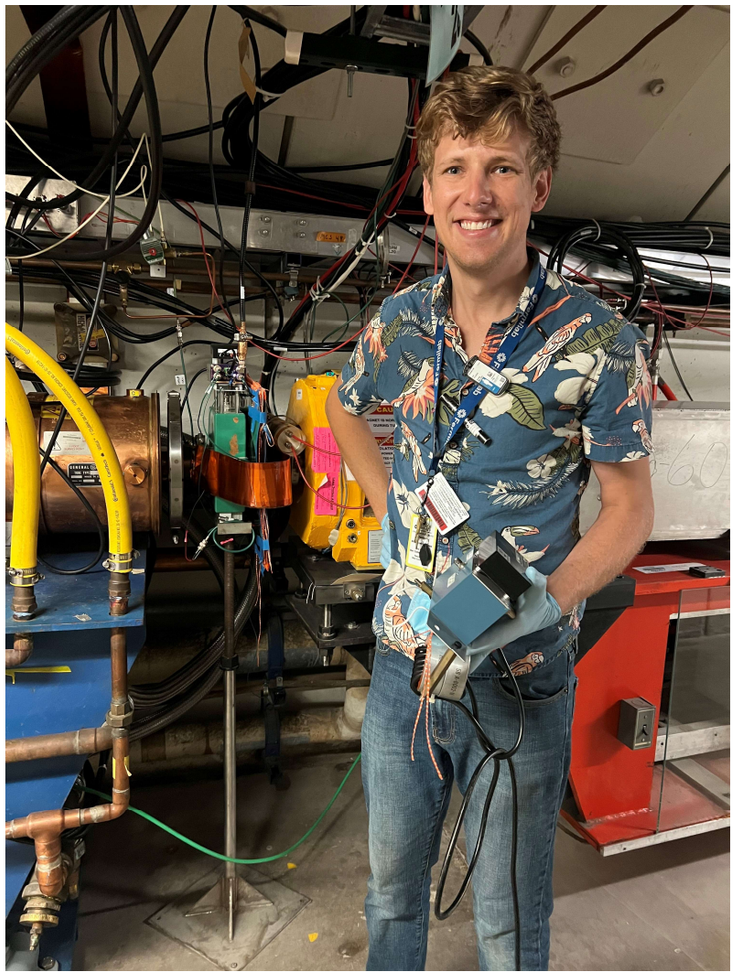
System Definition and Status

- eXtensible Rack Monitor (XRM)
  Successor to PiRM, HRM, IRM, SRM, MADC
- Provides general purpose Data Acquisition and Control for PIP-II, ~30 total
- Cost effective Commercial Off the Shelf (COTS) option under evaluation
- Full requirements at Final Design Review (FDR) stage, design to be finalized in 2025.
- Forward compatible into the ACORN era.

In this review we will cover ED0013500-REVB, the DAQ/XRM Technical Requirements Specifications



About Me



- **10 years in industrial control hardware (2011~2021)**
  - Rail / Semiconductor
  - Distributed data acquisition
  - Distributed (remote) control
  - Precision metrology
  - High reliability, long service life systems
- **2 years in Instrumentation at Fermilab (2021~2023)**
  - Beam Current Monitors
  - FPGA/MTCA development
- **1 year on ACORN at Fermilab (2024+)**
  - Systems Integration
  - Requirements management, lifecycle management
- **6 weeks on PIP-II at Fermilab (2024+)**
  - Taking over for Mike on Data Acquisition
  - Facilitating timing (LCLK/TCLK) integration

Charge Questions

Physical, Environmental, and Electrical Compliance

Has the XRM solution been shown to meet all physical, environmental, and electrical specifications, including form factor, connectorization, operating conditions, and robustness?

Documentation and Usability

Does the XRM solution include comprehensive and accessible documentation for hardware, software, and troubleshooting, as well as proper safety information, and operational guidelines?

Functional and Software Capabilities

Has the XRM solution been shown to meet all functional and software requirements, including EPICS compatibility, data acquisition, triggered operation, timestamps, and system configuration?

Lifecycle Support and Sustainability

Does the XRM solution meet all lifecycle and sustainability expectations, including service life, warranty period, backwards compatibility, vendor support, and environmental compliance?

Stakeholder Alignment and Interfaces

Have all intersecting parties (technical, engineering, and operations) reviewed and agreed upon the XRM specifications to ensure it meets functional, technical, and operational requirements?

Design Completion

Is the design at the 90% stage or better?

QA/QC

Does the design meet Fermilab's QA/QC requirements?

Component Database and Traveler Requirements

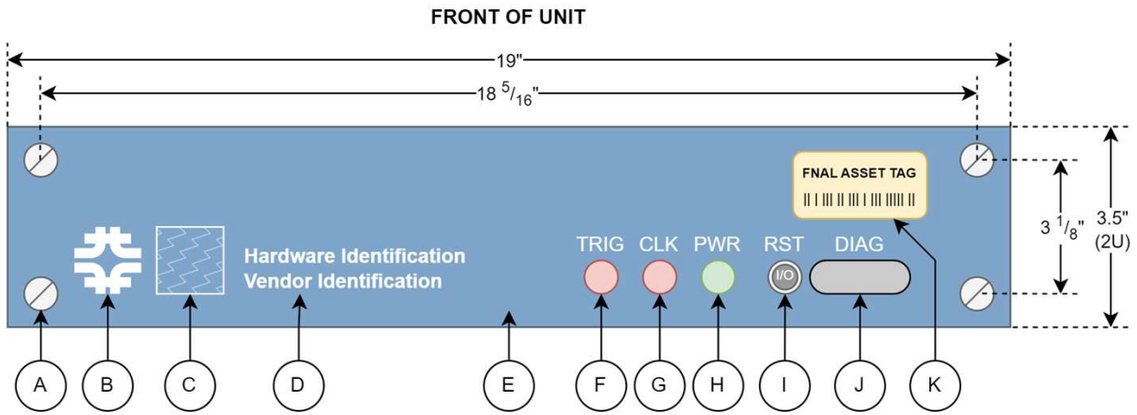
Does the acceptance plan include proper PIP-II Component Database documentation? Does the testing plan follow the PIP-II project's requirements for traveler documentation?

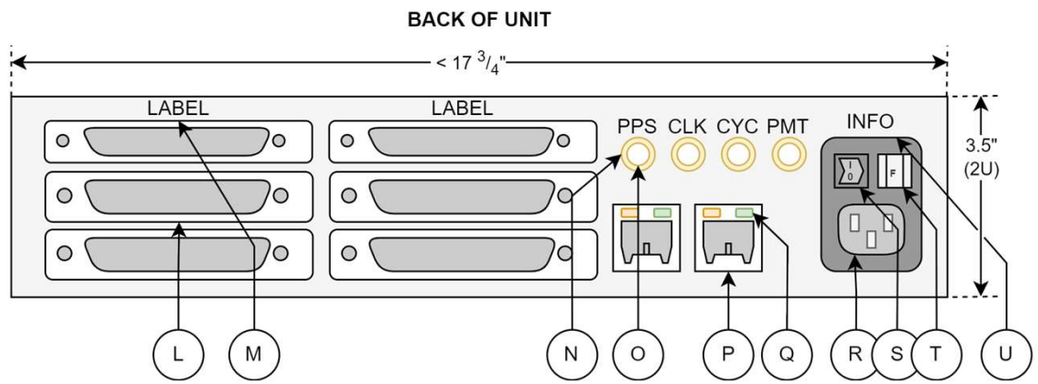
Physical Specifications

The XRM form factor is equivalent to typical server hardware. Fanout will be handled by a separate patch panel.

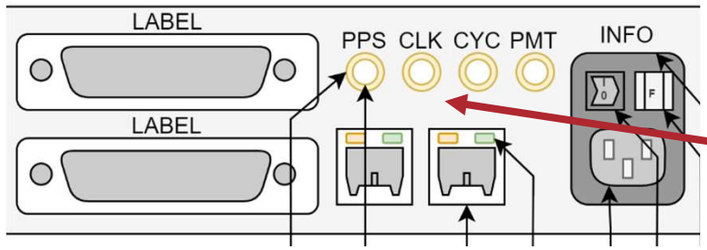
- EIA-310, 2U High (Standard server size)
- NAL Blue, Fermilab/Vendor identification
- Status indicator LED’s
- Diagnostic interface on front
- Connectorization on back
- TTL inputs for synchronization
- Standard power interfaces

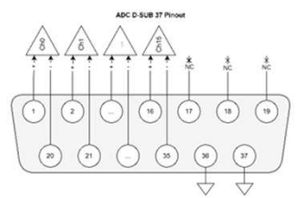
See specification document for callouts A~U.

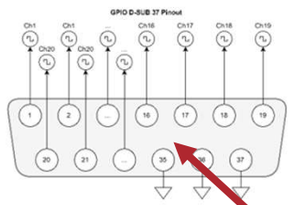




Interfaces







ADC Pinout (DB37)

Signal	Pin		Signal
CH1 +	1	20	CH1 -
CH2 +	2	21	CH2 -
CH3 +	3	22	CH3 -
CH4 +	4	23	CH4 -
CH5 +	5	24	CH5 -
CH6 +	6	25	CH6 -
CH7 +	7	26	CH7 -
CH8 +	8	27	CH8 -
CH9 +	9	28	CH9 -
CH10 +	10	29	CH10 -
CH11 +	11	30	CH11 -
CH12 +	12	31	CH12 -
CH13 +	13	32	CH13 -
CH14 +	14	33	CH14 -
CH15 +	15	34	CH15 -
CH16 +	16	35	CH16 -
NC	17	36	GND
NC	18	37	GND
NC	19		

Digital Pinout (DB37)

Signal	Pin		Signal
CH1	1	20	CH20
CH2	2	21	CH21
CH3	3	22	CH22
CH4	4	23	CH23
CH5	5	24	CH24
CH6	6	25	CH25
CH7	7	26	CH26
CH8	8	27	CH27
CH9	9	28	CH28
CH10	10	29	CH29
CH11	11	30	CH30
CH12	12	31	CH31
CH13	13	32	CH32
CH14	14	33	GND
CH15	15	34	GND
CH16	16	35	GND
CH17	17	36	GND
CH18	18	37	GND
CH19	19		

Present DB-37 definition, subject to change at contract approval.

Synchronized through the following:

- Pulse Per Second (PPS)
  Provides time synchronization
- ADC Clock (CLK)
  For beam-synchronous acquisition
- Cycle Trigger (CYC)
  Divides 20Hz period, triggers acquisition cycle
- Permit Output (PMT)
  Interfaces to Machine Protection

Other interfaces:

- Bundled cables for slow signals
- Coaxial option for high-speed signals
- Standard power/ ethernet connectors
- GPIO/DB-9 pinout in process

Compliance (QA & Safety)

1. The XRM shall have an estimated MTTF in excess of 100,000 hours (>11years).
2. The XRM shall comply with IEC 61010 safety standards for Inst. & Control hardware
    a. Comparable IEC standards / EU standards may be applied herein.
3. The XRM shall have a UL listed 120V power conversion stage, located internal to the unit
4. The XRM shall have a Category II over-voltage rated power conversion stage per IEC 61010.
5. The XRM shall recover gracefully from under-voltage scenarios after manual reset.
6. The XRM shall have a grounded chassis.
7. The XRM shall be RoHS compliant.
8. The XRM shall have overvoltage protection for all inputs and outputs.
9. The XRM shall comply with IEC 61000-4-2 standards for electrostatic discharge immunity
10. The XRM shall comply with IEC 61000-4-3 standards for radiated electromagnetic fields
11. The XRM shall be installable by a single individual without lift or rigging.
12. The XRM shall maintain functionality in a commercial operating range per IEC 60068
    a. The XRM shall operate from 0~50°C
    b. The XRM shall operate from 5~95%RH (non-condensing)
    c. The XRM shall operate with vibrations from 15~60Hz, 0.15~0.5mm displacement
    d. The XRM shall be subject to drop (100mm) and impact (5g) during normal handling.
    e. The XRM shall have airflow from the front to the back of the rack enclosure.
    f. The XRM shall be IP50 rated for dust ingress.

(The XRM *need not* be independently certified to the above standards)

Overview of applicable standards

- Long service life
- IEC 61010 Safety Standard (FESHM)
- UL power conversion stage (NRTL)
- Category-II voltage rating
- ESD / EMI compliant
- Standard server operating conditions

Performance Agreement (QA)

These requirements communicate to the vendor the level of support expected by Fermilab. Final wording of requirements will be done in conjunction with legal/ procurement.

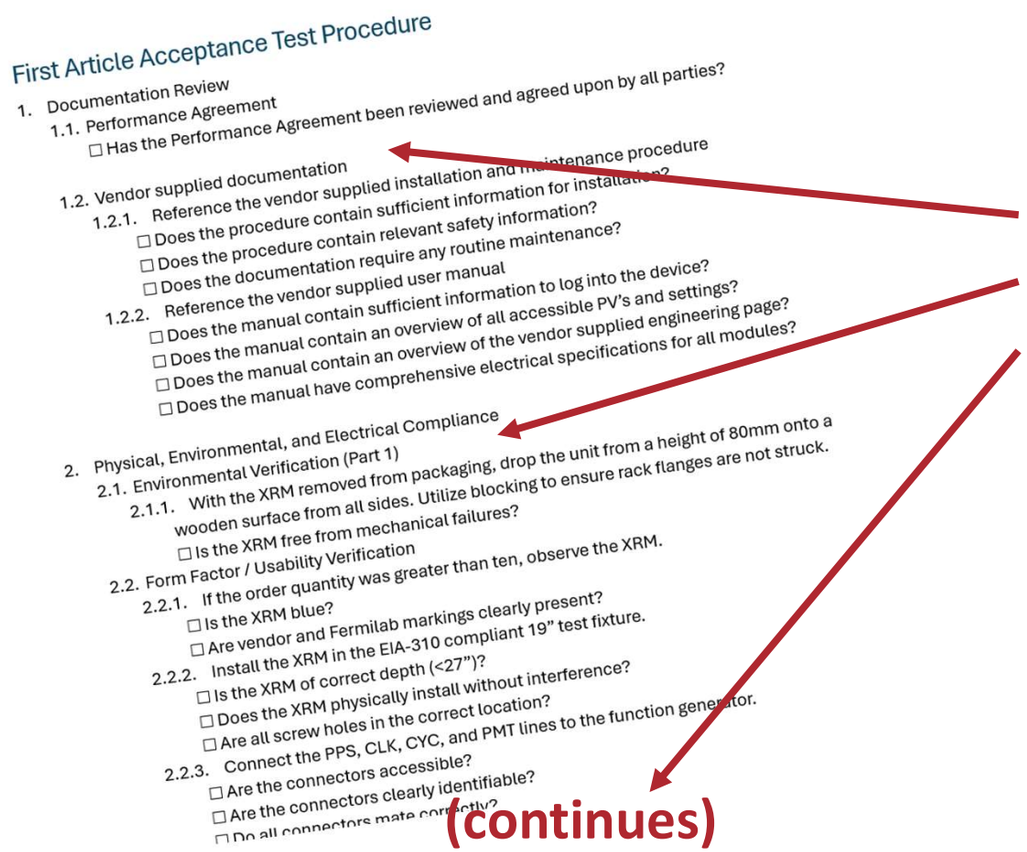
1. The XRM shall arrive fully tested, qualified, and ready for installation.
2. The XRM shall have a manufacturer-supported service life in excess of 10 years.
3. The XRM shall have post-commissioning support for firmware or security patches.
4. The XRM shall maintain compliance with the active safety standards at time of purchase.
5. The XRM shall have service availability via email or phone within 24 hours of request.
6. The XRM shall have a backwards-compatible form factor for inter-lifecycle updates.
7. The XRM shall have a hardware warranty period of one year from date of receival.
8. The XRM shall have an extended warranty period option.
9. The XRM shall have a procurement time less than 6 months, batch shipments acceptable.
10. The XRM shall have pricing valid from 90 days of quote during procurement.
11. The XRM shall have vendor support for NRE required to modify functional requirements.
12. The XRM shall have vendor support for NRE required to modify software requirements.
13. The XRM shall have an IP transfer agreement in the event of manufacturer default.

Overview of desired performance

- Long service life
- Vendor handles software image
- Safety updates (FESHM / NRTL)
- Future modifications may be required
- IP transfer, if vendor defaults

First Article Acceptance Test Plan (QA/QC)

This document validates all requirements have been met by the vendor design
The procedure is to be performed on first article units and subsequent revision changes.



First Article Acceptance Test Procedure

1. Documentation Review
   1.1. Performance Agreement
      ☐ Has the Performance Agreement been reviewed and agreed upon by all parties?
   1.2. Vendor supplied documentation
      1.2.1. Reference the vendor supplied installation and maintenance procedure
         ☐ Does the procedure contain sufficient information for installation?
         ☐ Does the procedure contain relevant safety information?
         ☐ Does the documentation require any routine maintenance?
      1.2.2. Reference the vendor supplied user manual
         ☐ Does the manual contain sufficient information to log into the device?
         ☐ Does the manual contain an overview of all accessible PV's and settings?
         ☐ Does the manual contain an overview of the vendor supplied engineering page?
         ☐ Does the manual have comprehensive electrical specifications for all modules?
2. Physical, Environmental, and Electrical Compliance
   2.1. Environmental Verification (Part 1)
      2.1.1. With the XRM removed from packaging, drop the unit from a height of 80mm onto a wooden surface from all sides. Utilize blocking to ensure rack flanges are not struck.
         ☐ Is the XRM free from mechanical failures?
   2.2. Form Factor / Usability Verification
      2.2.1. If the order quantity was greater than ten, observe the XRM.
         ☐ Is the XRM blue?
         ☐ Are vendor and Fermilab markings clearly present?
      2.2.2. Install the XRM in the EIA-310 compliant 19" test fixture.
         ☐ Is the XRM of correct depth (<27")?
         ☐ Does the XRM physically install without interference?
         ☐ Are all screw holes in the correct location?
      2.2.3. Connect the PPS, CLK, CYC, and PMT lines to the function generator.
         ☐ Are the connectors accessible?
         ☐ Are the connectors clearly identifiable?
         ☐ Do all connectors mate correctly?

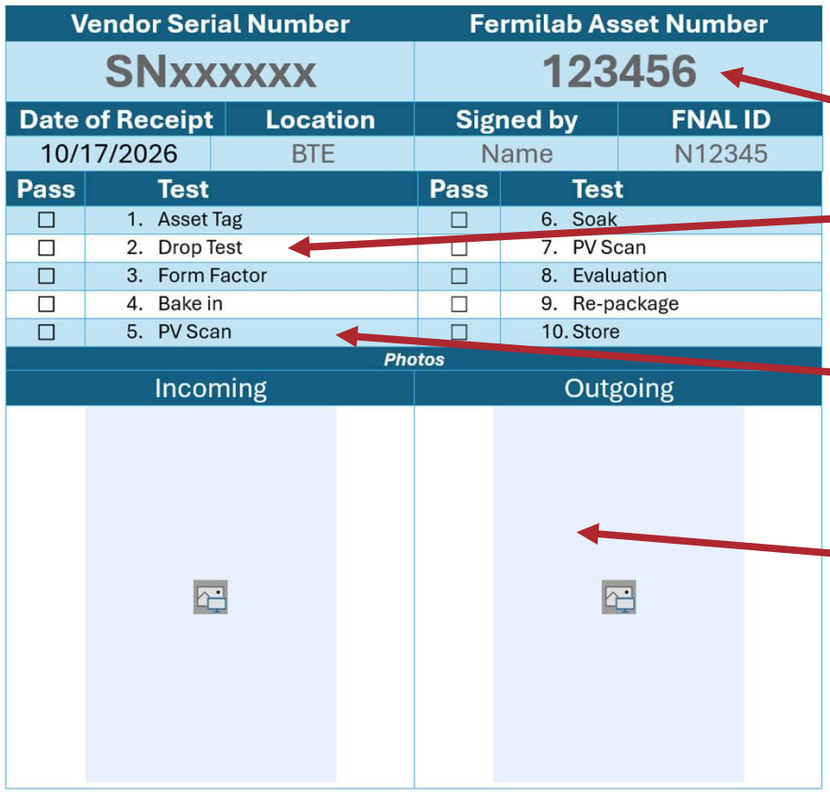
(continues)

Overview of Test Procedure

- Validate documentation/ agreement
- Perform environmental testing
- Perform lab testing (optional)
- Perform 'bake in period'
- Validate synchronization of modules
- Perform software testing for each module.
- Validate performance with stakeholders

Incoming Inspection Traveler (QC)

This document records that all incoming units have passed the inspection process



Vendor Serial Number		Fermilab Asset Number	
SNxxxxxx		123456	
Date of Receipt	**Location**	**Signed by**	**FNAL ID**
10/17/2026	BTE	Name	N12345

Pass	Test	Pass	Test
☐	1. Asset Tag	☐	6. Soak
☐	2. Drop Test	☐	7. PV Scan
☐	3. Form Factor	☐	8. Evaluation
☐	4. Bake in	☐	9. Re-package
☐	5. PV Scan	☐	10. Store

Photos	
Incoming	Outgoing

Overview of Test Procedure

- Apply/ record asset tag
- Basic drop test
- Install in rack
- Bake at 40c
- Scan PV’s
- Soak for 48 hours
- Scan PV’s
- Document results
- Re-package and store.

Software Interfaces

These requirements communicate to the vendor the intended method of integration
Final wording of requirements will be decided in conjunction with vendor/ during development

1. The XRM shall utilize EPICS for all software configuration and readback on request.
2. The XRM shall interface with Fermilab operator interface via EPICS-based Phoebus.
3. The XRM shall interface with Fermilab's EPICS archiving tools (Archiver Appliance).
4. The XRM shall support EPICS PV Access (PVA) protocols for network data exchange.
5. The XRM shall provision for migration to the excessively named PVXS implementation.
6. The XRM shall support EPICS Channel Finder functionality.
7. The XRM shall provide a template startup script for the base vendor configuration.
8. The XRM shall utilize a version controlled Fermilab startup script post installation.
9. The XRM shall support dynamic startup script configuration through SSH (push).
10. The XRM shall have internal diagnostic logs accessible via network or local diagnostic port.
11. The XRM shall have vendor-provided engineering screens to verify basic functionality.
12. The XRM shall allow reconfiguration of parameters via GUI or command-line without reboot.
13. The XRM shall provide configurable save/restore functionality, and power failure recovery.
14. The XRM shall support network power-off or restart commands.
15. The XRM shall have root privilege for Fermilab to administer certificates and security config.
16. The XRM shall adhere to site-specific security policies and DOE regulations.
17. The XRM shall have Kerberos-based authentication for all client access to the processor. (Fermilab shall provide Kerberos configuration files)

Overview of Applicable Interfaces

- EPICS
- Phoebus, Archiver Appliance
- PV Access, PVXS
- Fermilab startup scripts
- Basic diagnostics
- Kerberos

Hardware

The XRM will support several different module types.
These will be selectable / configurable at time of manufacture.

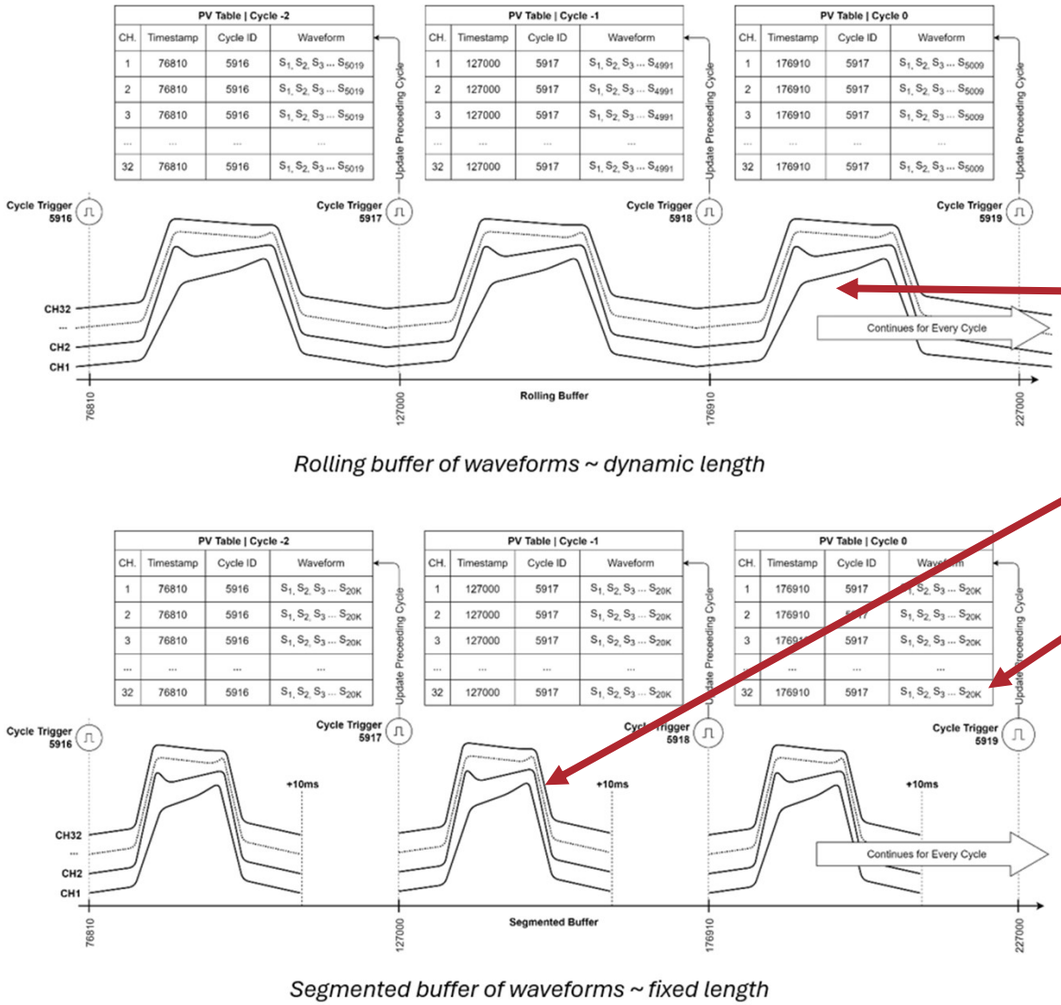
Unit			Spec's					
Type	Rate (sps)	Range	Channel	Res. (bits)	-3dB (Hz)	Term. (Ω)	Cur. (mA)	Conn.
GPIO	1M	5V (TTL)	32	-	-	4.7K Dn	64/32mA	DB-37
Relay	20	5V	4	-	-	-	100mA	DB-9
DAC	100K	±10V	4	≥16	~10K	1M	10mA	DB-9
ADC	100K	±10V	16	16	~50K	1M	-	DB-37
ADC	100K	±5V	16	16	~50K	1M	-	DB-37
ADC	100K	±2.5V	16	16	~50K	1M	-	DB-37
ADC	≥2M	±10V	16	≥16	~500K	1M	-	COAX
ADC	≥2M	±2.5V	16	≥16	~500K	1M	-	COAX
ADC	≥2M	±1V	16	≥16	~500K	1M	-	COAX

Overview of general use cases

- Basic GPIO
- Relay control
- Voltage settings (MagPS)
- Slow readback (Controls)
- Fast readback (Instrumentation)

Exact module spec's finalized w/ vendor.

ADC Functional Specifications



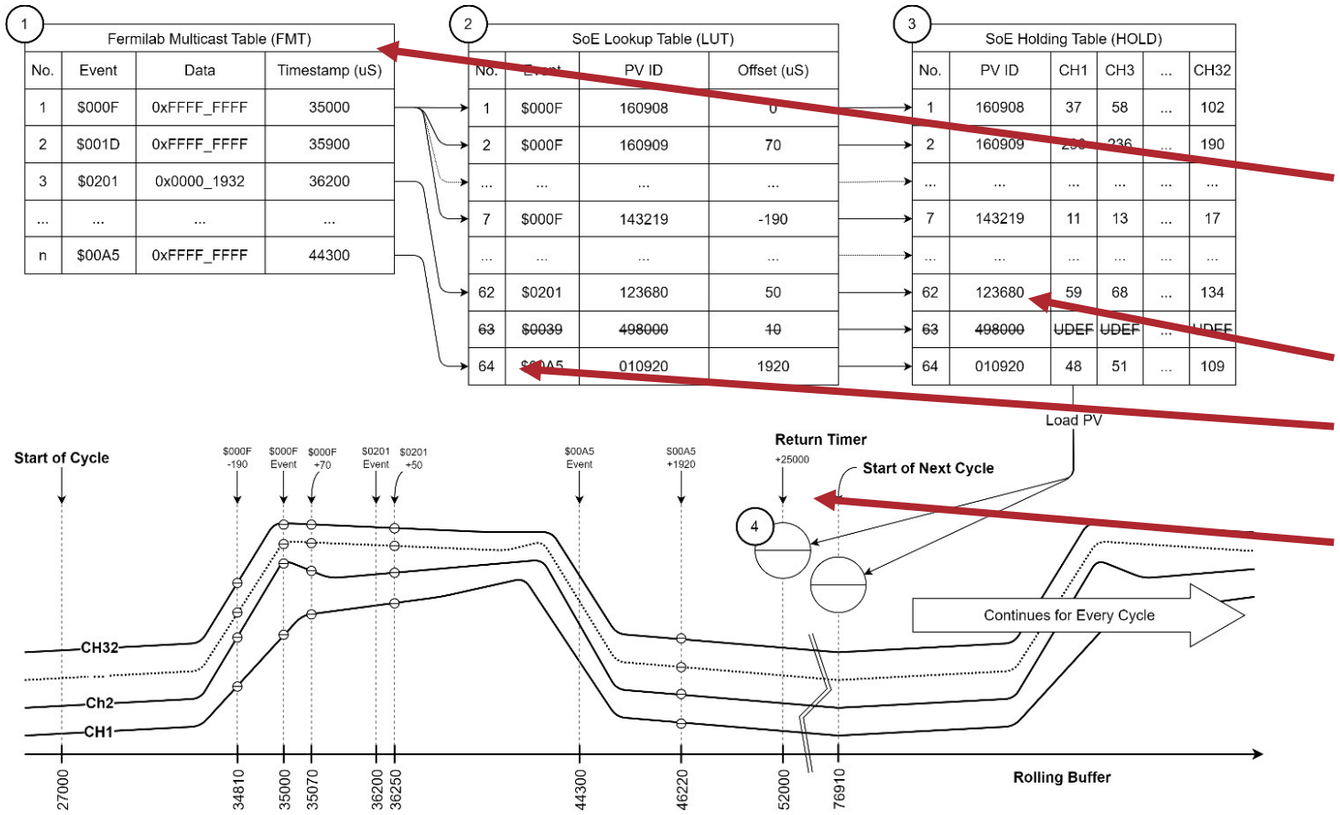
Rolling buffer of waveforms ~ dynamic length

Segmented buffer of waveforms ~ fixed length

Overview of ADC Behavior

- Rolling buffer at 100Ksps (Controls)
- Triggered buffer at 2Msps (INST)
- External ADC clock
- 1uS timestamps
- Waveforms present as PV's
- Previous 1 second of data retained
- State machine, updates cycle-by-cycle
- Spanning EPICS to ACNET behavior

Sample on Event Functional Specifications



Overview of Sample on Event Behavior

- Integrates with Fermilab timing systems
- Utilizes network events to select samples
- Events are correlated internally as triggers
- Samples present as PV's for each event
- Up to 64 options per slot
- 1uS timestamps
- State machine, 40Hz updates

20Hz is the cycle rate of PIP-II, 40Hz updates will facilitate feed forward compatibility.

Further Elaboration.

1

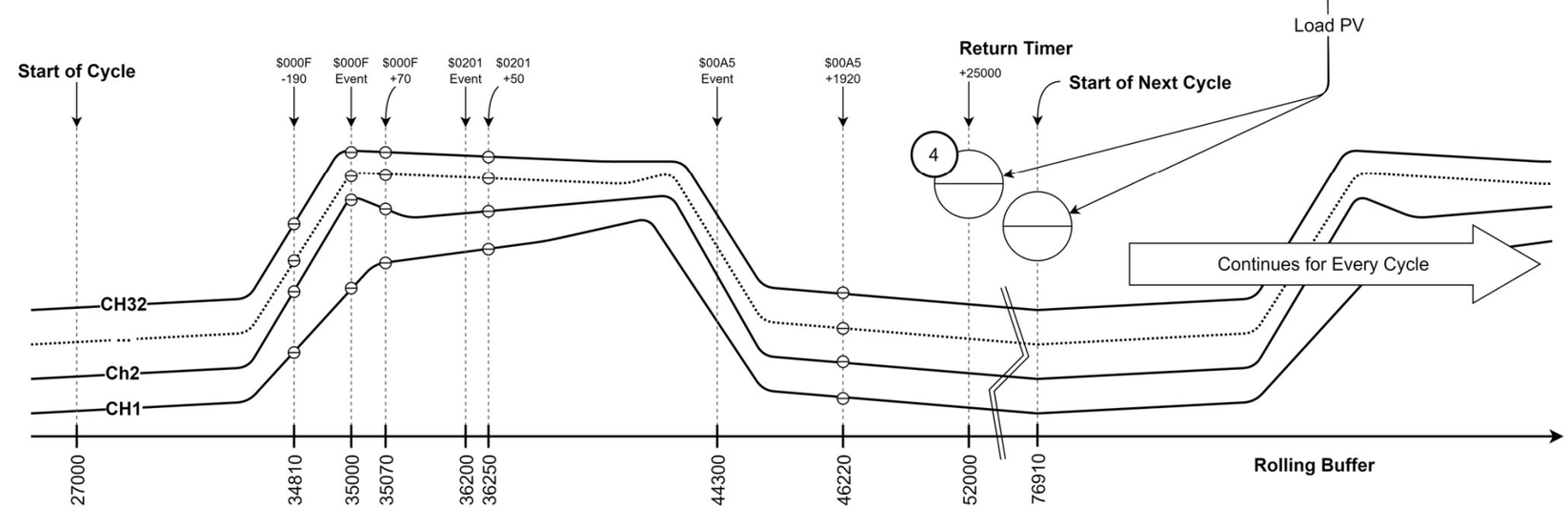
Fermilab Multicast Table (FMT)			
No.	Event	Data	Timestamp (uS)
1	$000F	0xFFFF_FFFF	35000
2	$001D	0xFFFF_FFFF	35900
3	$0201	0x0000_1932	36200
...	...	...	...
n	$00A5	0xFFFF_FFFF	44300

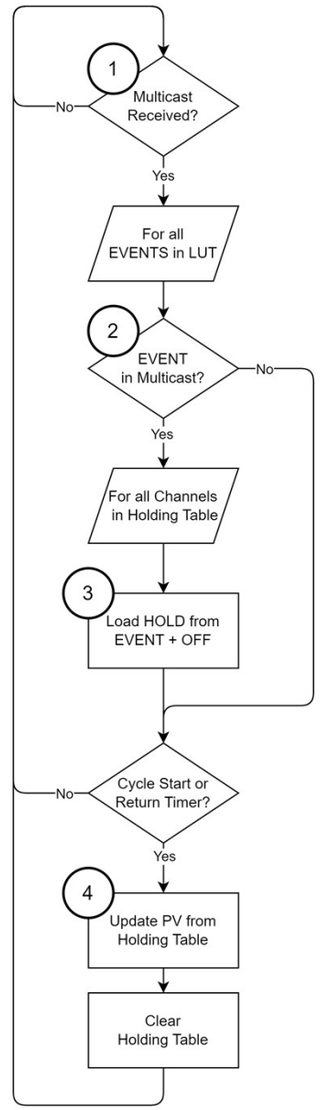
2

SoE Lookup Table (LUT)				
No.	Event	ARM(?)	PV ID	Offset (uS)
1	$000F		160908	0
2	$000F		160909	70
...	...		...	...
7	$000F		143219	-190
...	...		...	...
62	$0201		123680	50
~~63~~	~~$0039~~		~~498000~~	~~10~~
64	$00A5		010920	1920

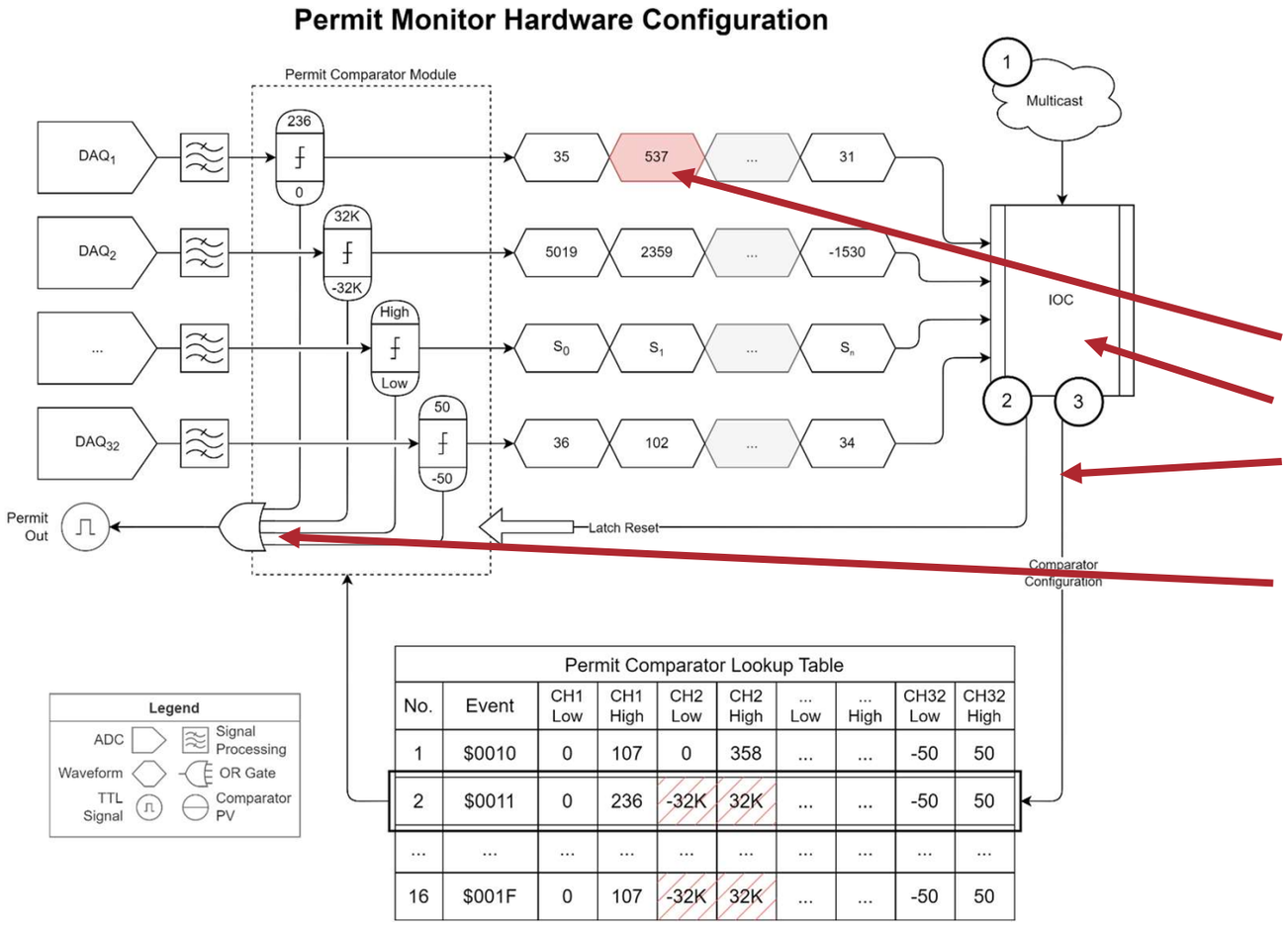
3

SoE Holding Table (HOLD)					
No.	PV ID	CH1	CH3	...	CH32
1	160908	37	58	...	102
2	160909	290	236	...	190
...	...	...	...	...	...
7	143219	11	13	...	17
...	...	...	...	...	...
62	123680	59	68	...	134
~~63~~	~~498000~~	~~UDEF~~	~~UDEF~~	...	~~UDEF~~
64	010920	48	51	...	109





Beam Permit Monitor Functional Specifications



Permit Comparator Lookup Table

No.	Event	CH1 Low	CH1 High	CH2 Low	CH2 High	... Low	... High	CH32 Low	CH32 High
1	$0010	0	107	0	358	...	...	-50	50
2	$0011	0	236	-32K	32K	...	...	-50	50
...	...	...	...	...	...	...	...	...	...
16	$001F	0	107	-32K	32K	...	...	-50	50

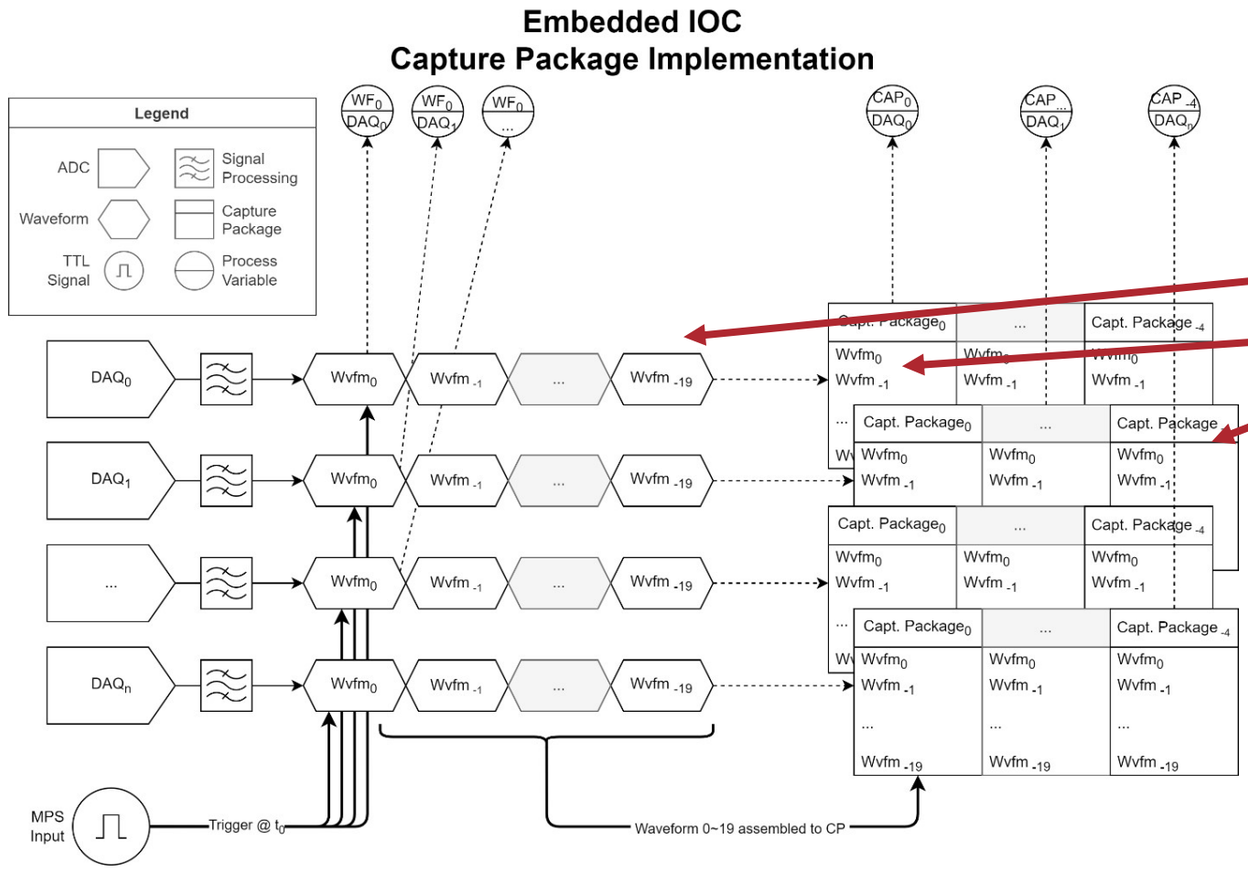
Overview of Permit Monitor Behavior

- Integrates with Machine Protection
- Hardware thresholds for each channel
- Configured via IOC
- Updates cycle-by-cycle
- Watchdog timer in FPGA
- One output for the XRM

Expected use case for PIP-II:

- Power supply out of tolerance

Postmortem Functional Specifications



On fault condition…

- Retain the previous one second of data
- Assemble into a capture package
- Retain the last 5 capture packages
- Each package presents as a PV
- Integrates with PIP-II Postmortem Capture System (PPCS)

Other Functional Specifications

General Purpose Input/Output (GPIO)

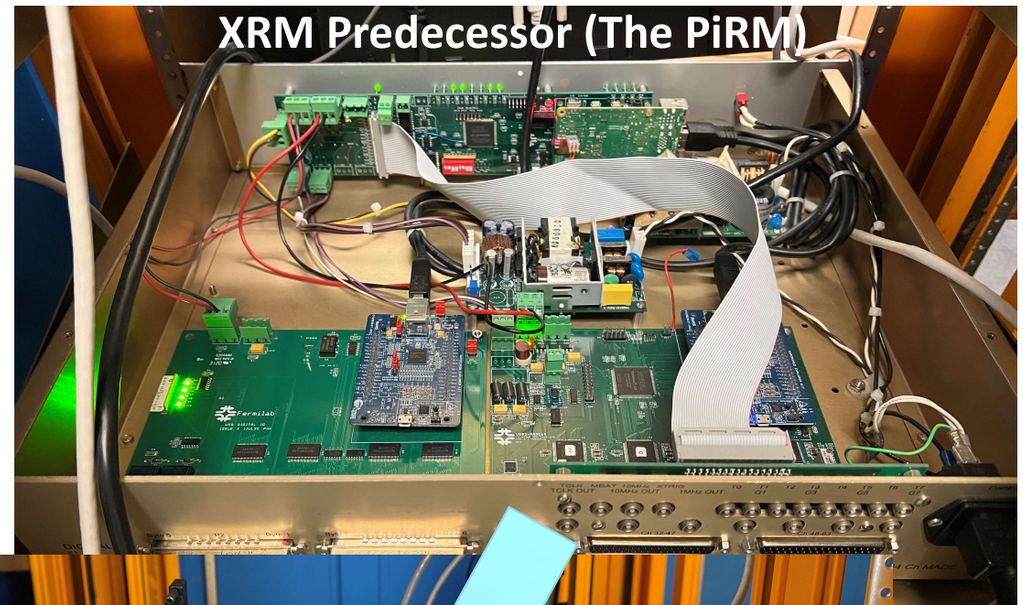
- Standard TTL levels
- Updates GPO status at 20Hz
- Samples GPI inputs with ADC clock
- Presents data as time/value pairs
- Captures all time/value pairs in a PV
- State machine, 40Hz updates

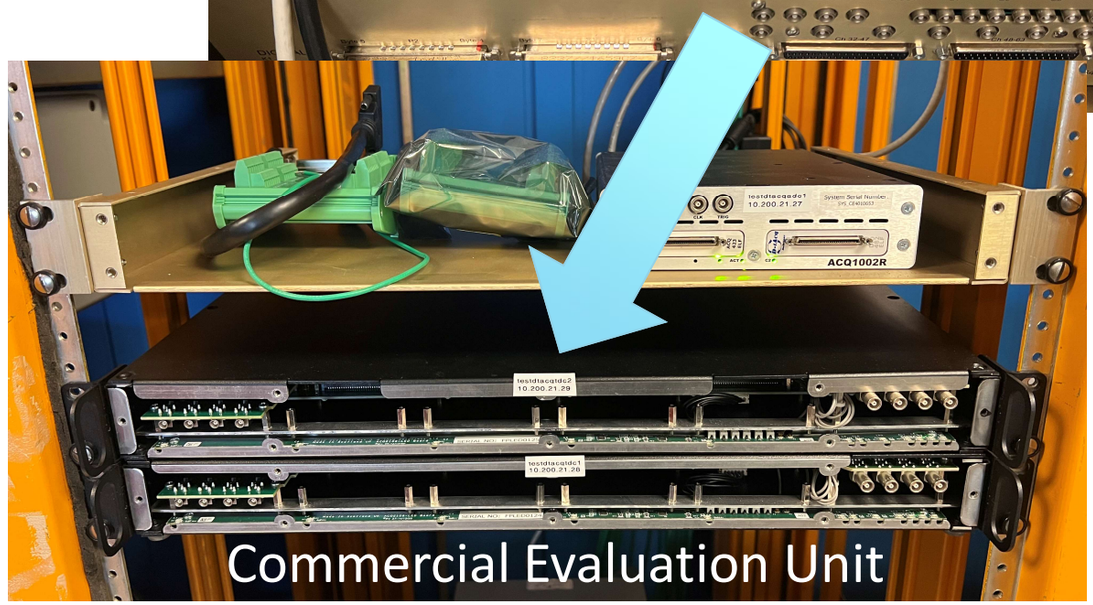
Digital to Analog Conversion (DAC)

- Primary user is MagPS
- Factory calibrated
- Continuous waveform generation
- User provided waveforms
- User provided voltage (DC)
- SIN or COS waveforms up to 5KHz
- Pulse generation, 0~50ms width.

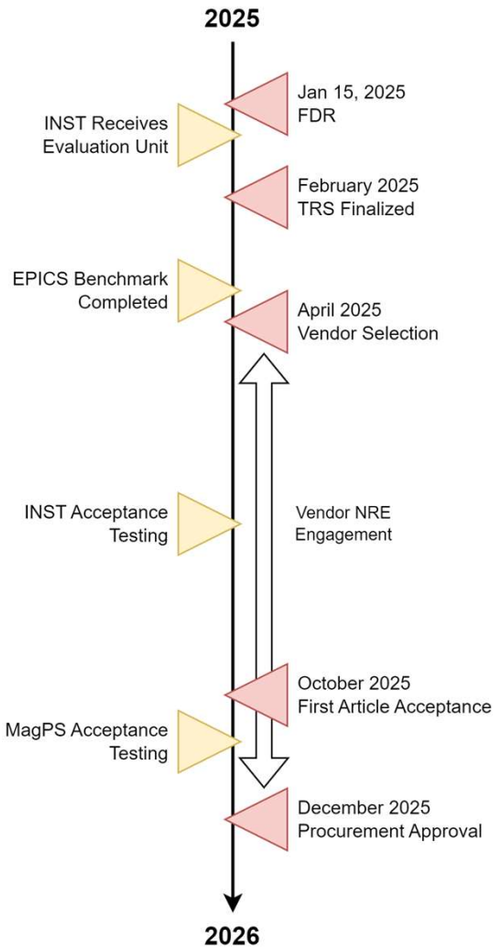
XRM Design Status

- The XRM has undergoes regular internal review with INST/OPS.
- 2 viable vendor solutions identified (D-TACQ / TUL)
- Instrumentation receiving evaluation units in January ‘25.
- Additional vendors/ collaborations are being sought out
- Some amount of NRE (Non-Recurring Engineering) required
- Preparing to go through quoting process after FDR
- Target First Article acceptance in October, delivery by end of year.



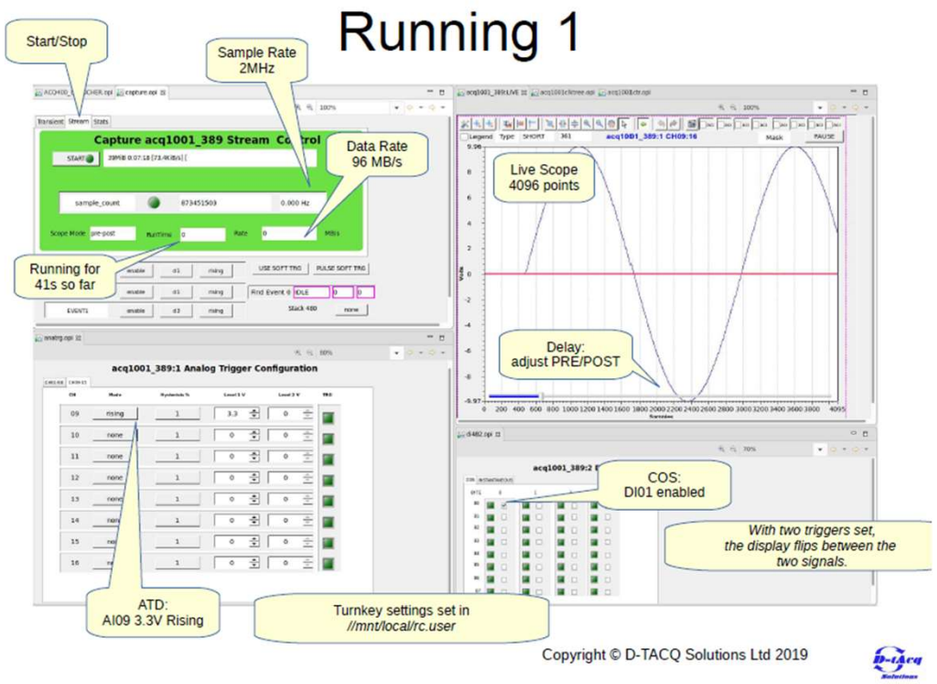


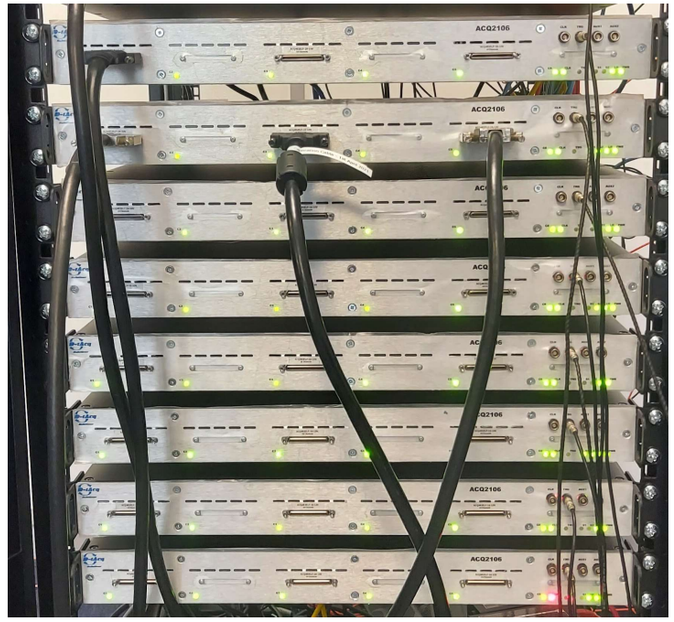
Timeline



- Vendor Selection by April 2025
- NRE process through October
- INST validation ahead of First Article
- MagPS validation upon receipt
- Ready for integration by 2026
- Batch shipments to be received through 2027

Present testing





- D-TACQ has provided an engineering unit
- Allows for basic EPICS benchmarking (in process)
- Mfg. spec of 192ch per unit (see rack)
- Present platform meets 90% of functional req's

- Poland also has platform with similar functionality
- Looking into commercialization process
- Either way, NRE will be required for full integration

Summary

- Requirements are well understood, specification is mature
- Q/A procedures are established and clearly defined
- Availability of engineering units has allowed for advanced testing
- Specification & Integration will continue after vendor selection
- Existence of similar platforms shows direction is viable
- Working closely with PIP-II procurement to stay on schedule

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Does the XRM solution meet all lifecycle and sustainability expectations, including service life, warranty period, backwards compatibility, vendor support, and environmental compliance?

Stakeholder Alignment and Interfaces

Have all intersecting parties (technical, engineering, and operations) reviewed and agreed upon the XRM specifications to ensure it meets functional, technical, and operational requirements?

Design Completion

Is the design at the 90% stage or better?

QA/QC

Does the design meet Fermilab's QA/QC requirements?

Component Database and Traveler Requirements

Does the acceptance plan include proper PIP-II Component Database documentation? Does the testing plan follow the PIP-II project's requirements for traveler documentation?