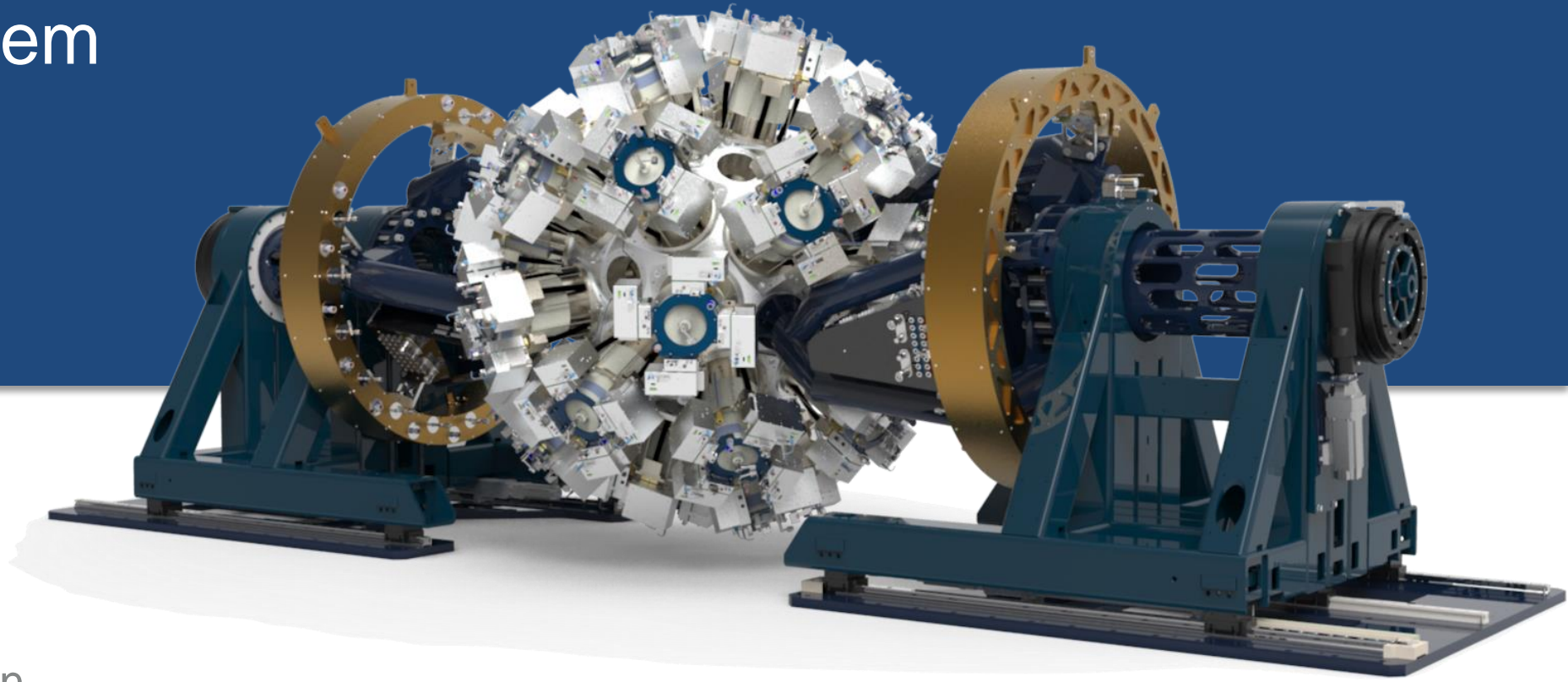


GRETA System Assembly



Heather Crawford
Deputy Project Director

Nuclear Science Division
Lawrence Berkeley National Laboratory

Approach to System Integration & Test

Approach:

Multiple stages of system integration ensure success for GRETA

- 1: End-to-end integration of prototype systems prior to CD-2/3
- 2: Final assembly and test with partial detector complement ensures performance and enables system delivery to FRIB at CD-4A

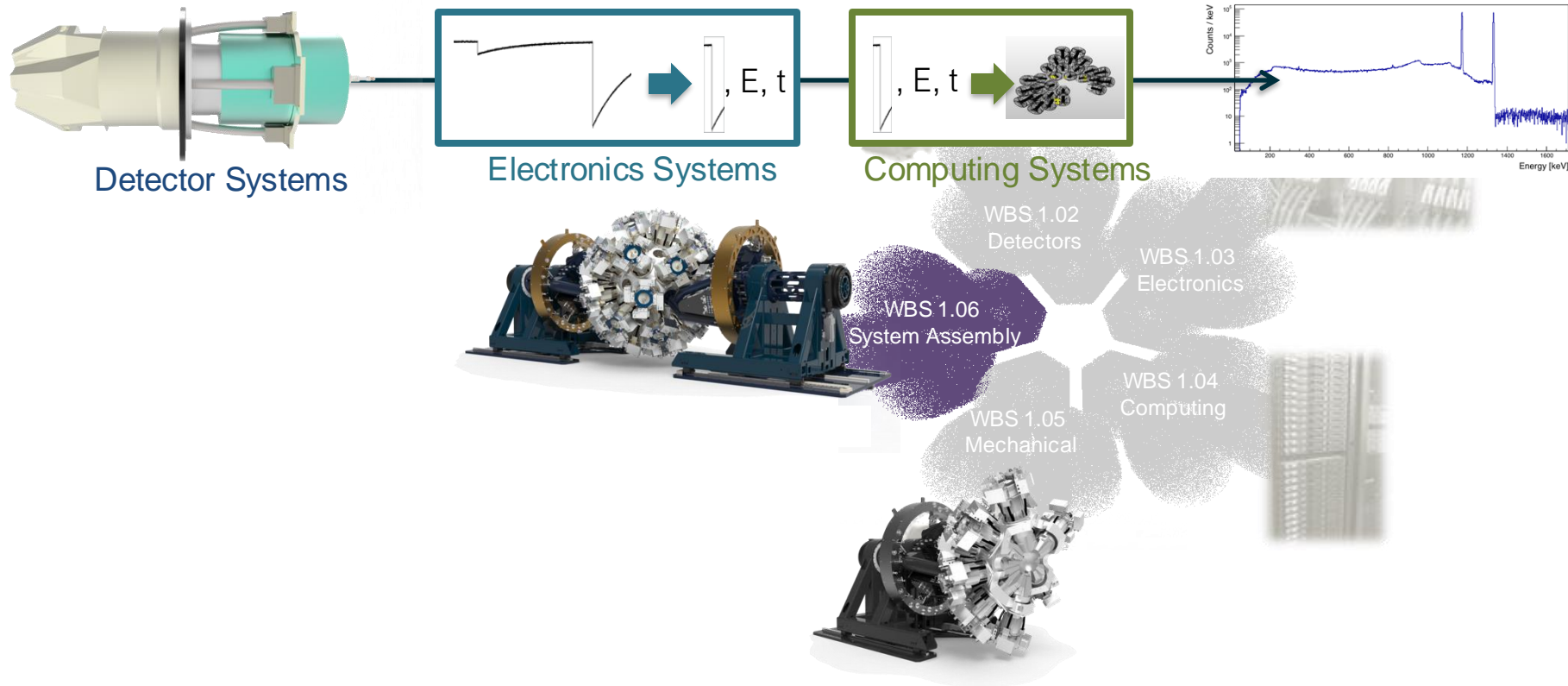


Approach to System Integration & Test

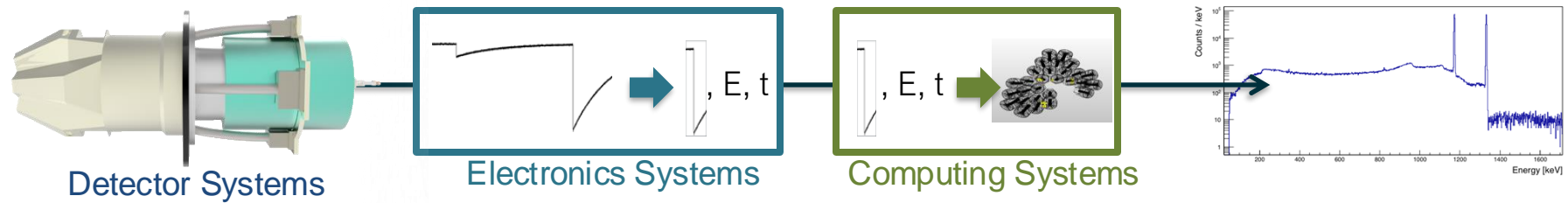
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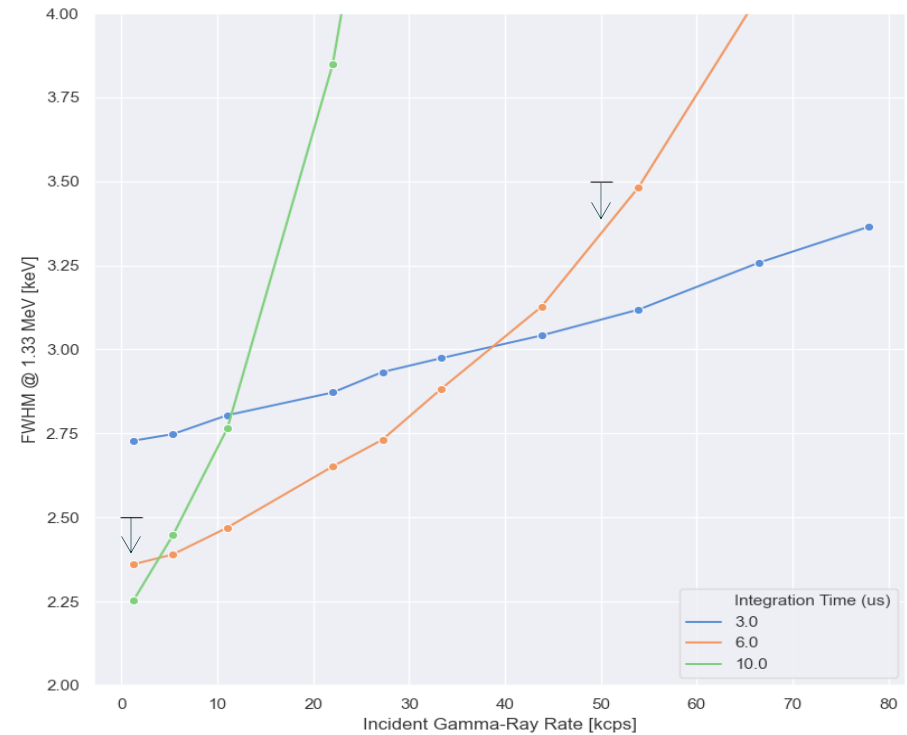


End-To-End Prototype Integration (2020)

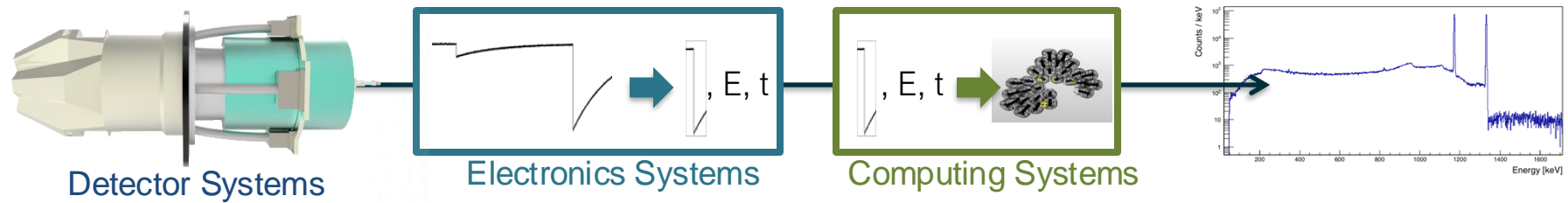


- Performance of the Digitizer Module and other ES and CS prototype systems was verified
- Energy resolution as a function of rate and gamma-ray energy was demonstrated
- ADC linearity was confirmed, via energy calibration residuals and as a function of ADC value

Rate	Required Resolution	End-to-End Test Result
1 kcps	≤ 2.5 keV	2.25 keV
50 kcps	≤ 3.5 keV	3.1 keV

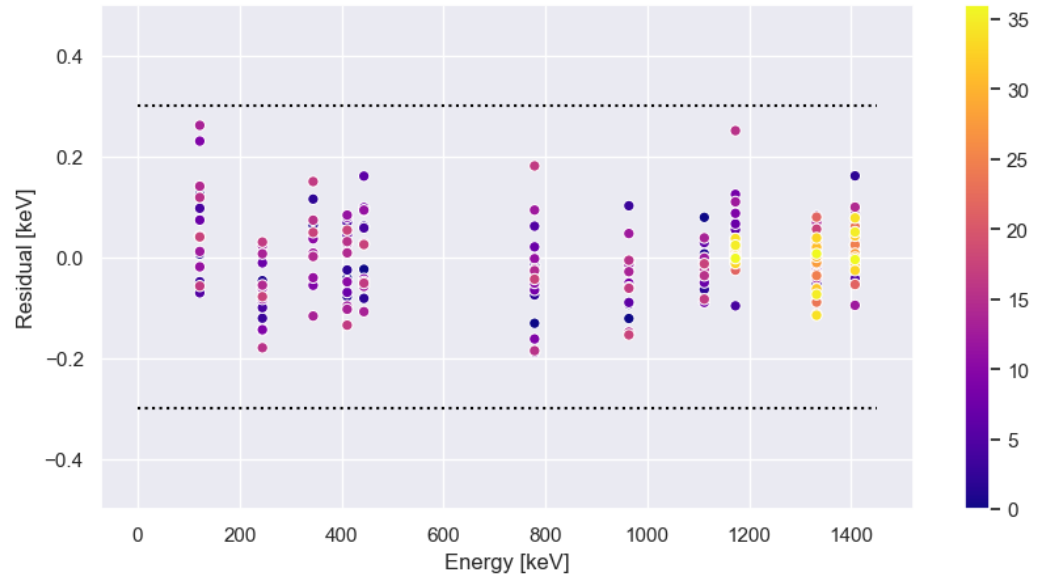


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Key Performance Parameters for GRETA

Table 1a. Preliminary Key Performance Parameters at CD-4A (Phase-1 Completion)

System	Parameter	Threshold KPP	Objective KPP
Detectors	Procurement and Acceptance	Accept 6 Quad Detector Modules	Same
Electronics	Signal Digitization	Deliver digital signal processing electronics to instrument 30 Quad Detector Modules. Provide preamplifier waveforms at ≥ 100 Mega samples/s	Same
Computing	Event Processing	2000 signal decomposition calculations per crystal/s	4000 calcs per crystal/s
Mechanical	Support Frame	Assemble the complete mechanical support capable of mounting 30 Quad Detector Modules with required tolerance and precision	Same
Array	Integrated systems performance*	Array energy resolution ⁺ ≤ 3.0 keV	Same

* Will be achieved with final electronics, computing, and mechanical systems together with at least 6 GRETA Quad Detector Modules

⁺ The average full-width-half-maximum as measured at 1.33 MeV with a ⁶⁰Co source

Table 1b. Preliminary Key Performance Parameters at CD-4 (Phase-2 and Project Completion)

System	Parameter	Threshold KPP	Objective KPP
Detectors	Procurement and Acceptance	Accept a total of 16 Quad Detector Modules *	Accept a total of 18 Quad Detector Modules*

* The total number of Quad Detector Modules accepted at project completion includes those delivered at Phase-1.

Key Performance Parameters for GRETA

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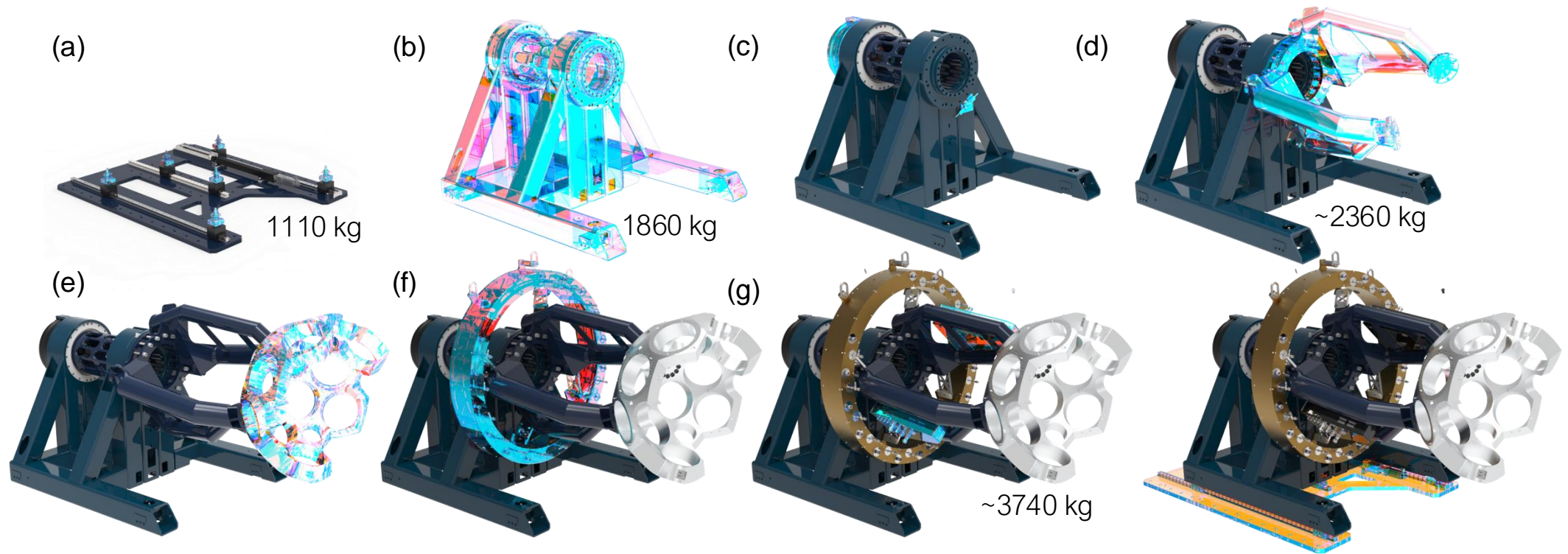
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* The total number of Quad Detector Modules accepted at project completion includes those delivered at Phase-1.

Mechanical Systems Installation



- For access to overhead cranes, the structure assembly was performed in the Bldg. 88 high-bay and then moved

A-Frames



Initial weldment of frame



Access for bottom features



Machining the interior surface



Shaft inserts



Completed assemblies prior to shipment



A-frames prior to integration of bearings/shaft

Support Arms



Rough machined tubing



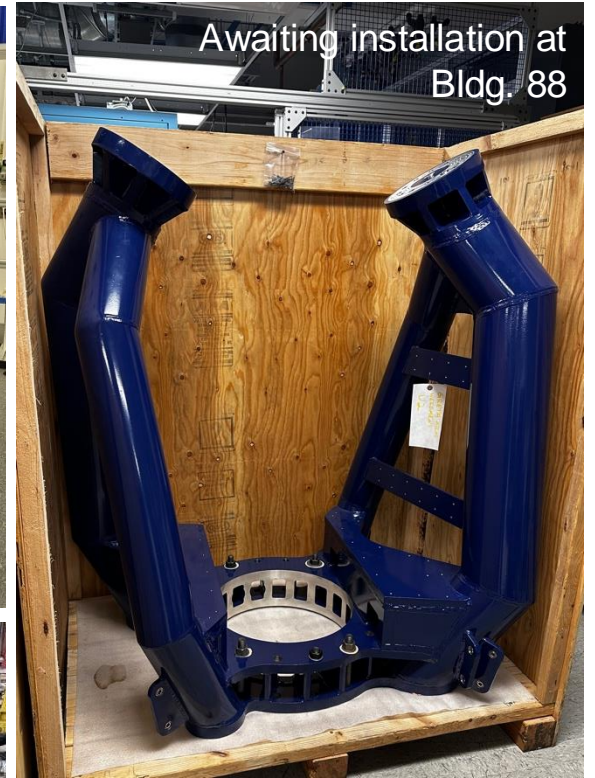
Arm being welded in jig



Welded arm base



On CMM for inspection at B77



Awaiting installation at Bldg. 88



Inspection at vendor

Hemispheres (Main Body) – Fabrication Steps



Raw Material



First Inner Machining Step



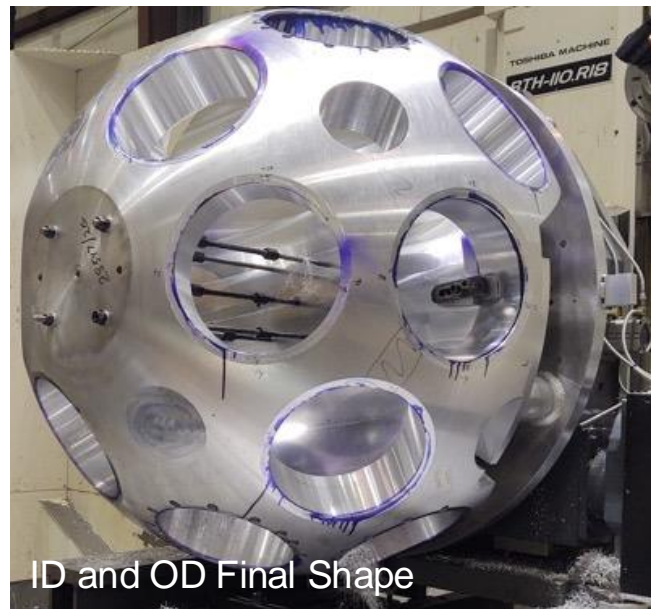
First Rough Hemisphere



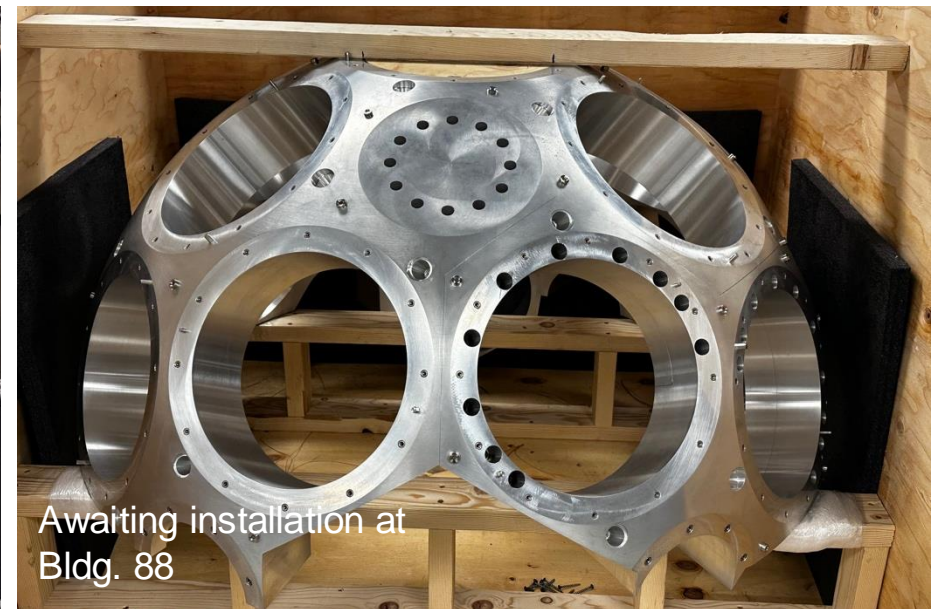
Ready for Last Machining Step



Ports Added to Hemisphere

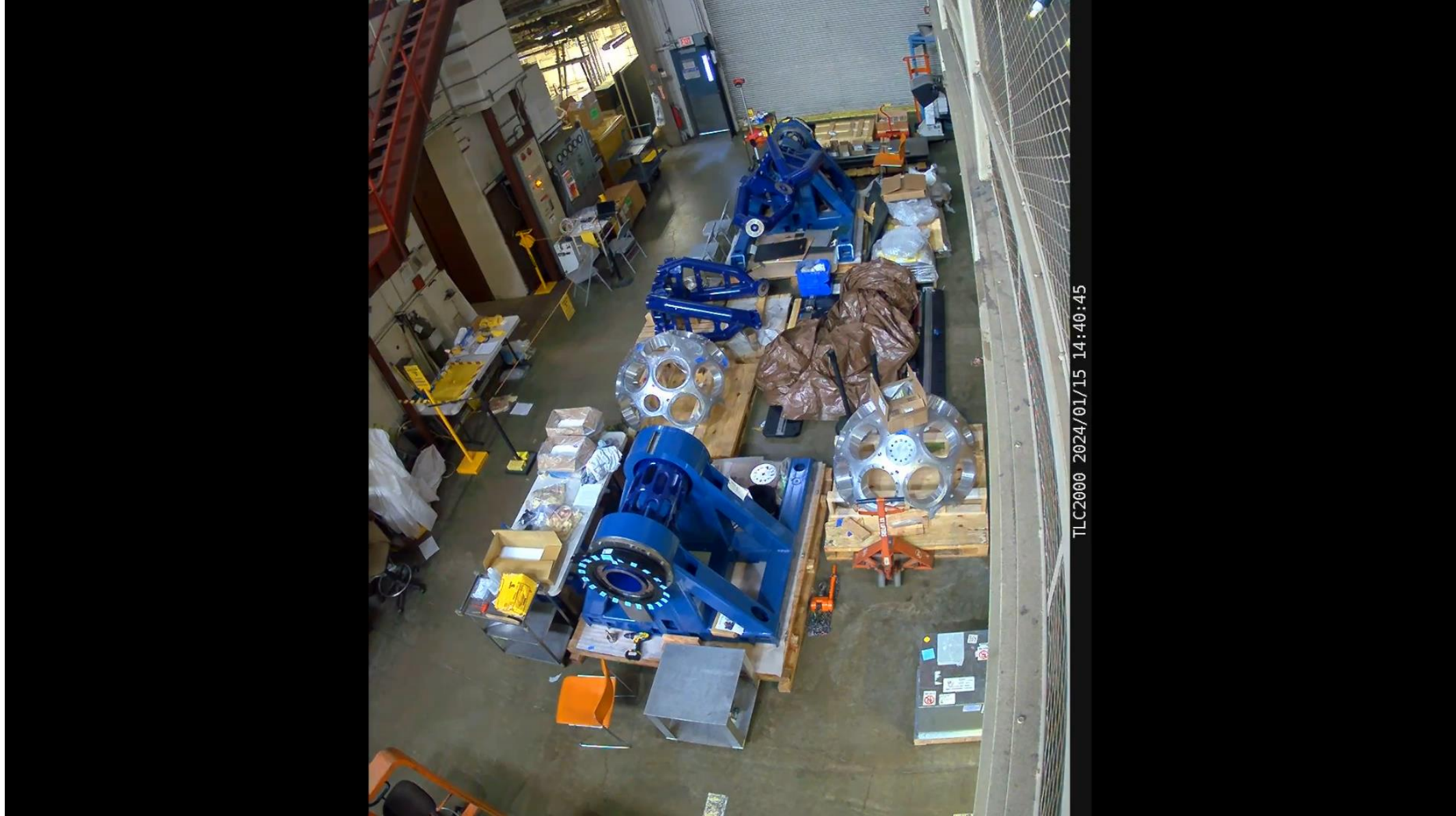


ID and OD Final Shape



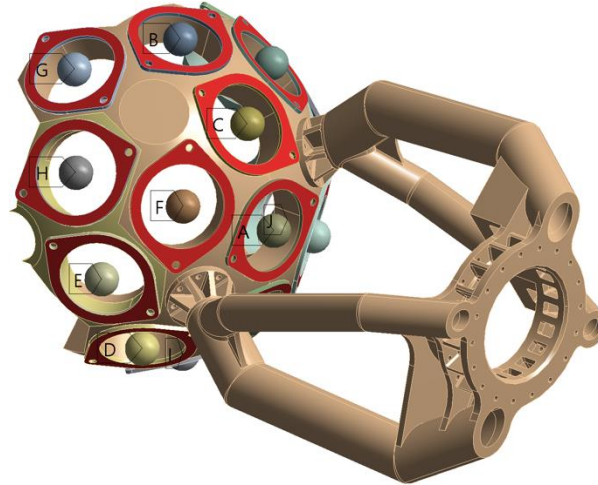
Awaiting installation at Bldg. 88

Mechanical Systems Installation

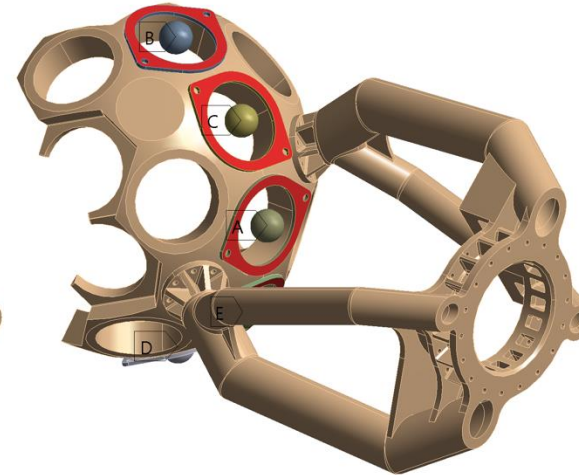


Demonstration of Mechanical Systems KPP

- In addition to installation and testing of all mechanical systems (e.g. LN and closed loop cooling, motion control) load testing will be performed during the final assembly and test (KPP)
- Dummy weights on wedge plate mounts will be used to confirm deflections and exercise alignment procedures without Quad Detector Modules
- Dummy weights will be installed following the same procedure as a detector (e.g. treated as a critical lift with detailed procedure, providing practice before Quads are installed)
- Load configurations planned:
 - Unpopulated
 - Fully loaded (30)
 - Asymmetric
 - Minimal load (90°)

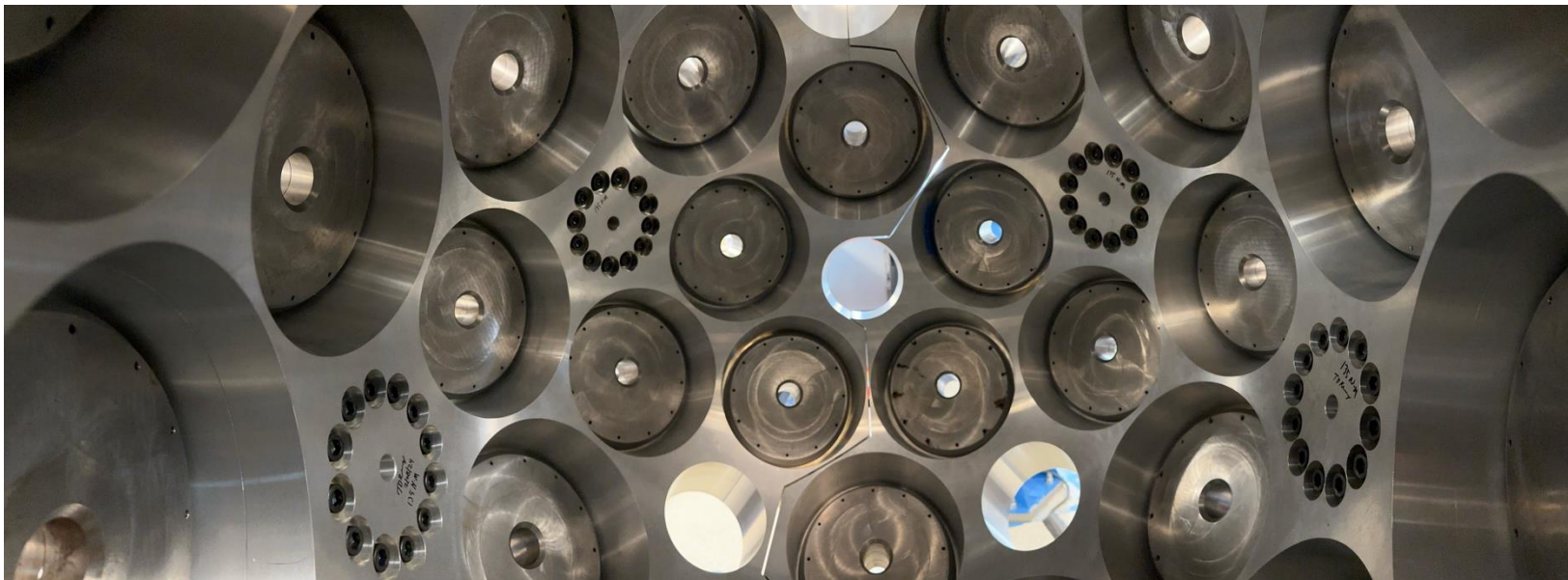
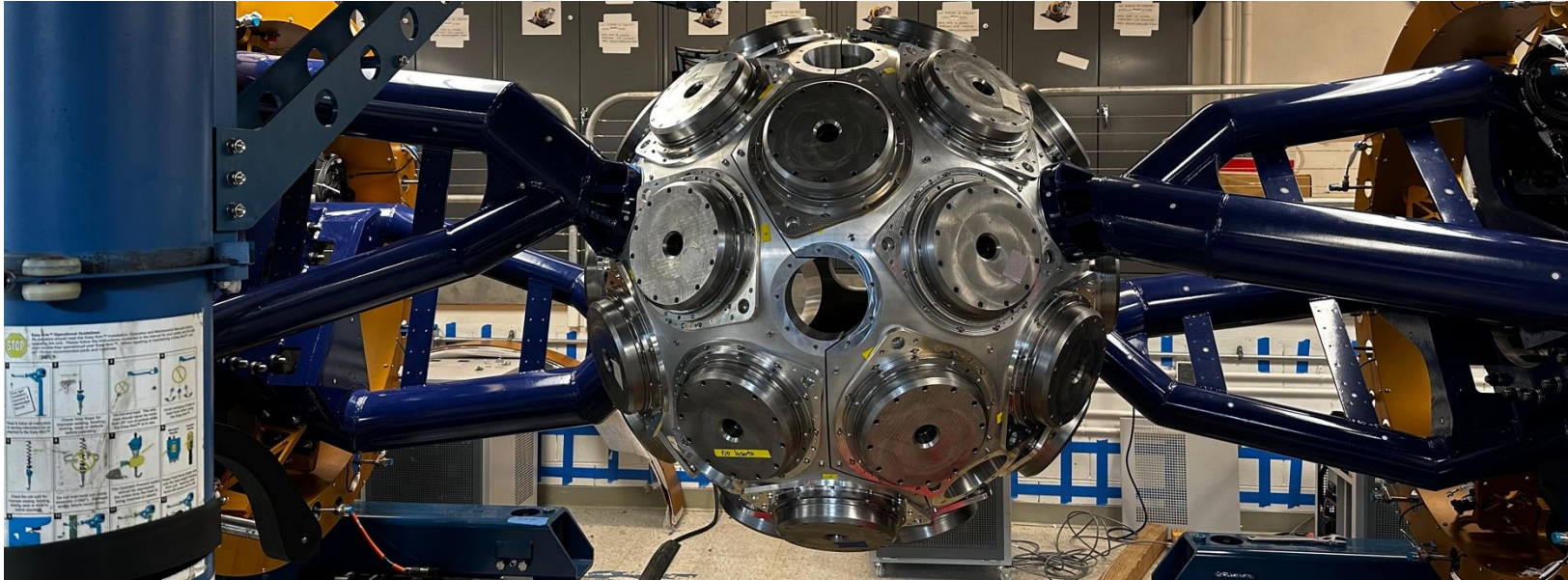


Maximum experimental load
(Full hemisphere, 15 detectors)



Minimum experimental load
(No entry/exit rings, 5 detectors @ 90°)

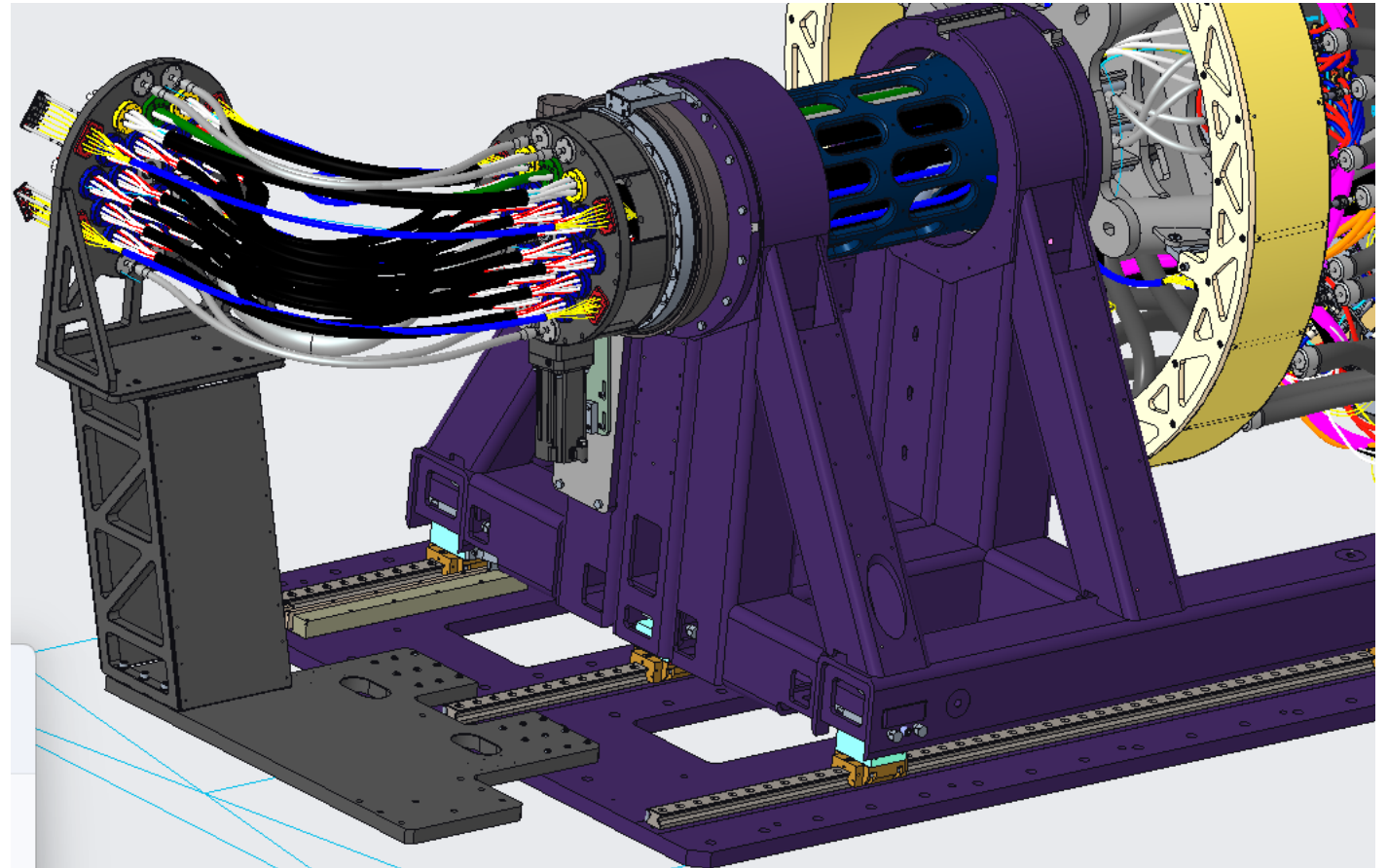
Demonstration of Mechanical Systems KPP



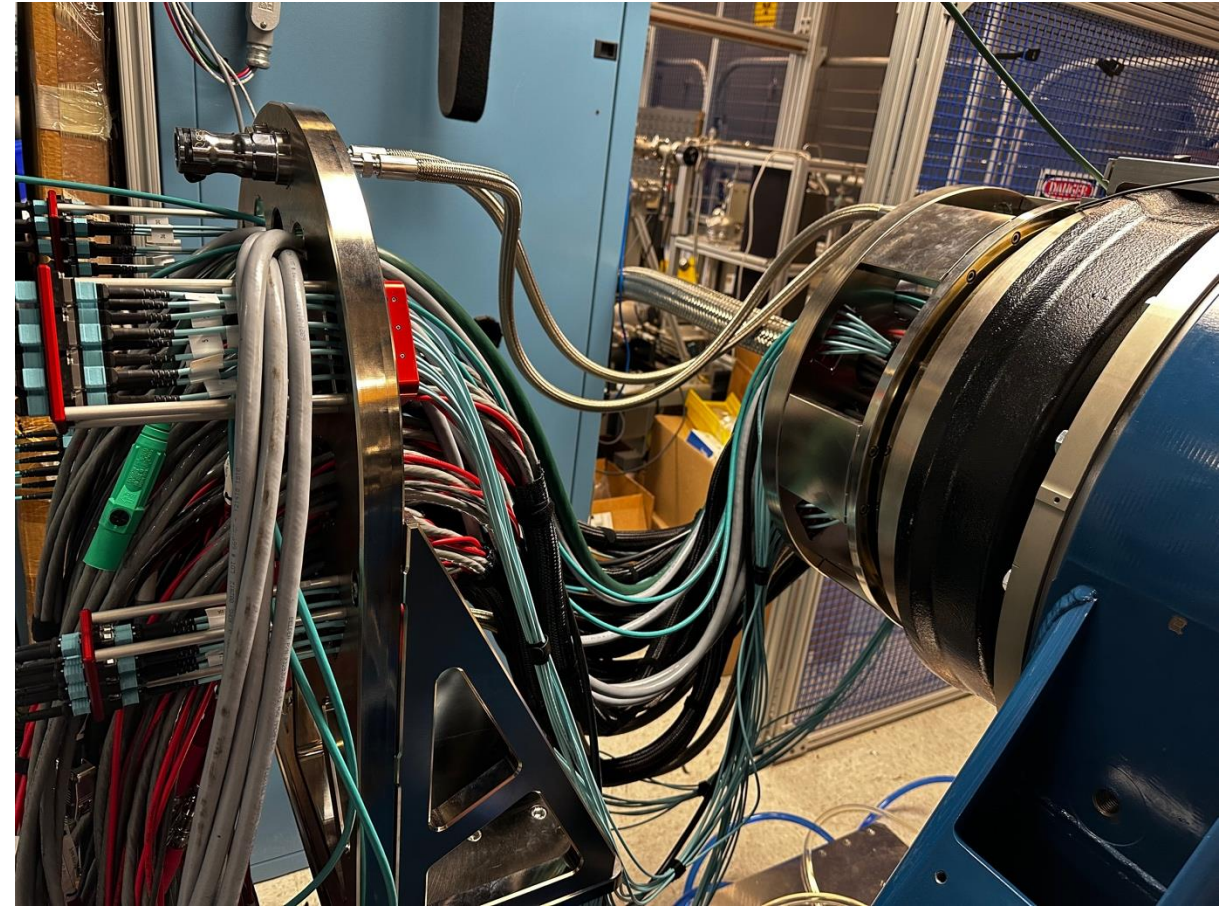
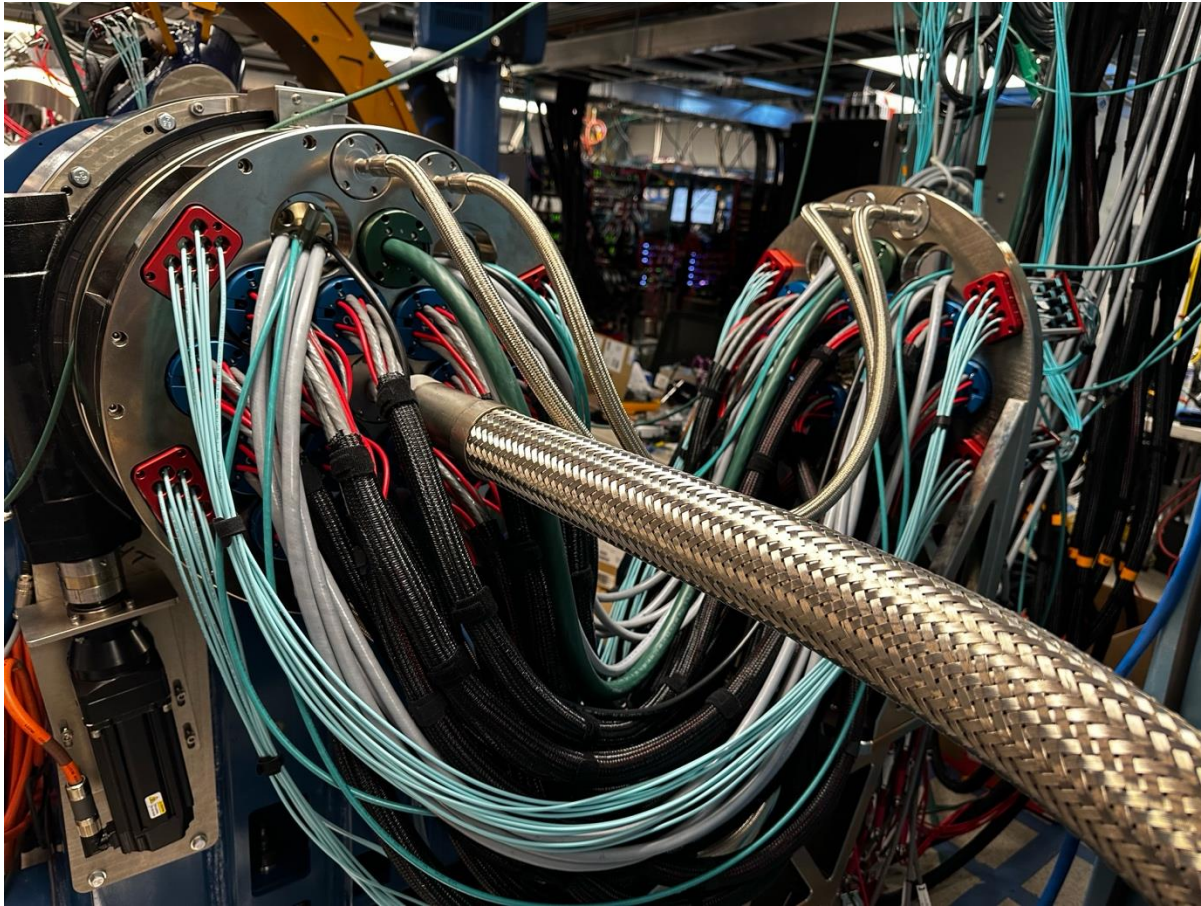
- Deflections were measured based on laser survey – from empty to fully-loaded each hemisphere deflected 1.7 mm
- Additional measurements showed deflection ~ proportional to # of mounted weights
- Alignment capability is confirmed to allow for 10 mm adjustment in x, z

Other Mechanical Aspects –Cabling

- In order to allow for translation and to take up $\pm 180^\circ$ rotation, cables are clamped at two cable management assemblies and routed through the axle
- The array will be shipped/moved with the thru-axle cables connected

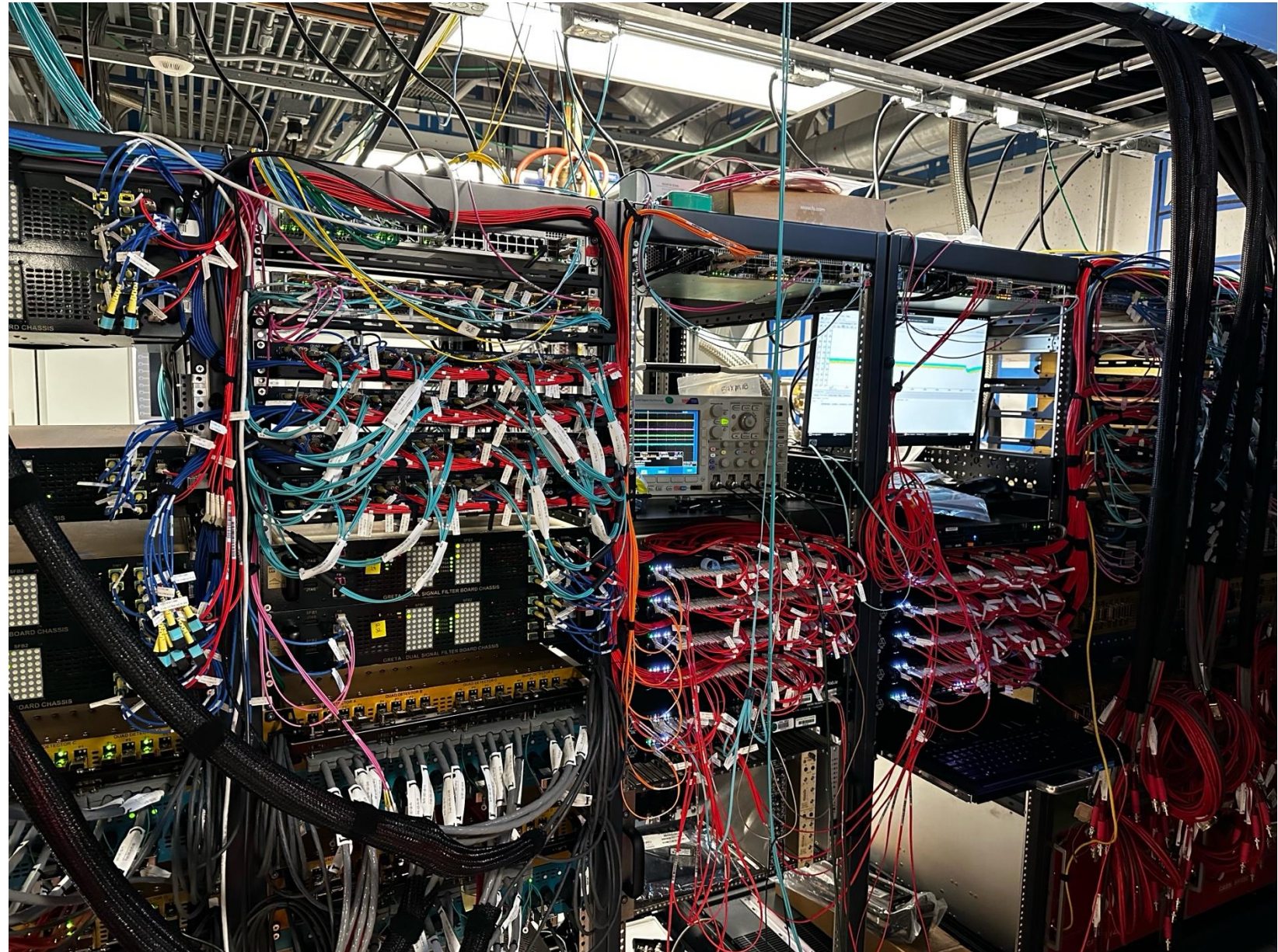


Other Mechanical Aspects –Cabling

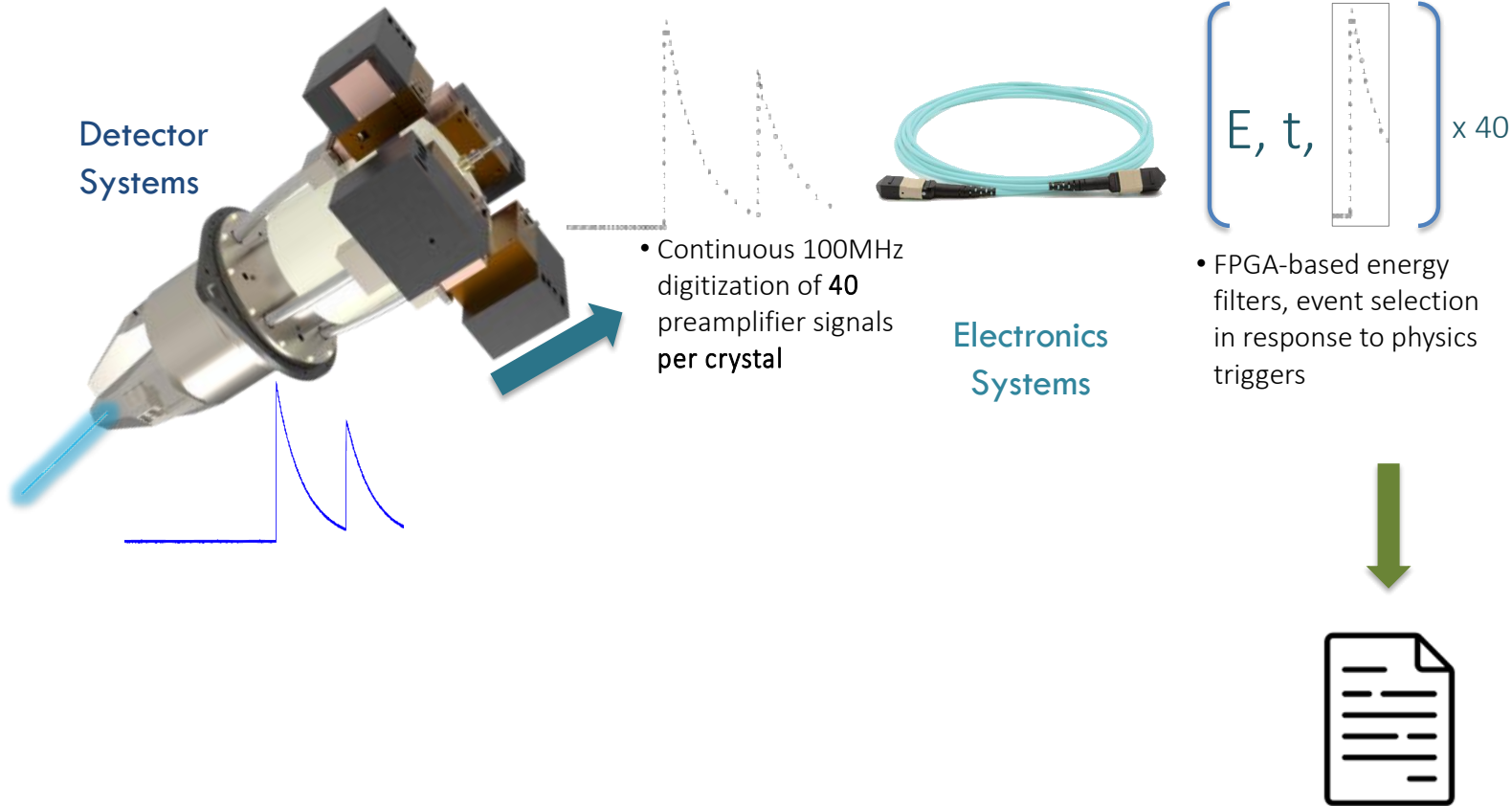


Electronics & Computing Installation and Performance

- Electronics systems (FPGA signal filter boards and power supplies) and computing switches are installed in racks local to the array and all cabling (fiber) is routed semi-permanently
- Footprint of electronics for entire array is 6 standard racks; separable into 2 banks of 3 racks for each hemisphere



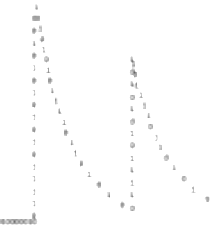
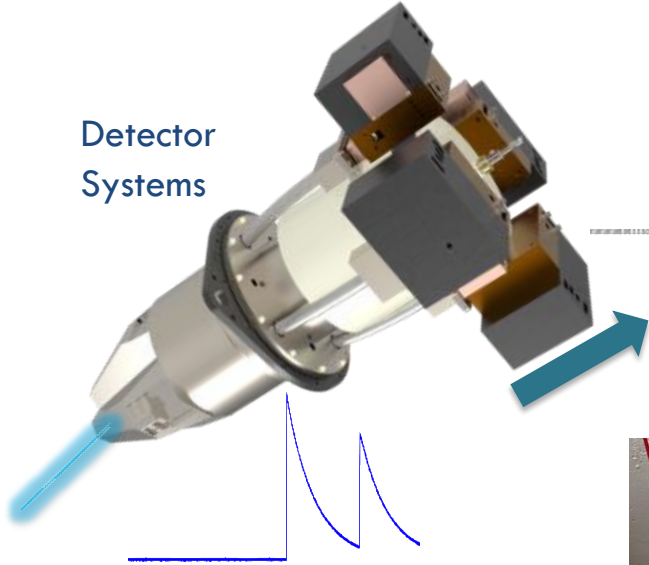
Single Quad Module Test with Production Systems



- With basic function confirmed a single Quad Module will be instrumented on the bench to provide stringent test of the production systems
- Verifies the production electronics units, including the timing system, and the pipeline of the production computing system

Single Quad Module Test with Production Systems

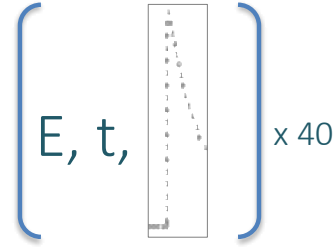
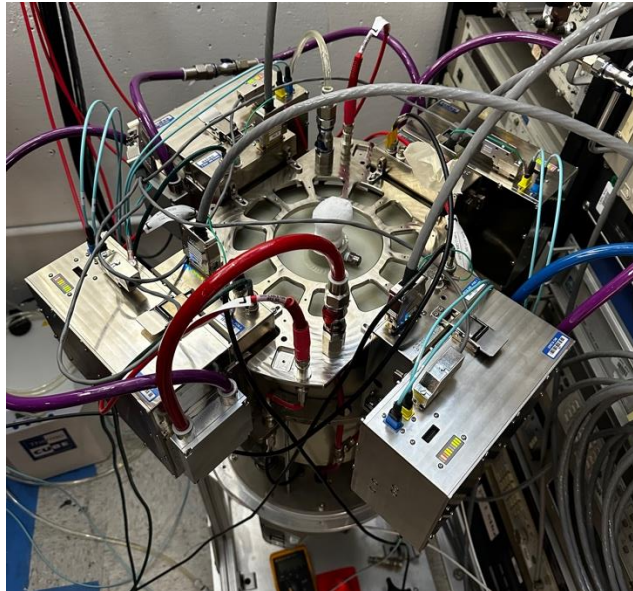
Detector Systems



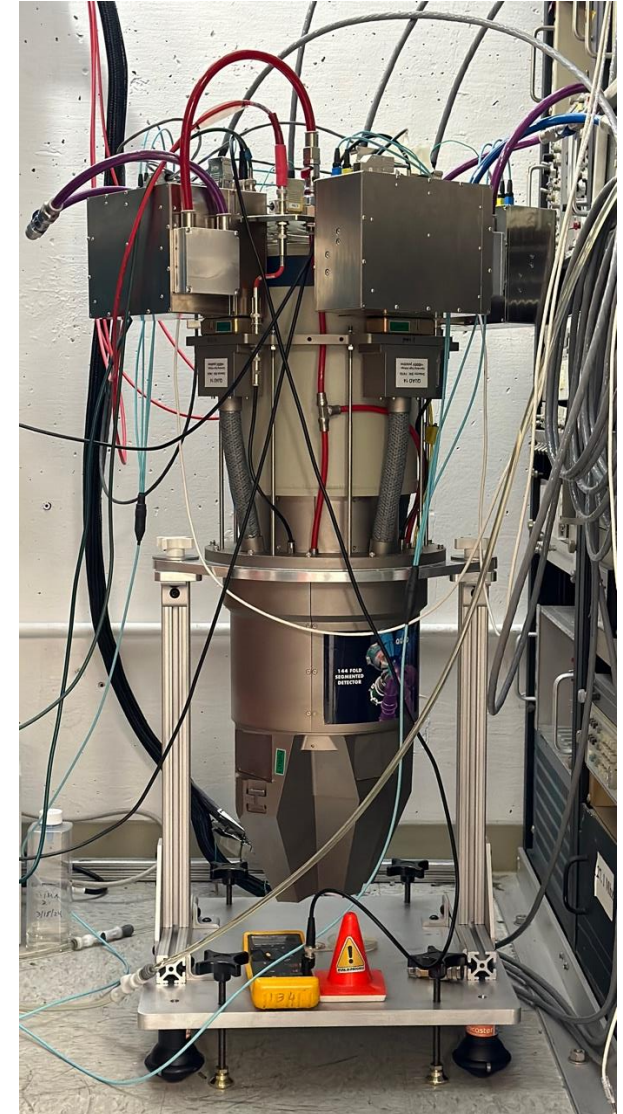
- Continuous 100MHz digitization of 40 preamplifier signals per crystal



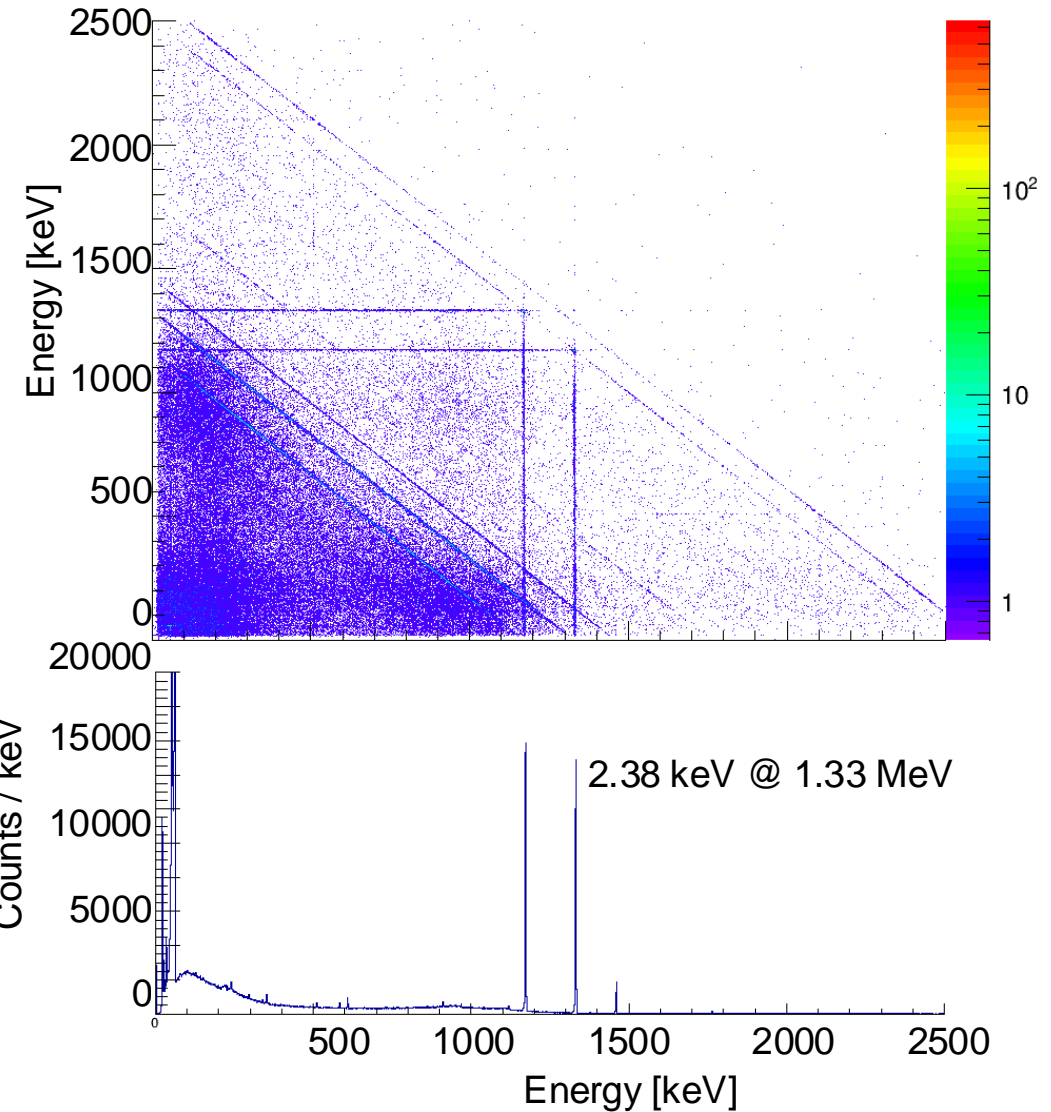
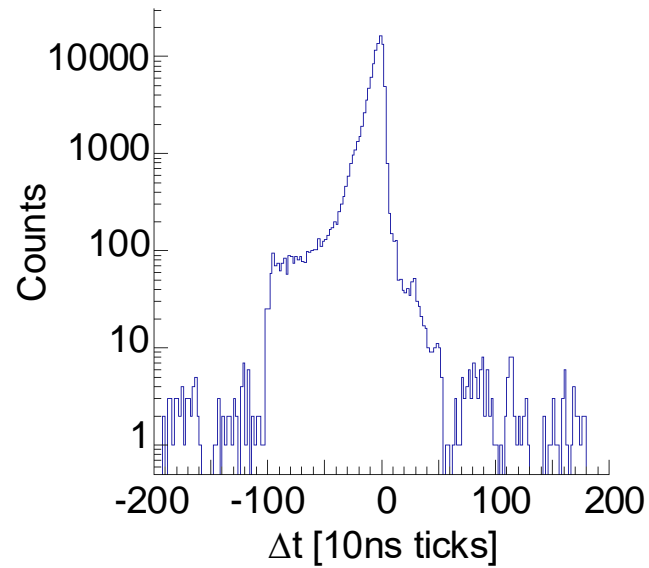
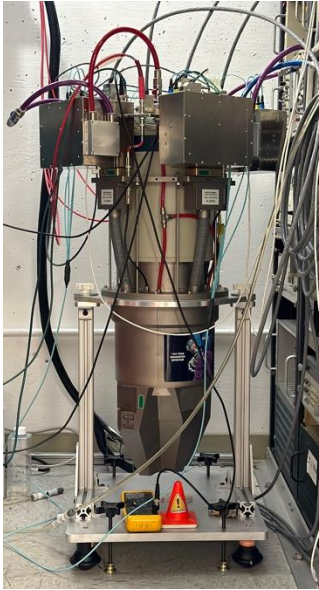
Electronics Systems



- FPGA-based energy filters, event selection in response to physics triggers

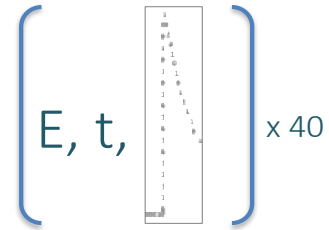


Single Quad Module Test with Production Systems



- Single quad test is underway
- Time synchronization of the 4 Digitizer Modules has been confirmed, coincidence data for ^{60}Co looks good
- Resolution achieved is 2.38 keV at 1.33 MeV for summed spectrum of 4 crystals; KPP requirement for 6 Quads in the array is 3.0 keV

Demonstration of Computing Systems KPP



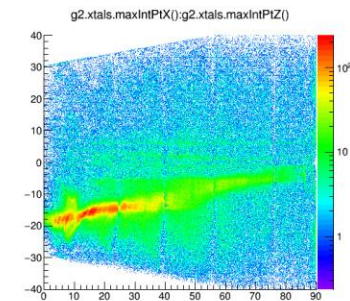
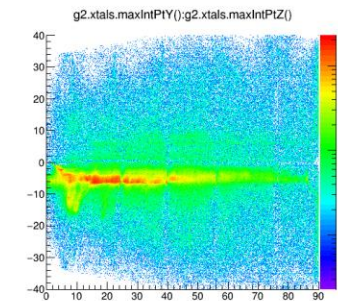
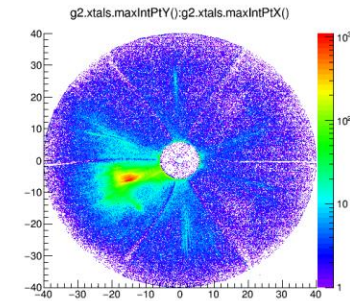
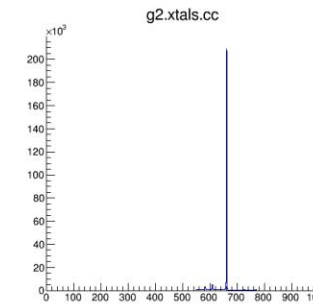
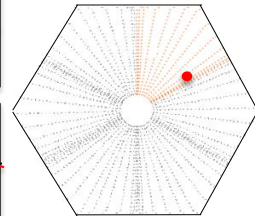
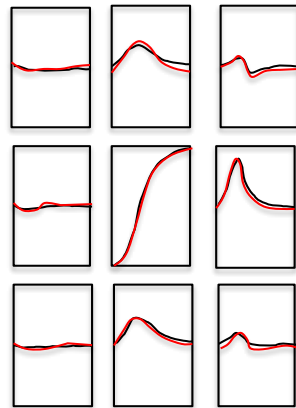
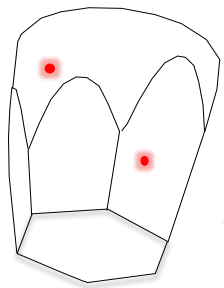
- FPGA-based energy filters, event selection in response to physics triggers

Computing KPP

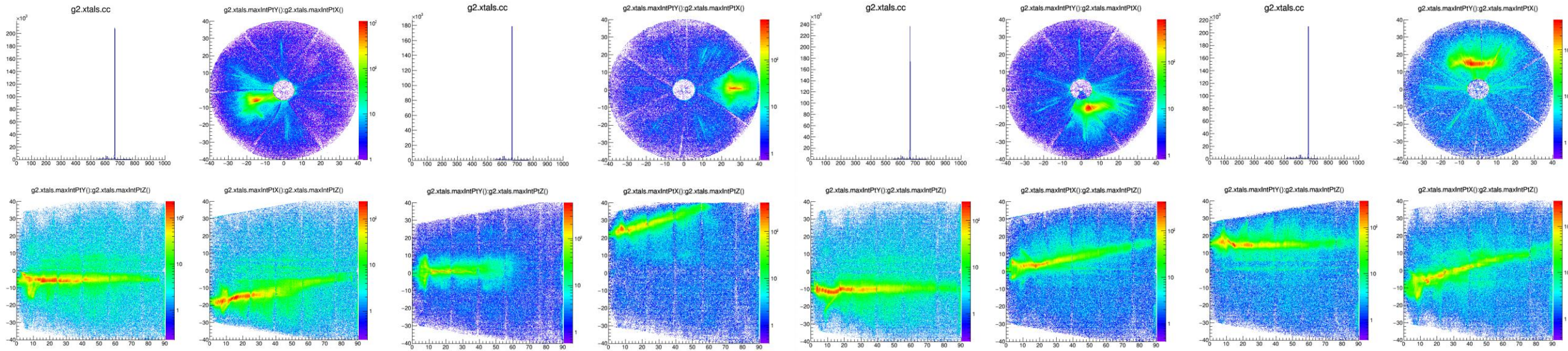
- With pre-recorded data sets, all 120 crystals will be simulated within the computing system (with data senders) at full rate to demonstrate computing throughput
- Saved pencil beams offer a clear visual demonstration of the accuracy of signal decomposition, and represent an average time per decomp calculation

Computing Systems

$$\left[E, t, (x, y, z)_{\text{crystal}} \right]_n$$



Demonstration of Computing Systems Throughput Performance



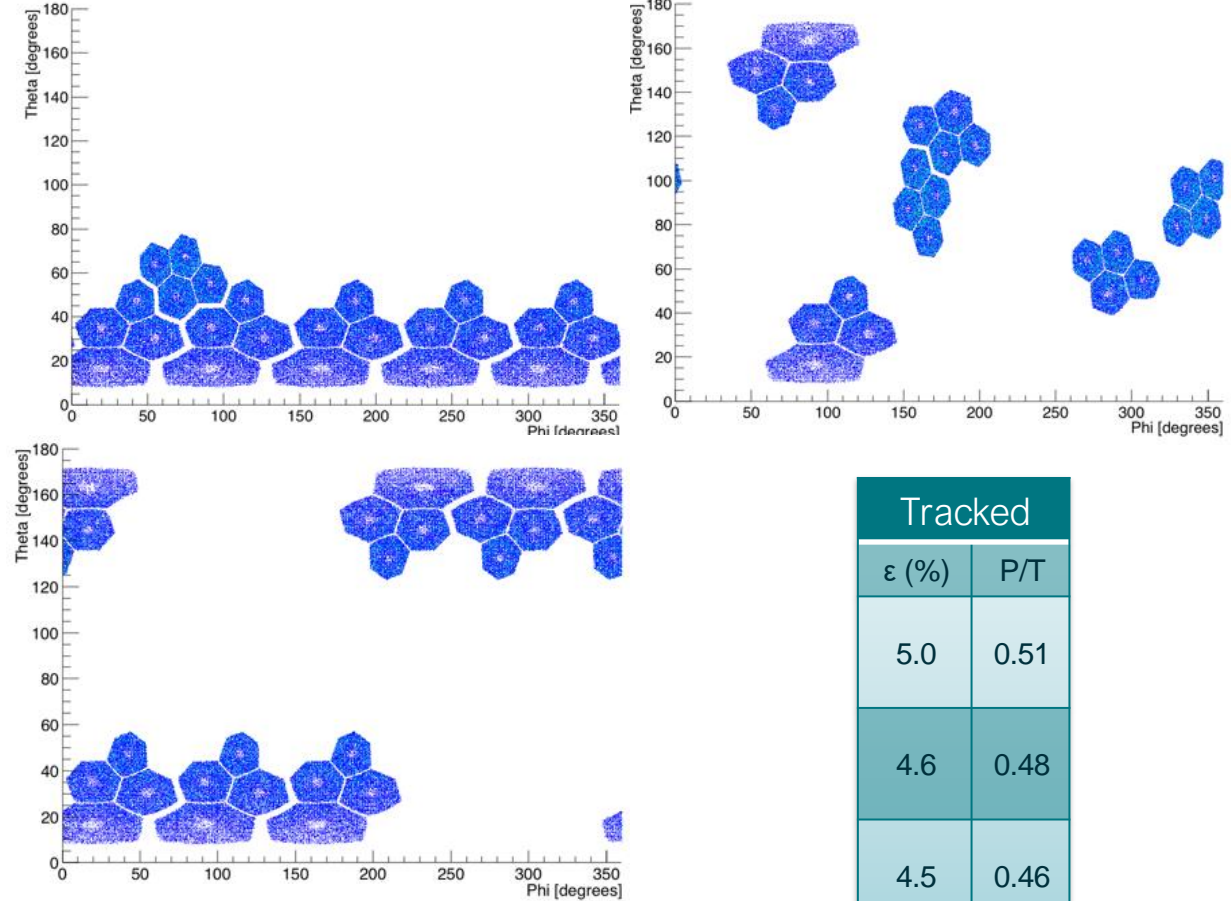
X 30

Computing KPP

- The threshold throughput performance of 240k decomp/s (2000 decomp/s/crystal) has been achieved
- Scaling up to the objective performance rate (480k decomp/s, 4000 decomp/s/crystal) is underway

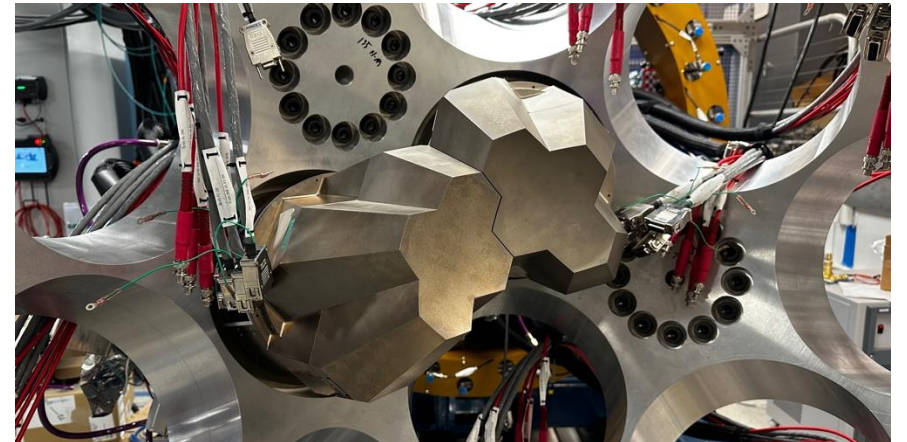
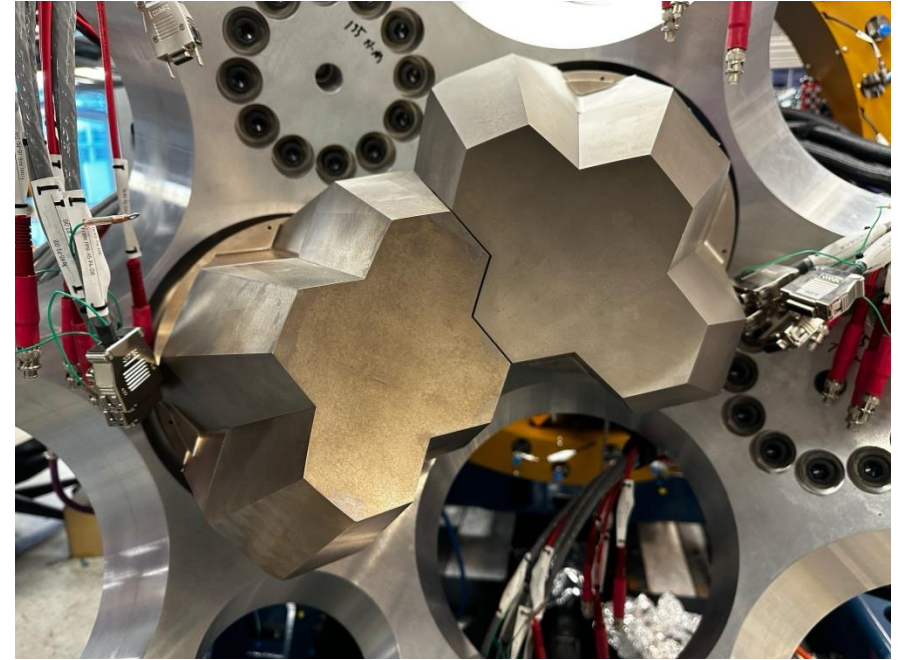
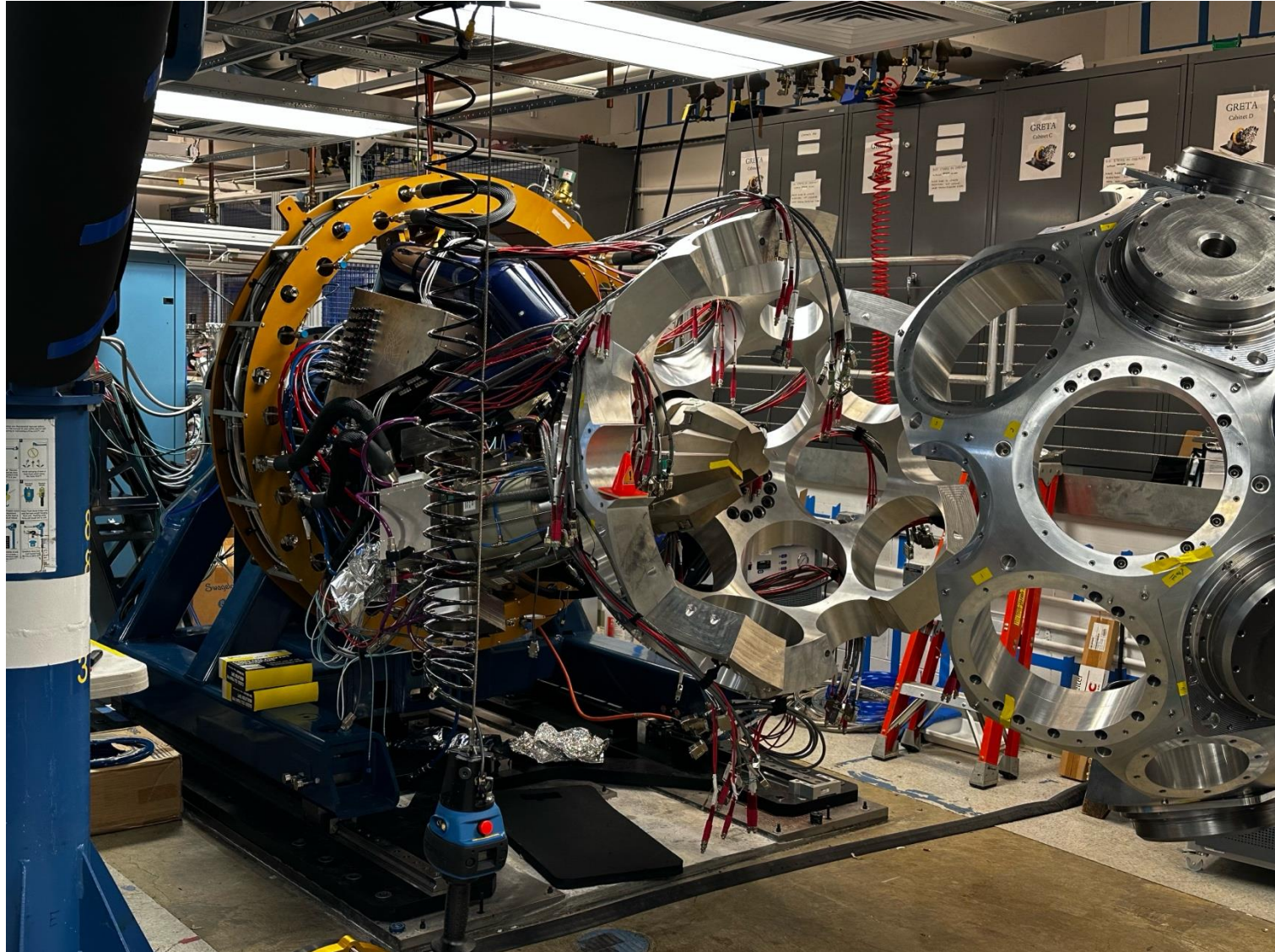
Final System Test & Demonstration of Array KPP

- At least 6 Quad Modules will be installed, instrumented and tested in three distinct configurations
- Data will be taken with a range of sealed sources (from ^{241}Am to ^{56}Co)
 - Comparison with simulations provides confirmation of predicted performance for full array
- Test will use ~72 complete electronics + computing signal chains
- Validates load testing of mechanical systems with dummy weights
- ^{60}Co source measurement will satisfy **overall performance parameter**

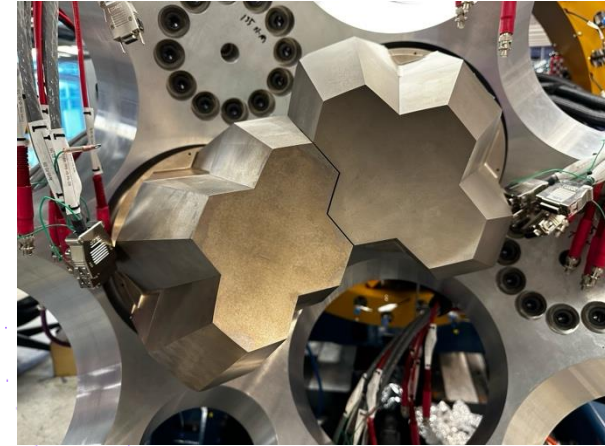
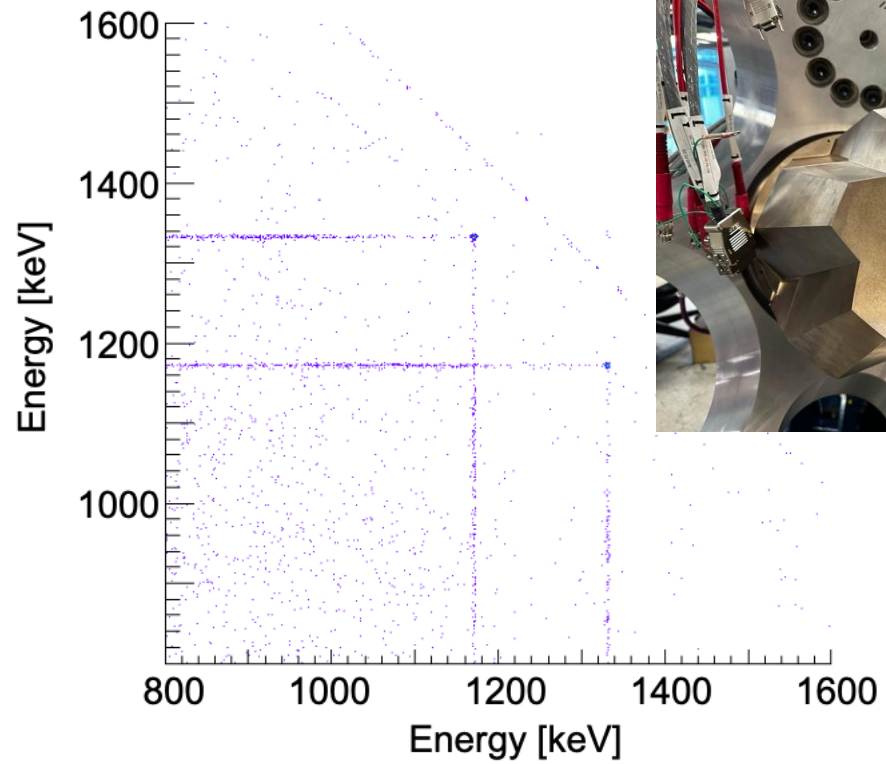
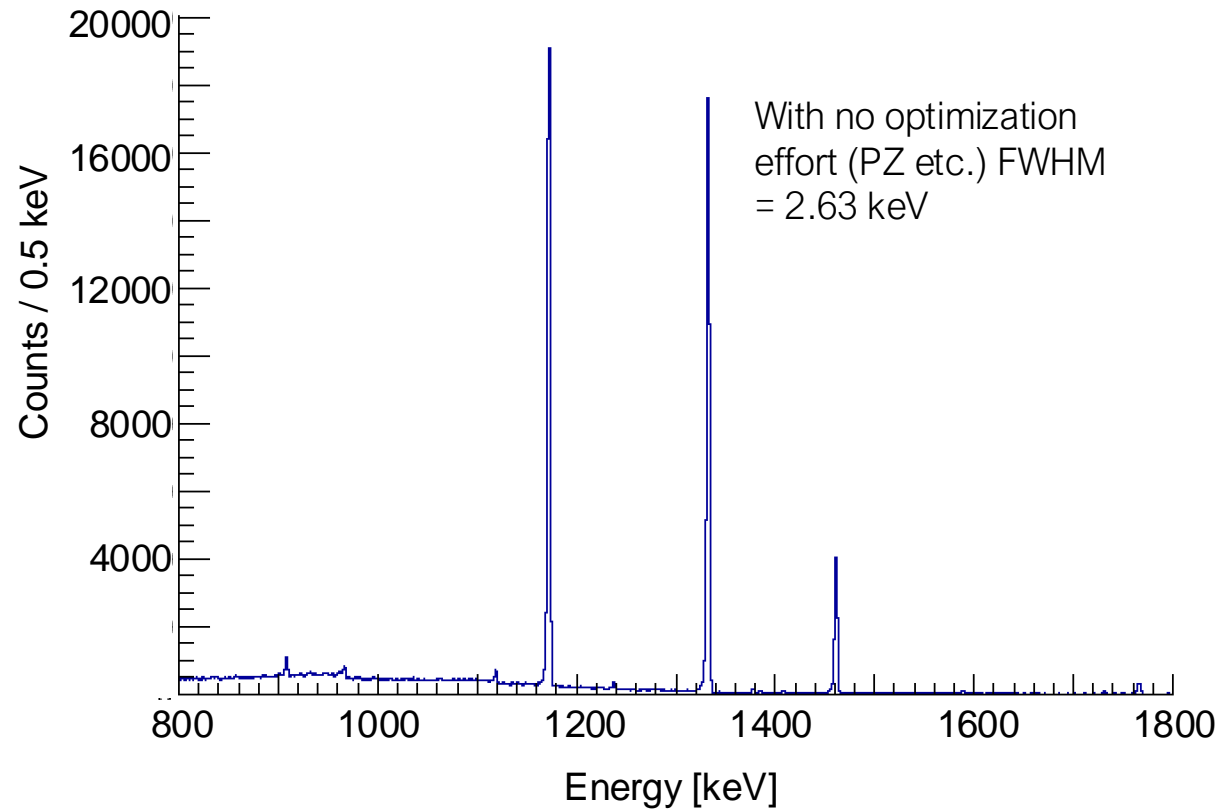


Tracked	
ϵ (%)	P/T
5.0	0.51
4.6	0.48
4.5	0.46

Final System Test – 2 Quads So Far...



Final System Test – 2 Quads So Far...



- Performance of 2 Quads (8 crystals) installed in the area is now being tested with the final systems and full implementation of trigger/timing systems, liquid cooling etc.
- Initial measurement (Monday!) shows resolution satisfying the required performance, and systems are performing well

Summary

- Final assembly and testing of GRETA is well underway, and advancing smoothly, testing to continue through the first half of 2025
- The performance measures (KPPs) for Detectors and Mechanical systems are complete, the remaining are planned to be demonstrated before the end of the calendar year
- Deliver of GRETA to FRIB is anticipated for July 2025

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Mark your calendars to join us in Berkeley for a 2-day GRETA Dedication and Physics Workshop - April 23-24, 2025.