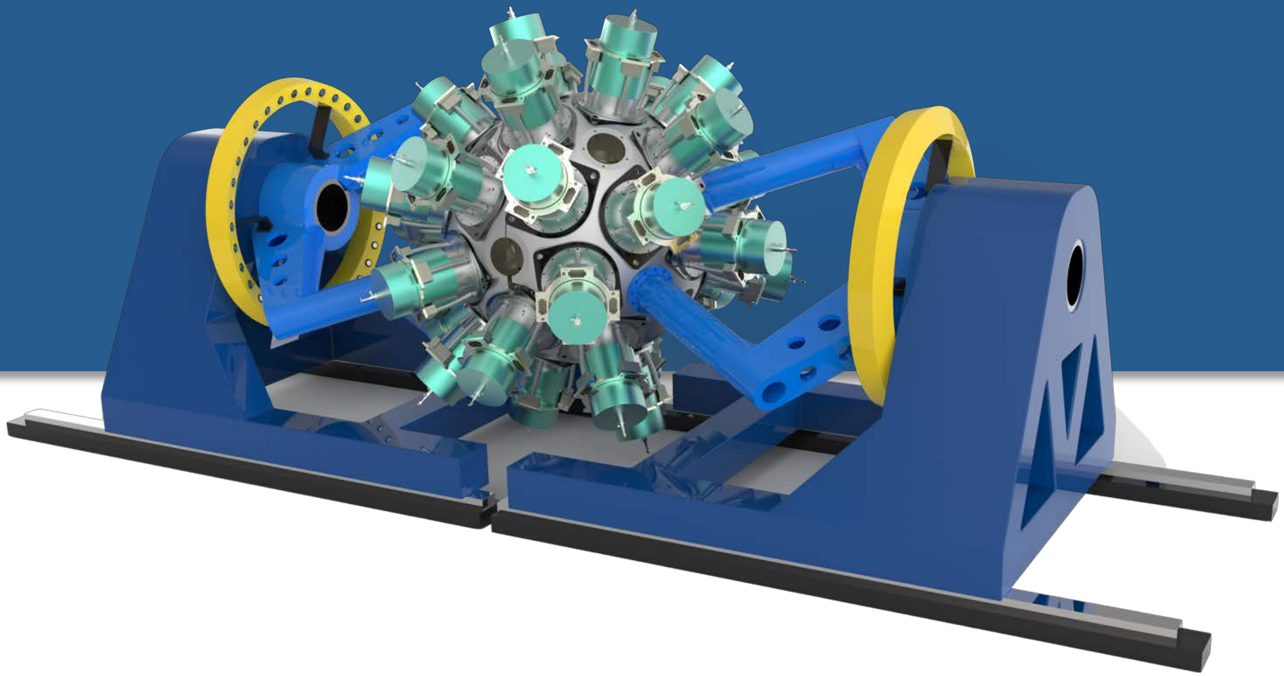
GRETA Status

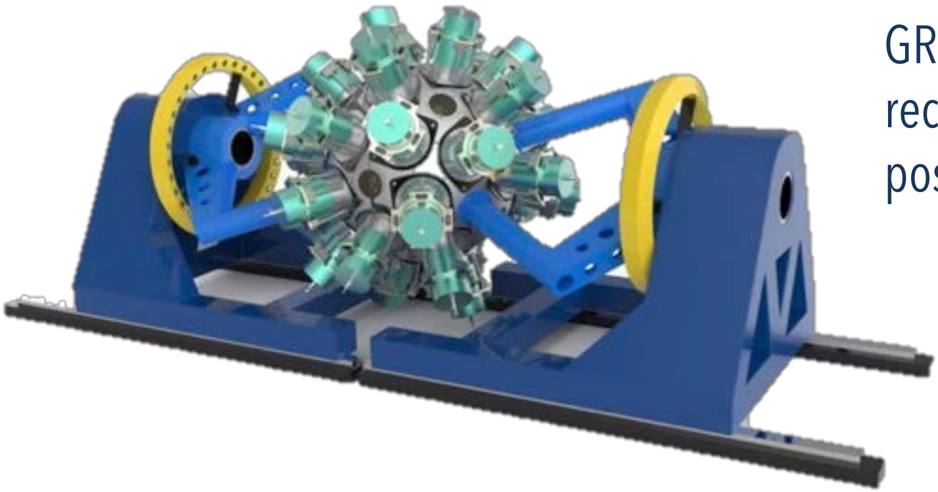


Paul Fallon
Project Director
Nuclear Science Division
Lawrence Berkeley National Laboratory

Outline

- Introduction and background to GRETA
- GRETINA Status
- GRETA Status
- Summary

The Gamma-Ray Energy Tracking Array: GRETA



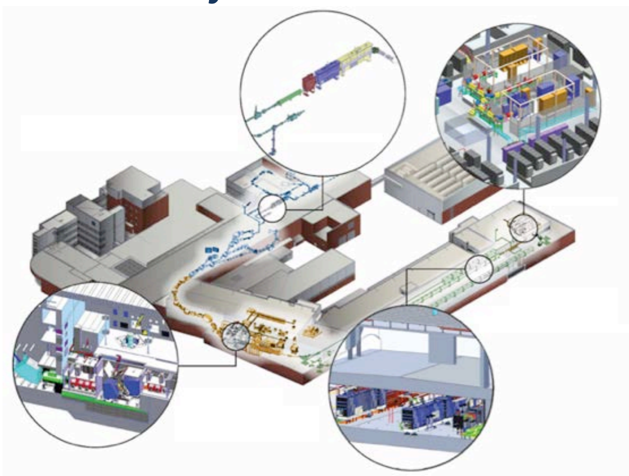
GRETA is a 4π tracking detector capable of reconstructing the energy and three-dimensional position of γ-ray interactions

Provides an unprecedented combination of
- *full solid angle coverage and high efficiency*
- *excellent energy and position resolution*
- *good background rejection (peak-to-total)*

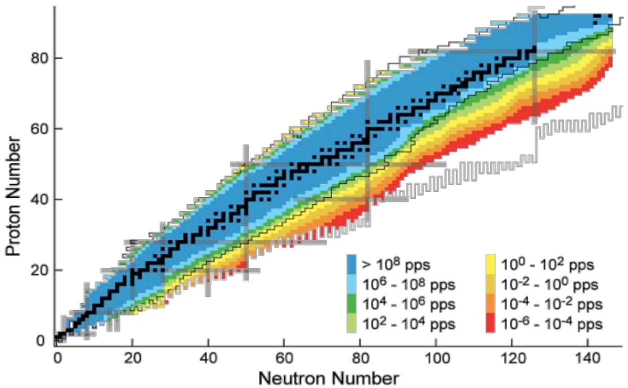
Funded by DOE Office of Science, Office of Nuclear Physics. LBNL lead lab in collaboration with ANL, NSCL, and ORNL

GRETA builds directly on the success of GRETINA, which has been operating for physics since 2012, with 4 campaigns completed

A key detector for FRIB



GRETA is a Key Detector for Science at FRIB



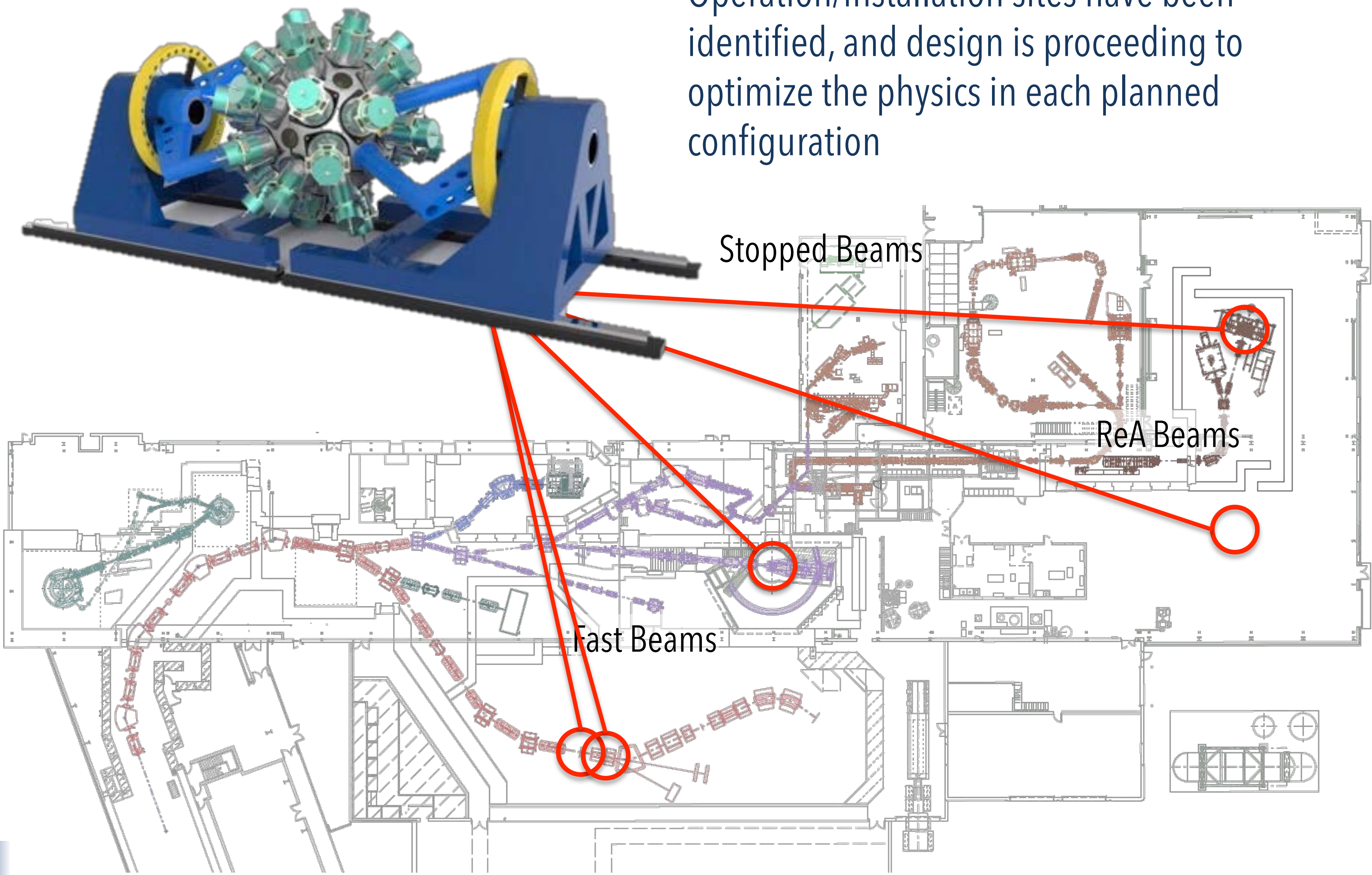
- FRIB beams will provide access to 1000s of nuclei
- GRETA will provide the sensitivity to maximize the physics opportunities at FRIB, with both fast-fragmentation and reaccelerated beams

Nuclear Structure	Nuclear Astrophysics	Tests of Fundamental Symmetries	Applications of Isotopes
Intellectual challenges from NRC Decadal Study 2013			
How does subatomic matter organize itself and what phenomena emerge?	How did visible matter come into being and how does it evolve?	Are fundamental interac-tions that are basic to the structure of matter fully understood?	How can the knowledge and technological progress provided by nuclear physics best be used to benefit society?
1. Shell structure ✓ 2. Superheavies ✓ 3. Skins ✓ 4. Pairing 5. Symmetries ✓ 6. Equation of state 13. Limits of stability ✓ 14. Weakly bound nuclei ✓ 15. Mass surface ✓	1. Shell structure ✓ 6. Equation of state 7. r-Process ✓ 8. ^{15}O(α,γ) 9. ^{59}Fe s-process 13. Limits of stability ✓ 15. Mass surface 16. rp-Process 17. Weak interactions ✓	12. Atomic electric dipole moment ✓ 15. Mass surface 17. Weak interactions	10. Medical 11. Stewardship ✓

17 Benchmark programs introduced by the NSAC Rare-Isotope beam task force (2007)

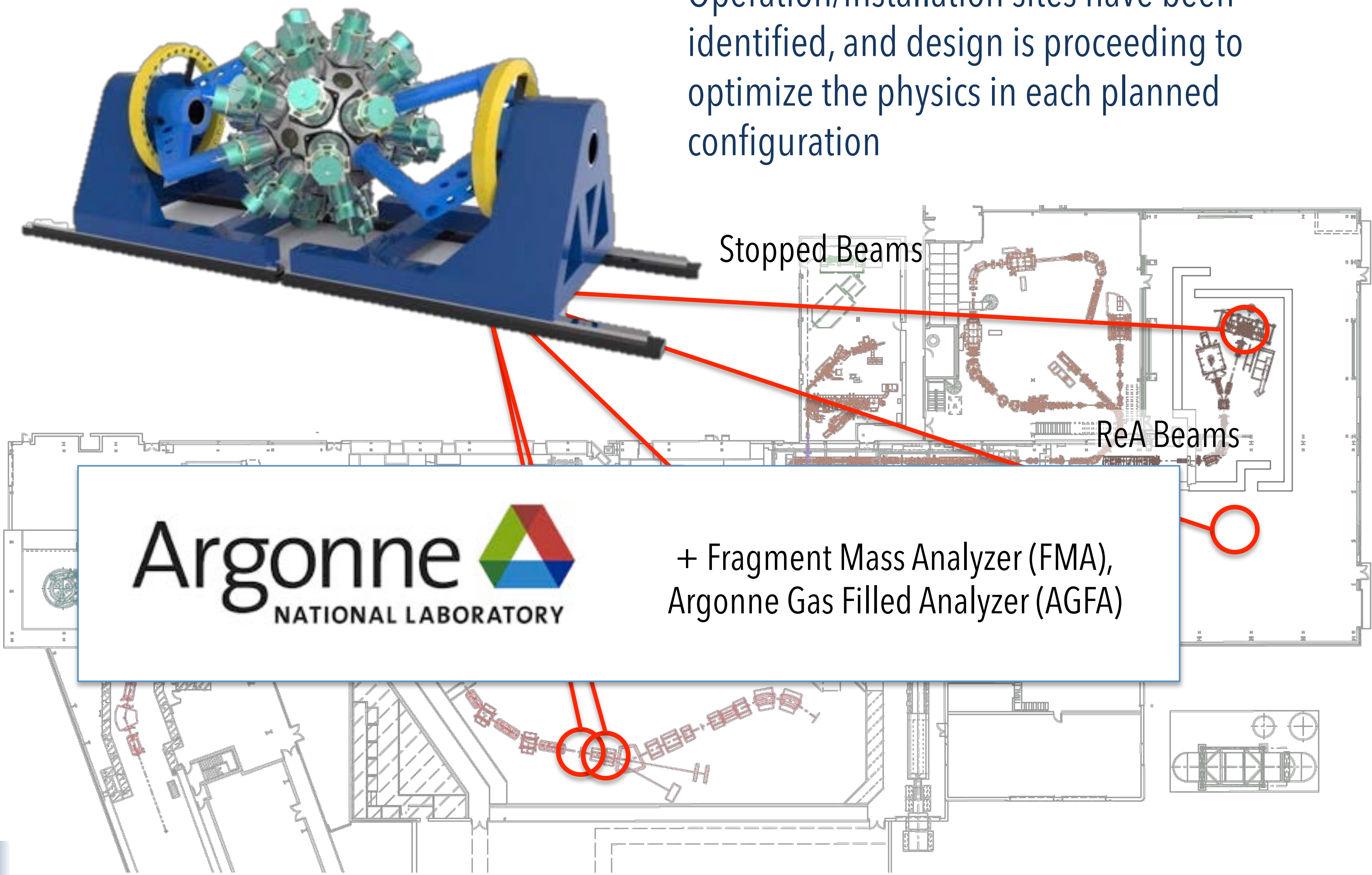
Science Requires Fast, Stopped, and Reaccelerated Beams

Operation/installation sites have been identified, and design is proceeding to optimize the physics in each planned configuration



Science Requires Fast, Stopped, and Reaccelerated Beams

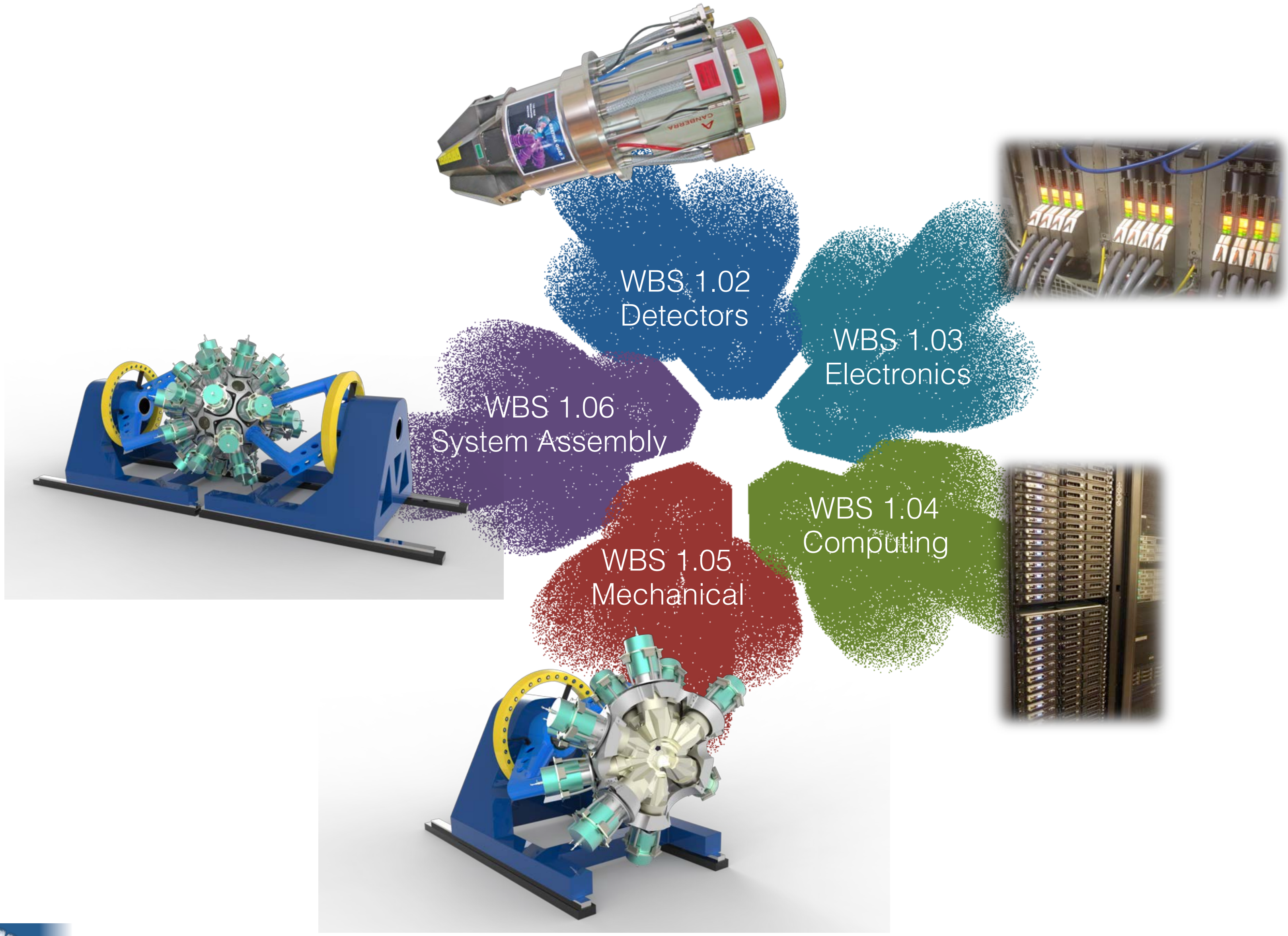
Operation/installation sites have been identified, and design is proceeding to optimize the physics in each planned configuration



Argonne NATIONAL LABORATORY

+ Fragment Mass Analyzer (FMA), Argonne Gas Filled Analyzer (AGFA)

GRETA Project Overview



The Gamma-Ray Energy Tracking Array: GRETA

GRETA Project includes:

- 18 Quad modules, to be combined with 12 GRETINA modules for a total of 30
- Mechanical structure for 30 modules, covering 80% of solid angle
  - Removable forward and rear detector rings
  - Rotation and translation capabilities
- Electronics to instrument all 30 Quad modules
  - Detector-mounted digitizer modules with continuous streaming of waveforms to FPGA-based signal filter boards
  - New trigger, timing and controls systems

- Computing cluster to support full array
  - Real-time signal decomposition up to total through-put of 480k decompositions/s
  - High-speed local network
  - 1 PB local RAID storage

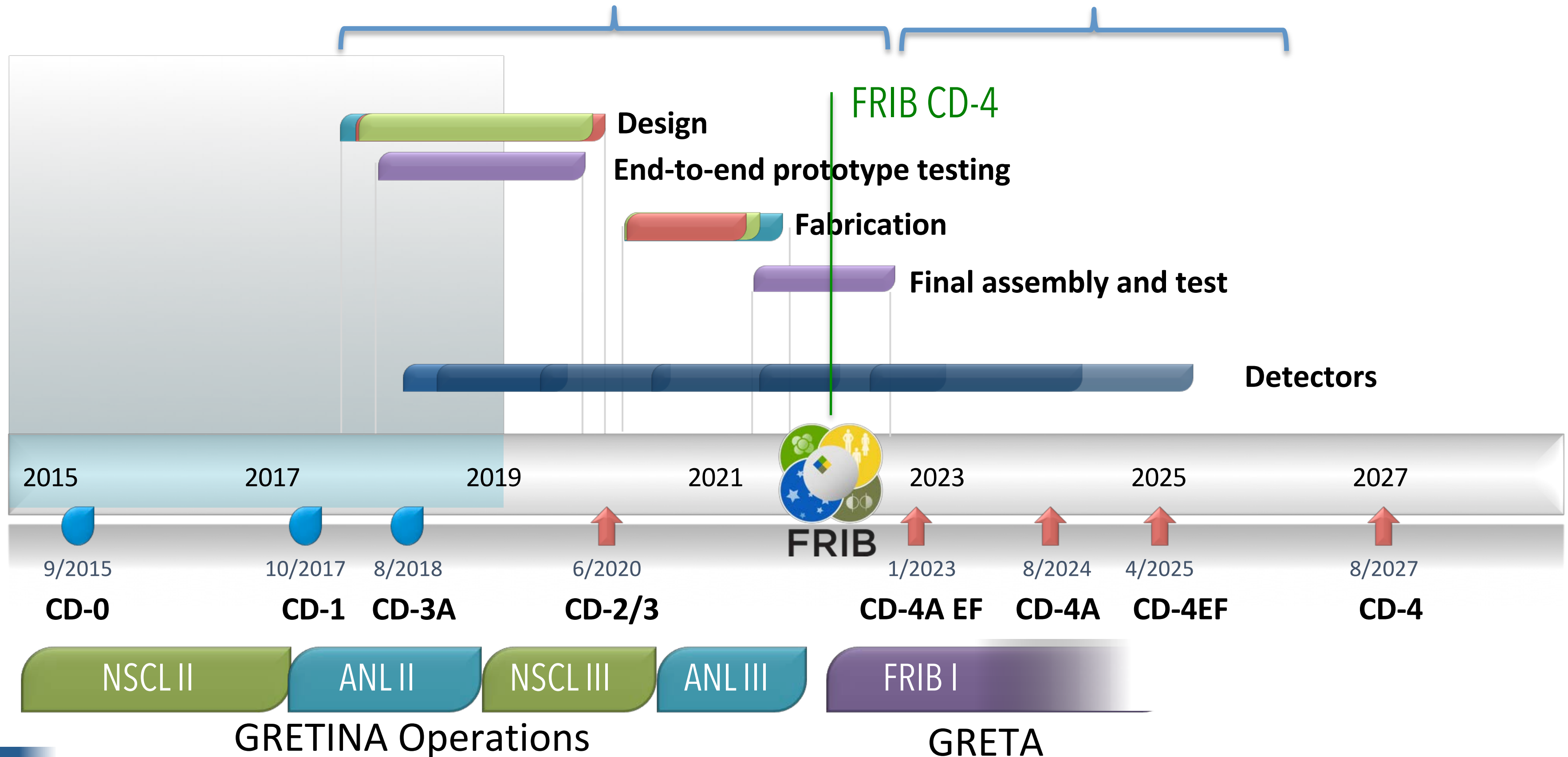
Project Strategy Tailored to Deliver GRETA to FRIB for Early Science Operation (managing to early completion)

CD-4A Scope

- Electronics, Computing and Mechanical systems for 30 Quad Detector Modules
- Subset of Detector Modules (6)
- Delivered to FRIB for Science Operation

CD-4 Scope

- Accept the remaining Quad Detector Modules (For a total of 18)



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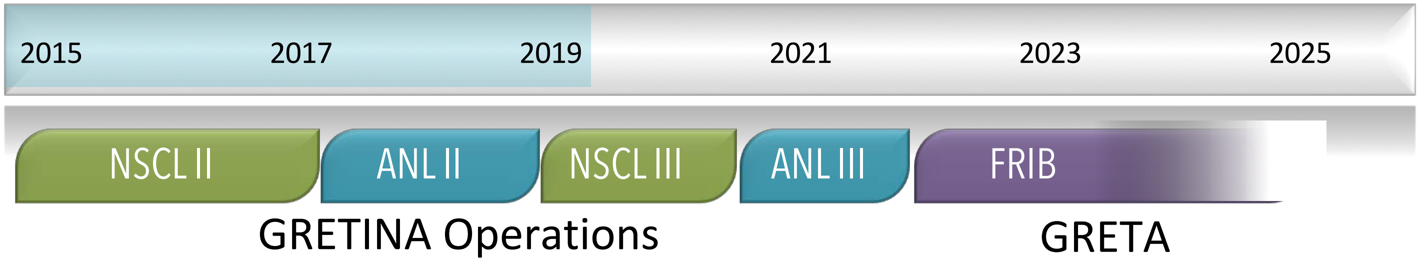
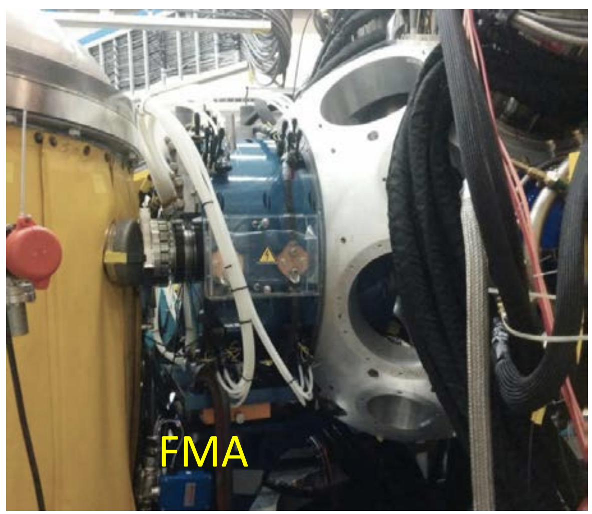
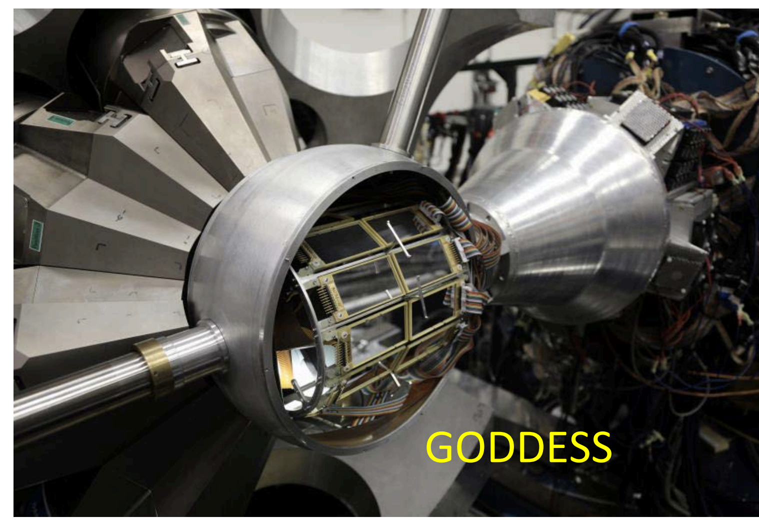
GRETINA Science Campaigns (ANL)



ANL II - Second GRETINA campaign at ATLAS July 2017-April 2019
GRETINA coupled to …





Slides from Darek Seweryniak (ANL)

Second GRETINA Campaign at ATLAS

GRETINA+CHICO – Coulex, deep inelastic (stable, CARIBU beams)

- R. V. F. Janssens *et. al.*, Shape coexistence in the neutron-rich germanium isotopes ^{72}Ge and ^{76}Ge
- S. Zhu *et. al.*, Angular Distribution Measurements of Target-Like Products of N=126 Neutron-Rich Isotopes
- R. V. F. Janssens *et. al.*, Shape Coexistence in ^{64}Ni?
- J. Li *et. al.*, Properties of high-lying 0^+ states in ^{70}Zn
- S. Zhu *et. al.*, Octupole Strength of Condensing Octupole Phonons in ^{240}Pu
- J.M. Allmond *et. al.*, Shape Evolution and Coexistence in the Mo-Ru Region: A Request for Additional Beam Time with the New EBIS
- A. O. Macchiavalli *et. al.*, Octupole Correlations in neutron-rich Ba nuclei: Coulomb Excitation of odd-A ^{143}Ba and ^{145}La

GRETINA+FMA – nuclei far from the line of stability (intense stable beams)

- D. Seweryniak *et. al.*, Integration of the digital FMA DAQ with the GRETINA DAQ
- D. Seweryniak *et. al.*, Core excitations and single-neutron states in ^{101}Sn
- D. Seweryniak *et. al.*, Mirror-energy differences in the A=93, T=1/2 mirror pair ^{93}Ag-^{93}Pd
- C. R. Hoffman *et. al.*, First Study of ^{38}S at High Excitation via Fusion Evaporation
- G. Lotay *et. al.*, The importance of the ^{33}Cl(p,γ)^{34}Ar reaction in explosive binary systems : Spectroscopy of ^{34}Ar with GRETINA

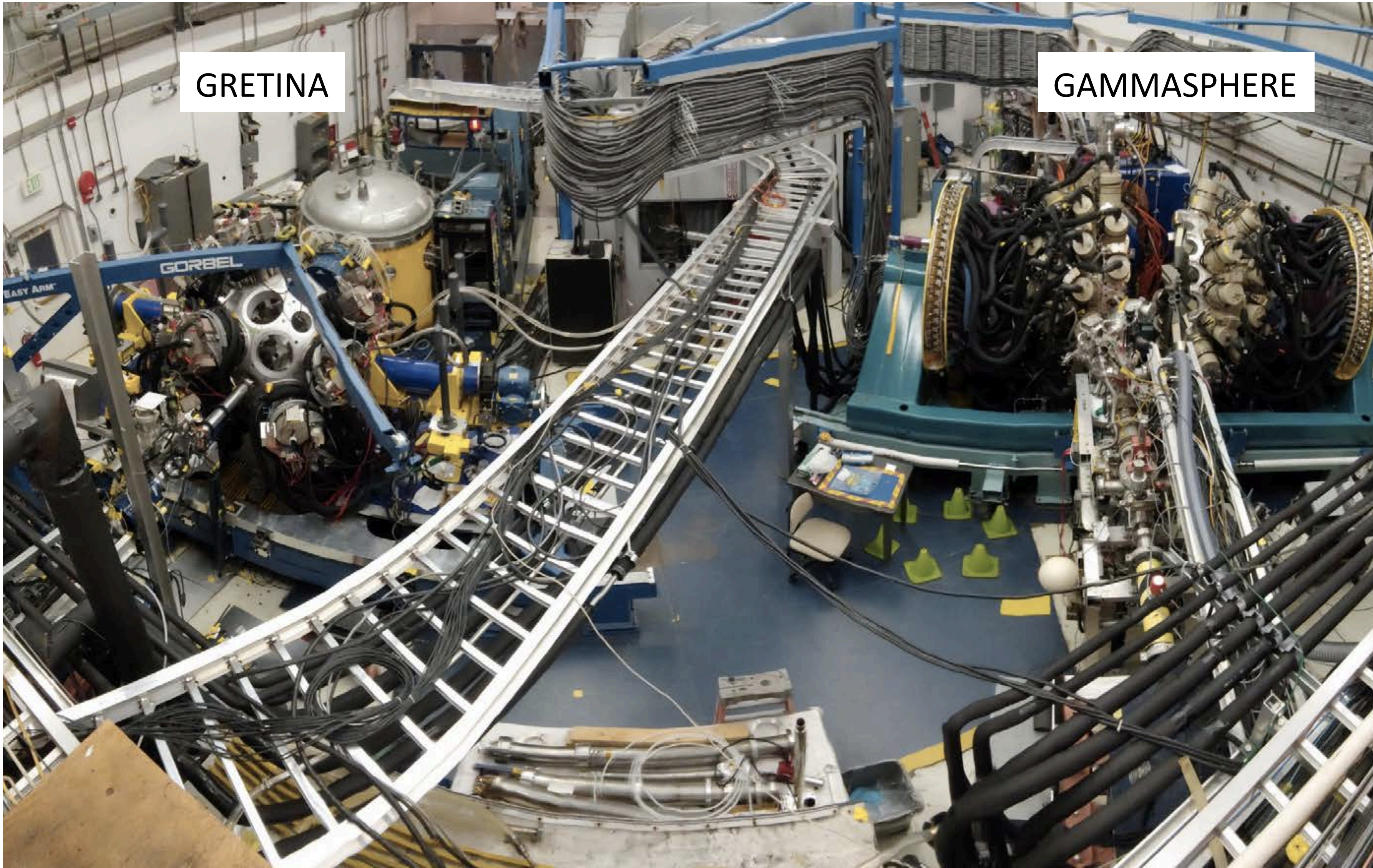
GRETINA+GODDESS – transfer reactions (stable, CARIBU, RAISOR beams)

- S. Pain *et. al.*, Measurements of (d,pγ) on neutron-rich Xe and Te with CARIBU beams (CARIBU)
- S. Pain *et. al.*, Constraining the ^{30}P(p,γ)^{31}S reaction using ^{30}P(d,pγ)^{31}P with GODDESS (In-flight-RAISOR)
- M. D. Jones *et. al.*, Determining the E1/M1 polarization of the Low-energy Enhancement in the gamma-ray Strength Function of ^{56}Fe

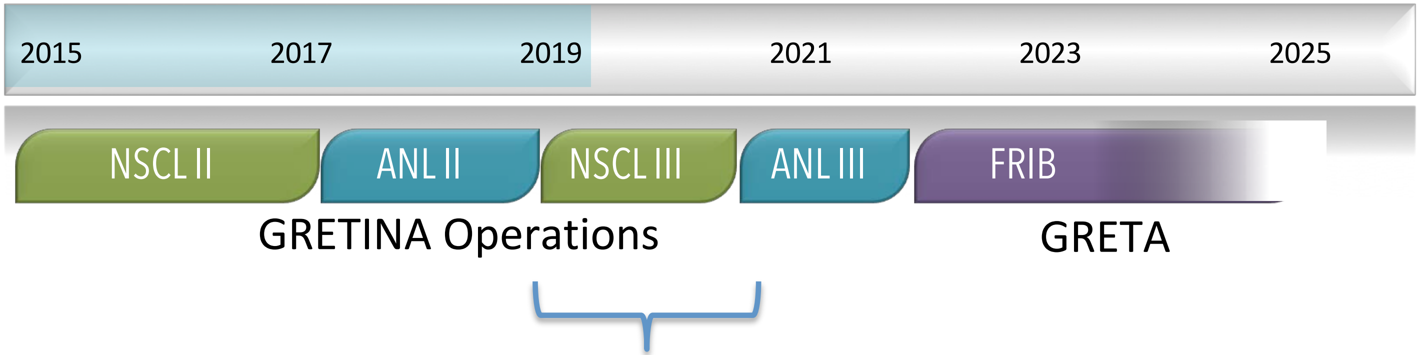
16 PAC-approved experiments were performed with > **100** scientists from **15** institutes.

GRETINA and CHICO in Front of the FMA

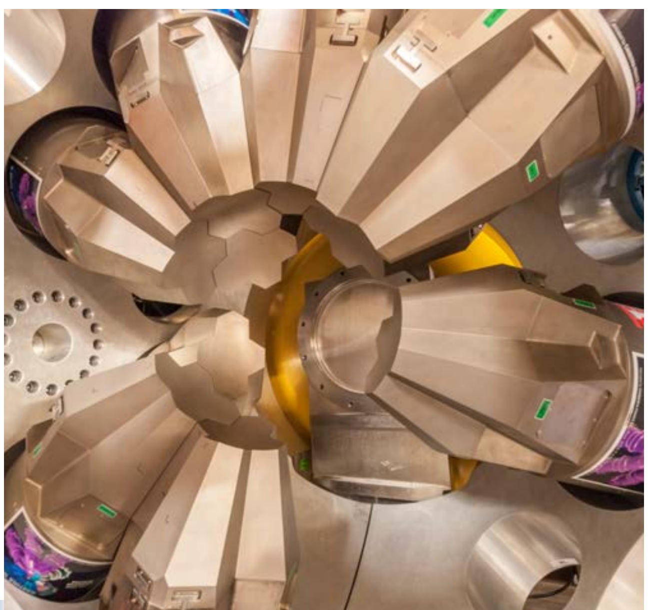
ATLAS Experimental AREA IV



GRETINA Science Campaigns (NSCL)



NSCL III - Third GRETINA campaign at NSCL (Summer 2019 for ~18 months)
GRETINA coupled to S800



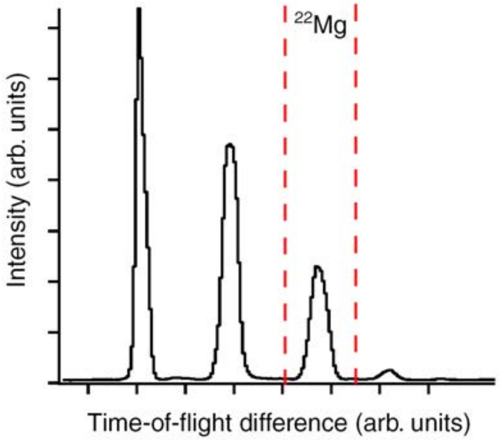
"Standard Configuration"
ε (1.3MeV) ≈ 6.8% (singles)
9.7% (calorimeter)

11 quad modules installed ,12th module expected in October. All channels (but one shorted segment) operational

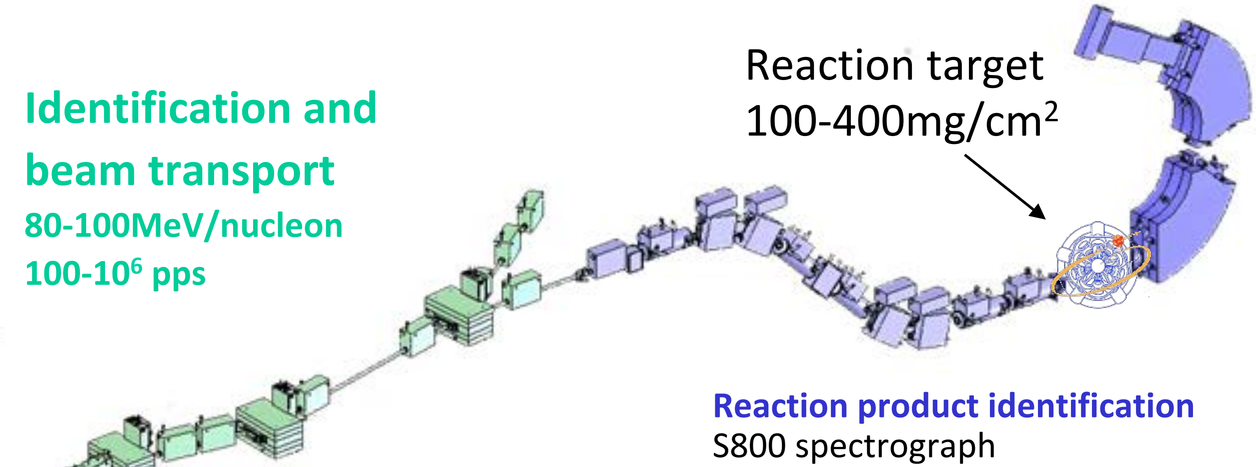
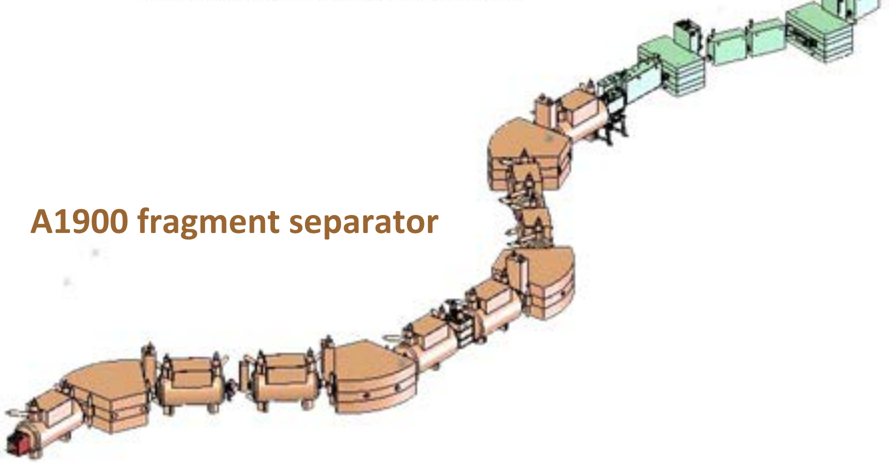
12 modules, that's it, GRETINA won't grow any further

Slides from Dirk Weisshaar (NSCL)

Fast-beam Campaign at NSCL



…involving the S800 spectrograph

Identification and beam transport

80-100MeV/nucleon

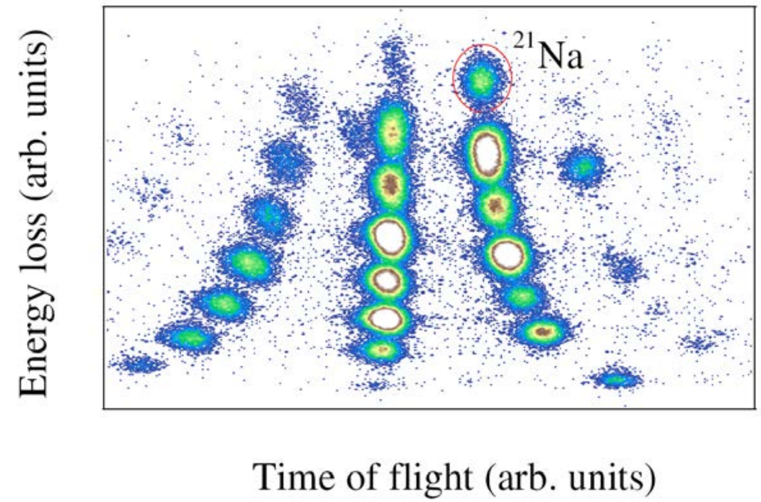
100-10^{6} pps

Reaction target
100-400mg/cm^{2}

A1900 fragment separator

Production target
Beam energy from cyclotrons 100-150MeV/nucleon

Reaction product identification
S800 spectrograph



D. J. Morrissey, NIM B **204**, 90 (2003)
D. Bazin, NIM B **204**, 629 (2003)

Length ~80m (260 ft)
(linear distance)

Approved Experiments at NSCL 2019/20

Already done:

19014 Weisshaar, D. Commissioning of GRETINA-S800
19005 Iwasaki, H. Electromagnetic responses of weakly-bound deformed nuclei
19002 Gade, A. Spectroscopy at N=28: Putting the Pandemonium to work
15130 Chowdhury, P. Search for isotopes and isomers in the neutron-rich Hf region

To be done:

19034 Recchia, F. Shape coexistence along N=Z
19028 Spieker, M. Octupole collectivity in 74,76Kr studied with inelastic proton scattering in inverse kinematics
19027 Carpenter, M. Rotational States in the N=40 Island of Inversion
19024 Weisshaar, D. Measurement of quadrupole transition strength in n-deficient Ca isotopes
19023 Crawford, H. Quadrupole Collectivity in the Odd-Z Mn Isotopes Near N=40
19019 Crawford, H. Spectroscopic Factors in the N=40 Island Of Inversion
19015 Revel, A. Isospin symmetry breaking at the proton dripline
19001 Gade, A. Understanding the N=40 Island of Inversion
17001 Gade, A. Cross sections in the fp shell - When size matters

13 experiments in total

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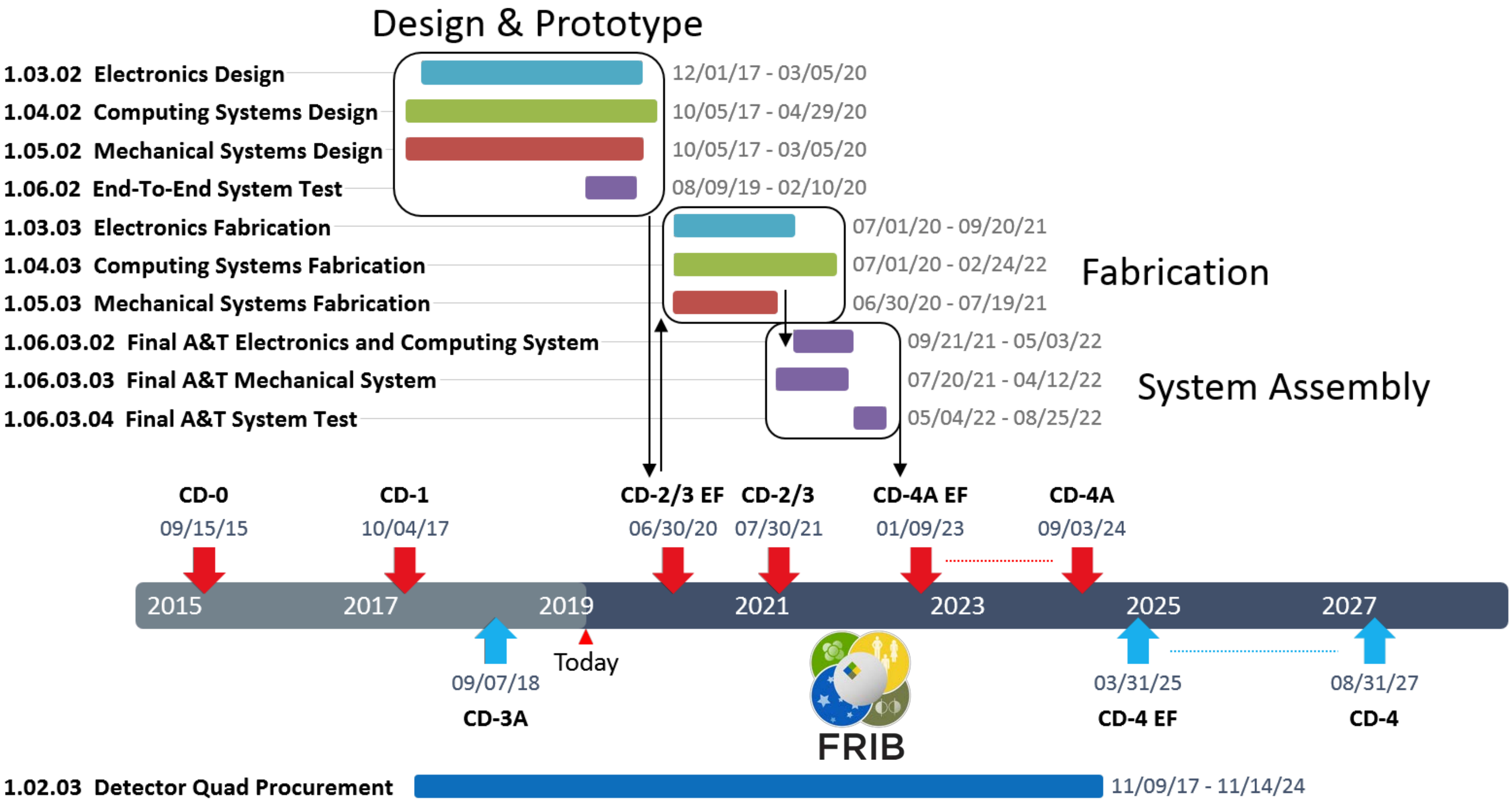
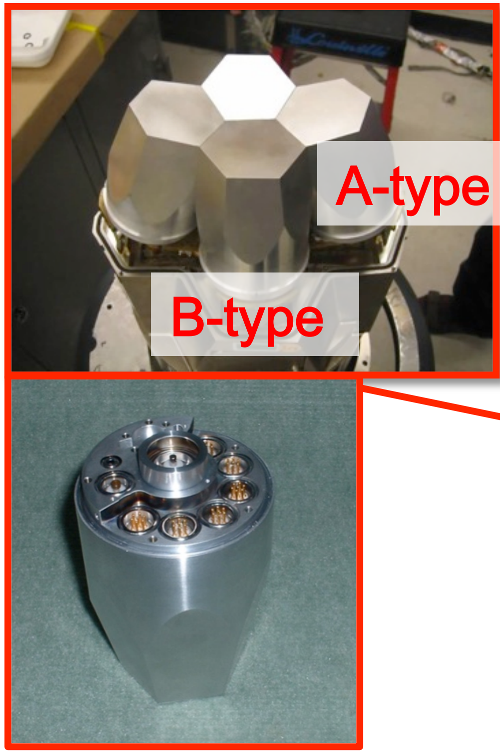
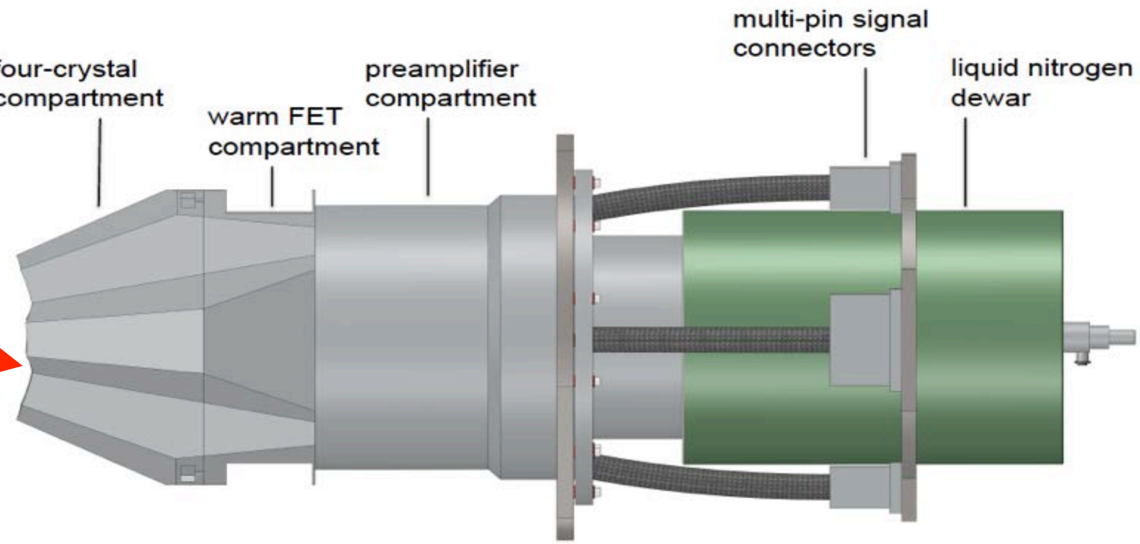
GRETA Project Status

- Technical Systems in Final Design and Prototype testing phase
- Detector Procurements on an advanced schedule



Detectors





GRETINA/GRETA Quad Detector Module

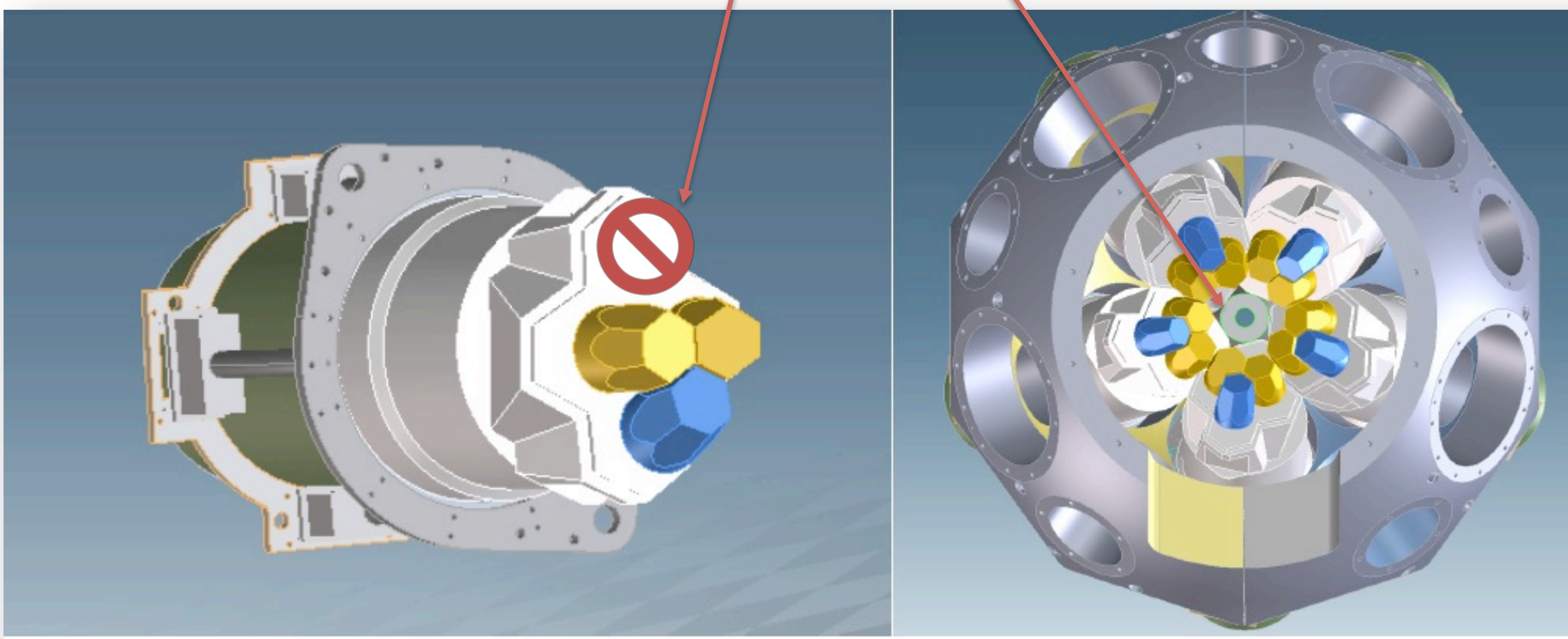
- GRETA uses 30 Quad Modules
  - Q1 - Q12 (GRETINA)
  - Q14 - Q31 (GRETA)
  - Q13 (purchased under GRETINA as a spare)

Augusto Macchiavelli (LBNL) Dirk Weisshaar (NSCL)

The Triplet End-Cap

Removal of the 5 capsules surrounding the in/out pentagon holes optimizes trade-off between array-efficiency and beam-pipe size requirements for certain experiments (coupling to auxiliary devices and/or specialized beam optics).

Remove single crystal and replace end-cap to convert standard Quad module to Triplet module.



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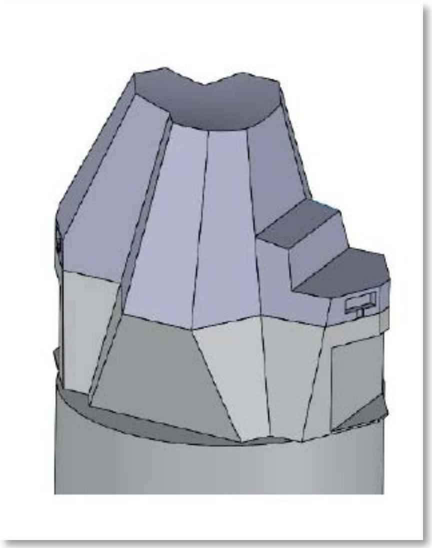
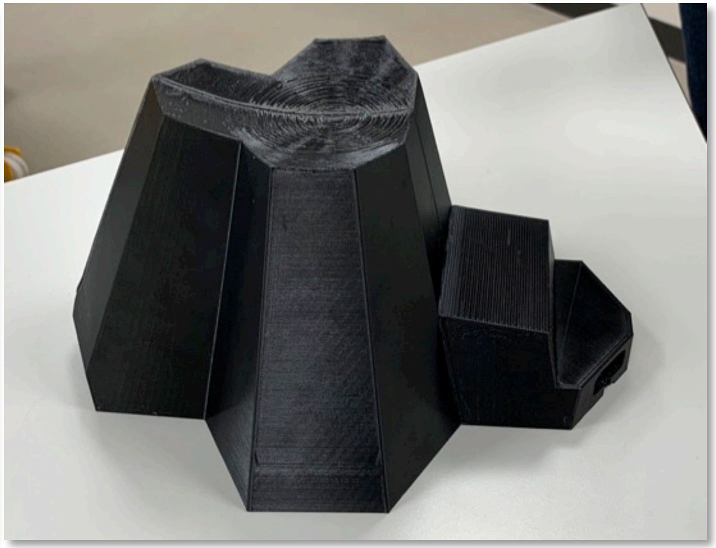
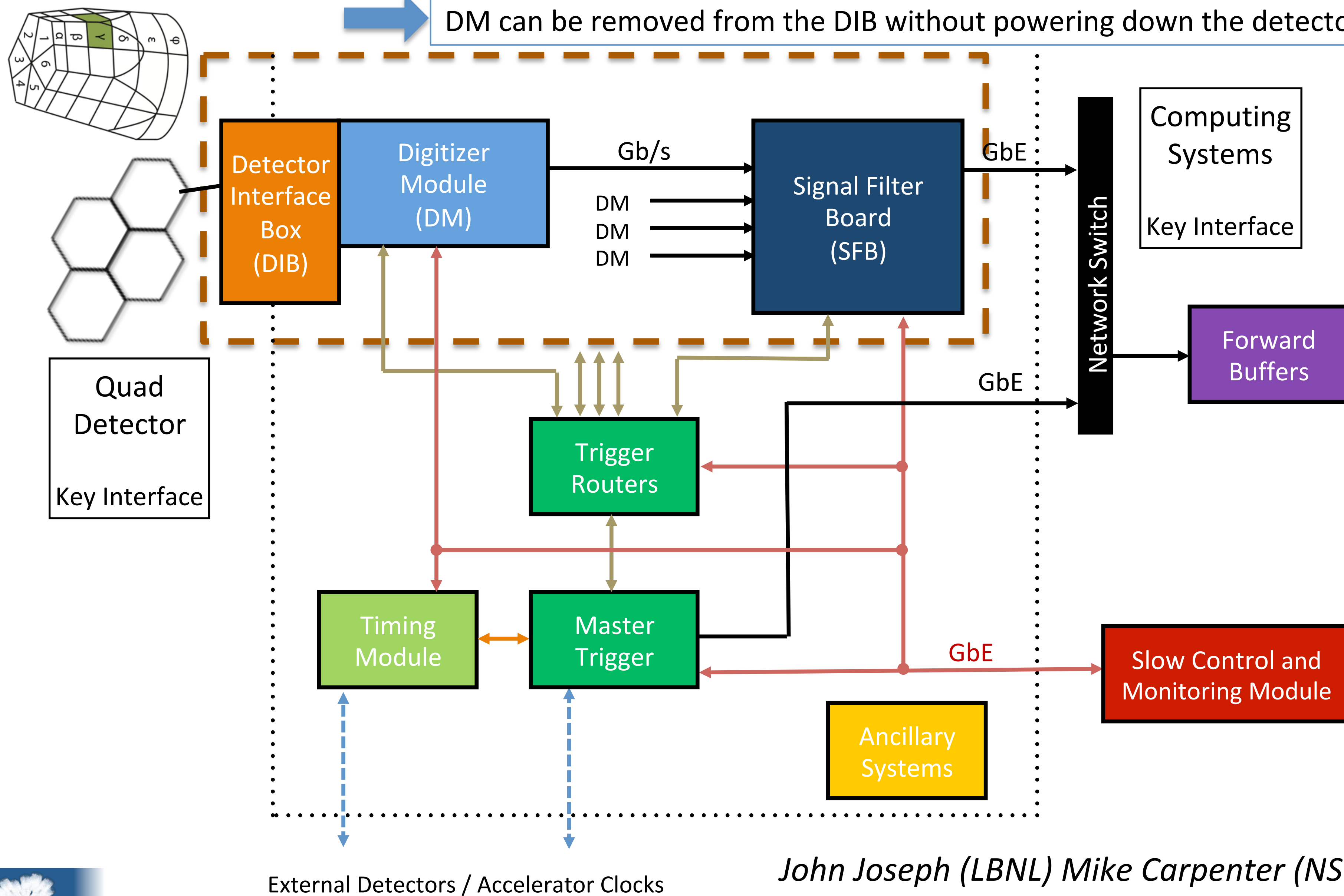




~12 cm diameter pipe can be accommodated vs. standard 5 cm diameter

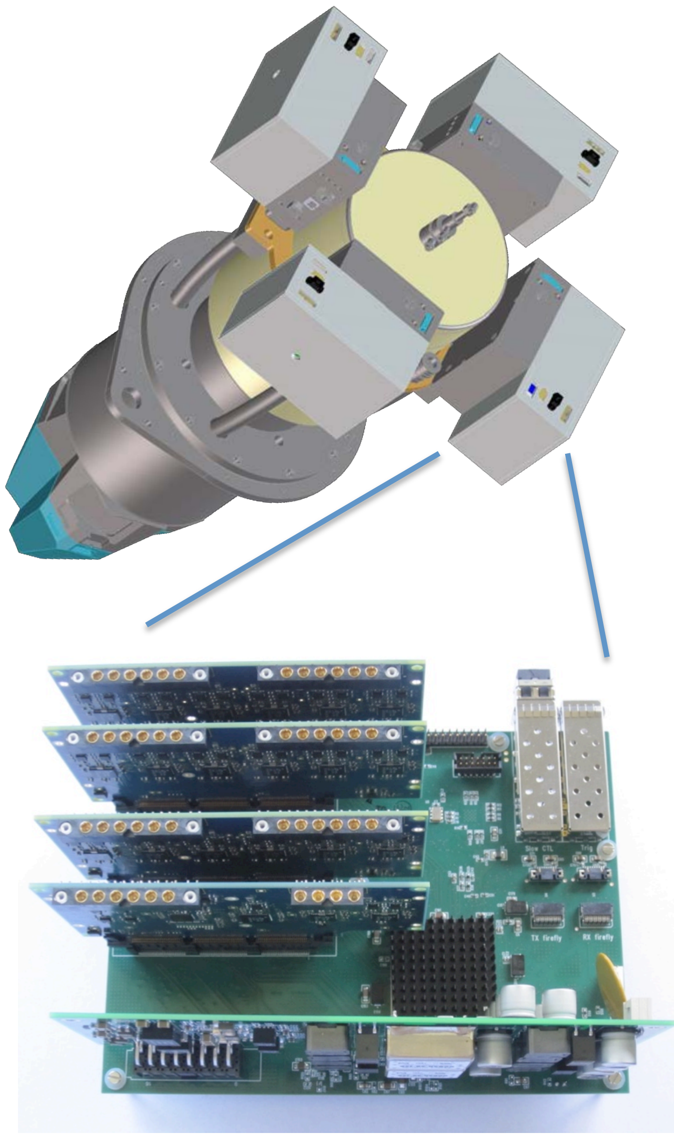
Electronics Systems - Architecture

DM can be removed from the DIB without powering down the detector



John Joseph (LBNL) Mike Carpenter (NSCL)

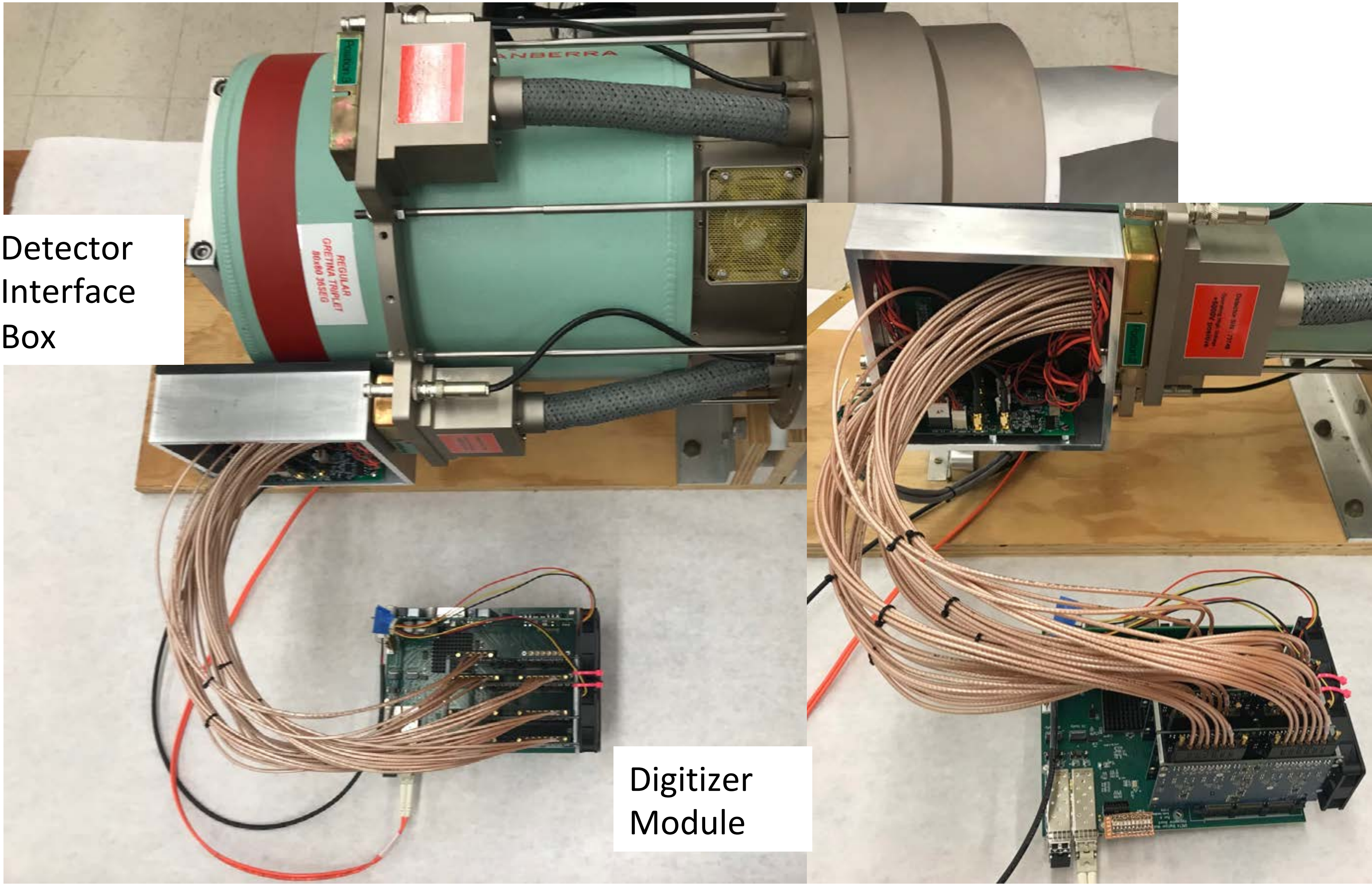
Detector Interface Box and Digitizer Module



- Pre-amplifier signal is digitized locally and outputs as a digital stream across fiber-optic
- Prototype boards successfully tested and shown to meet performance specifications
- Fully assembled Digitizer Module has been fabricated is being tested with a GRETA (GRETINA) Quad Module Detector

Thorsten Stezelberger (LBNL)

Prototype Detector Interface Box and Digitizer Module



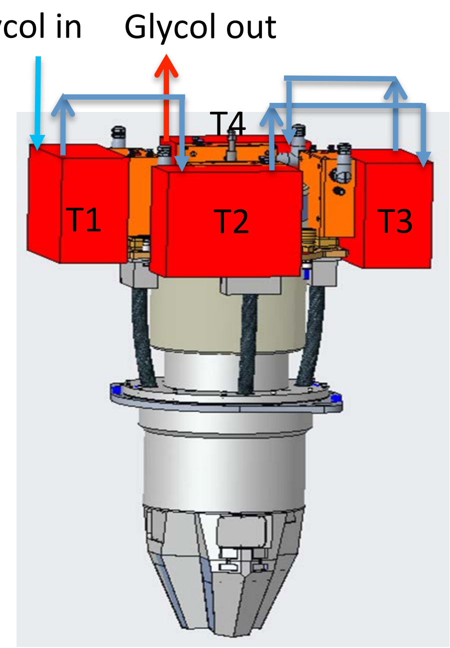
Cooling System for Pre-amps and ADC (Digitizer)

Closed Loop Cooling

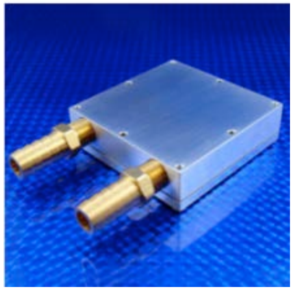
- Operating temperature of Pre-amplifiers and Digitizer Modules: between 4ºC to 35ºC
- Temperature stability of Pre-amplifier and Digitizer Module: <= +/-2.0ºC
  - ➢ (4 Digitizer Modules x 50W) x 30 Quad modules = 6 kW total or 3 kW per hemisphere
  - ➢ 75W Pre-Amp x 30 Quad modules = 2.25 kW total or 1.125 kW per hemisphere

Qe=75W
4ºC<Te<35ºC
ΔTe≤+/-2ºC

Pre-amplifiers cooling



Digitizer Module Cooling Block



Qe=50W x 4=200W
4ºC<T1<T2<T3<T4<35ºC
ΔTe≤+/-2ºC

Digitizer Module cooling in series

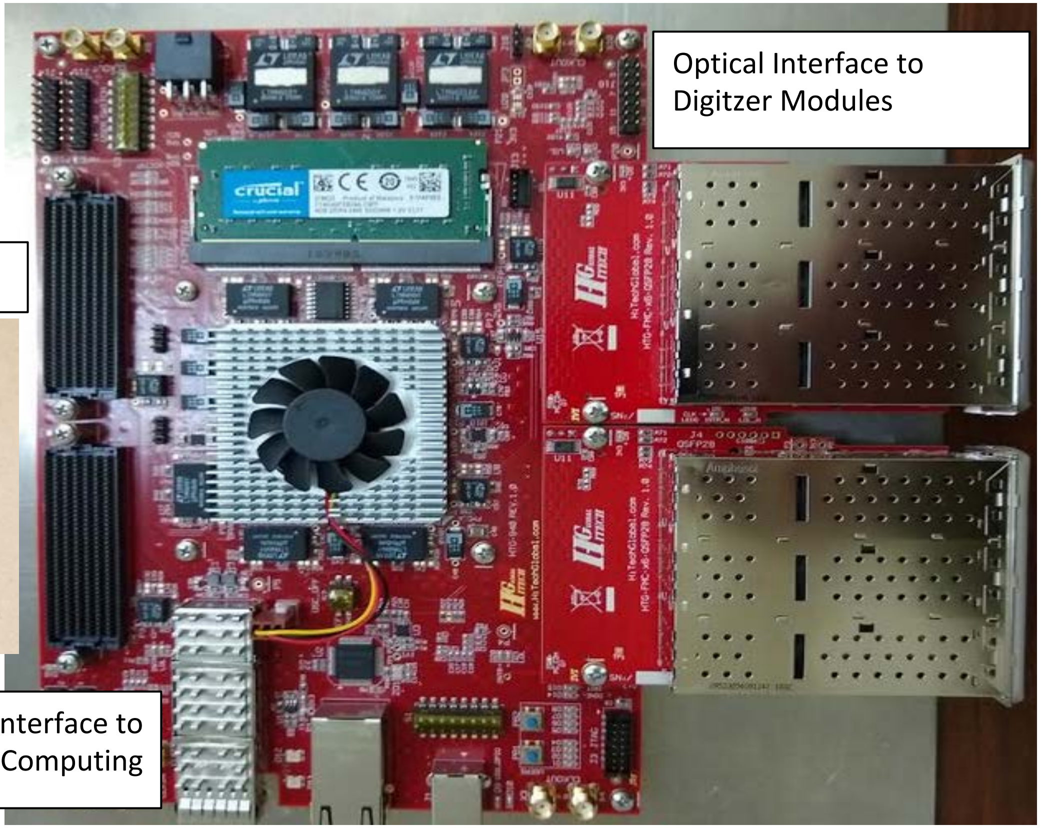
Interface Box and Digitizer Module in the Array

Signal Filter Board

Commercial board with large FPGA; substantial data reduction from Digitizer (75 Gbits/s) to Computer Systems (256 Mbits/s average)

Exploring FPGA resources to see if we need 1 SFB or 2 SFBs per Quad

Optical Interface to TTC



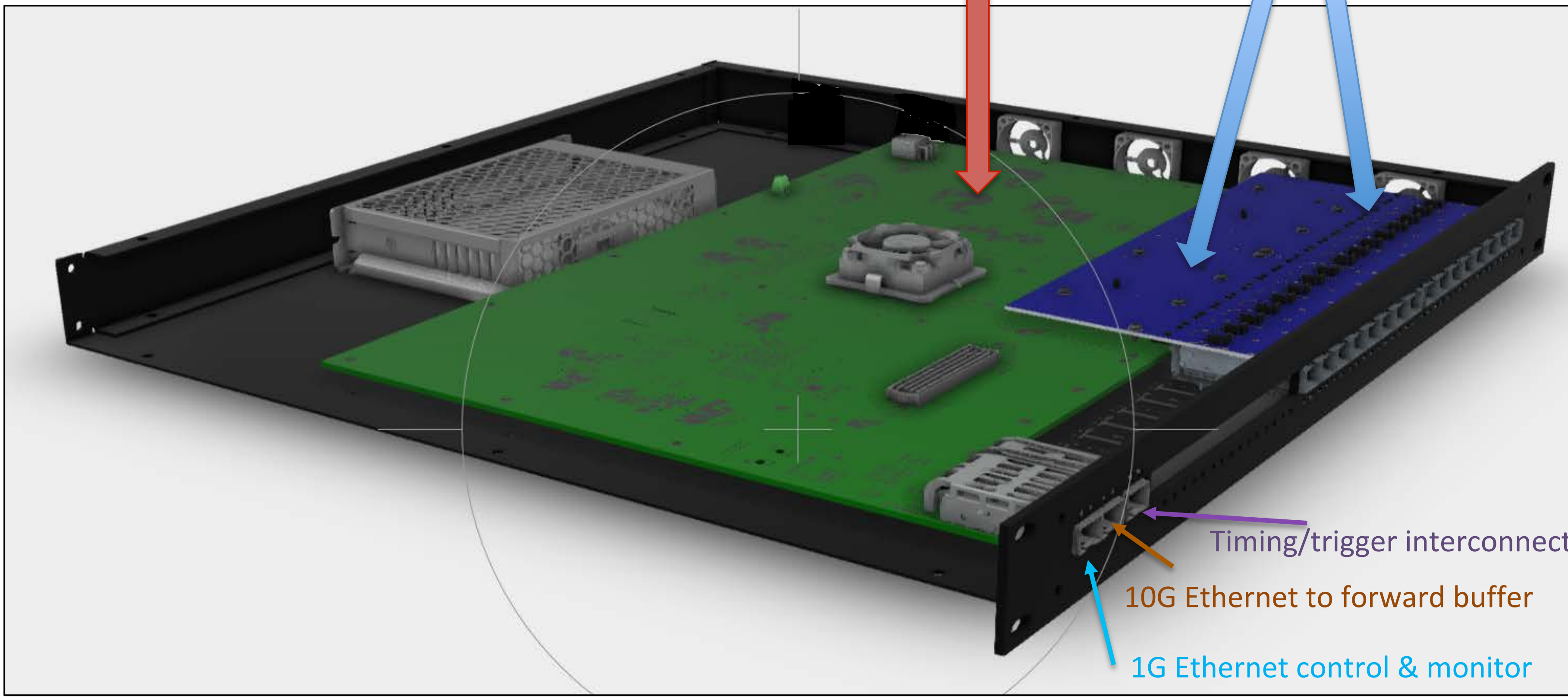
Optical Interface to Digitzer Modules

Optical Interface to Computing

Vamsi Vytla (LBNL)

Trigger Timing - Common Motherboard Design

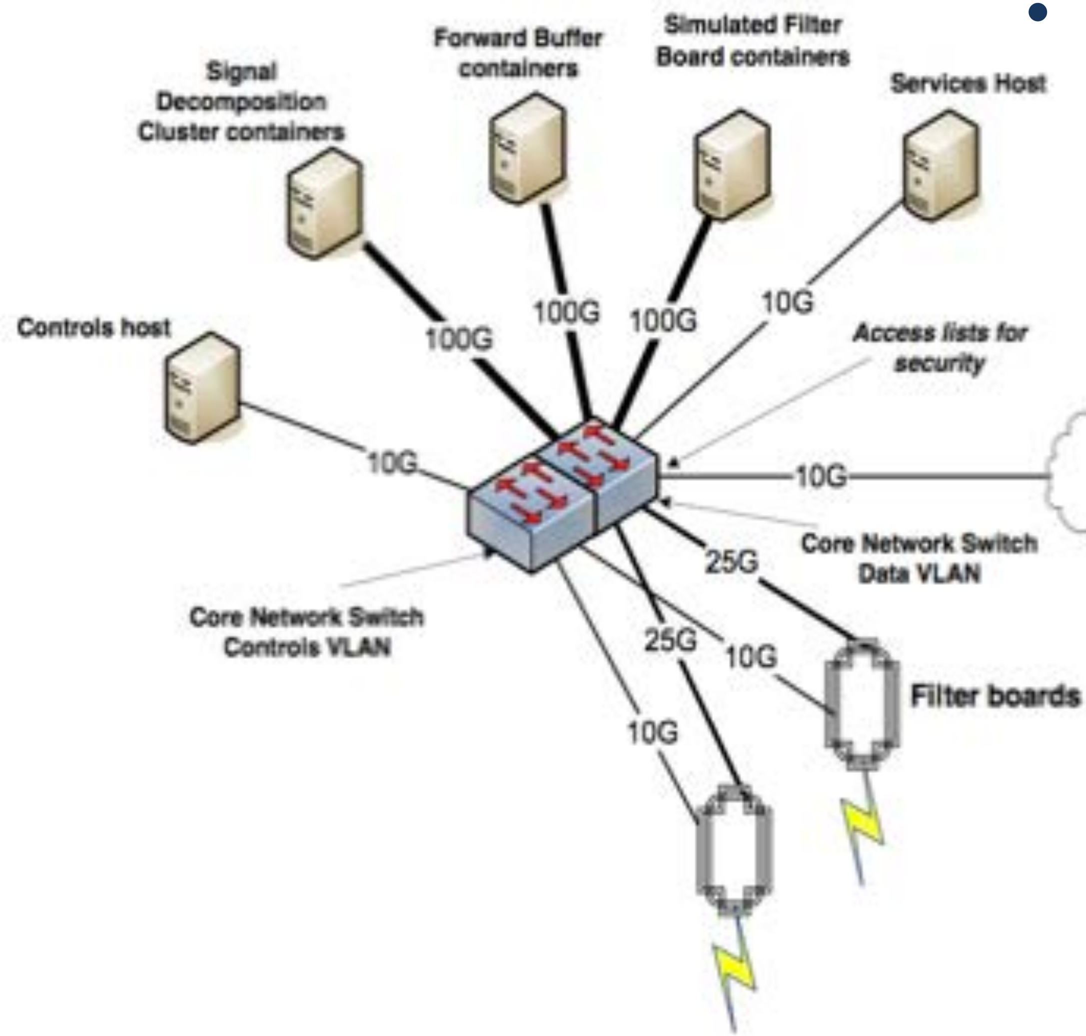
The trigger and timing systems use a ***common*** motherboard design with modular I/O capability provided by three swappable daughter cards.



Three variants required by **GRETA** – Timing, Master Trigger and Router Trigger modules: Variations achieved by specific configurations of daughter boards, FPGA Firmware and mounted chassis front panels.

John Anderson, Mike Oberling (ANL)

Computing Architecture



- Network based architecture
  - employs industry standards and available solutions

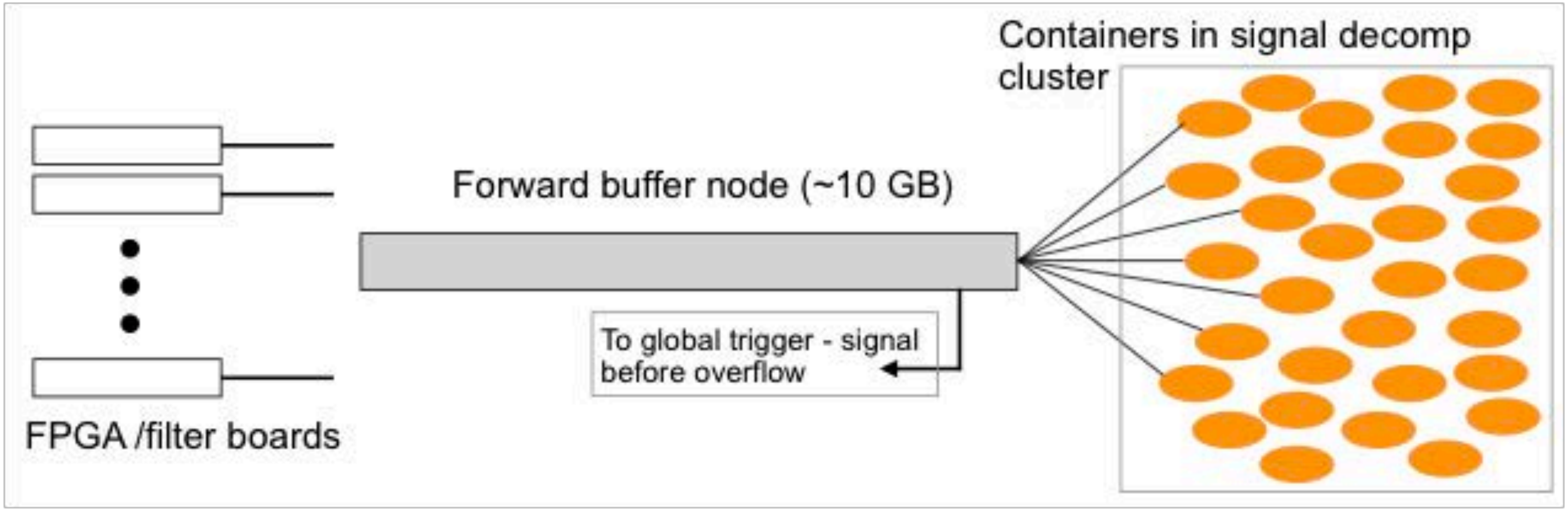
Major Elements

- Event Processing
- Event Building
- Controls
- Storage and Archive

Mario Cromaz, Eli Dart (LBNL)

Event Building – Forward Buffer

- Forward buffer is central to GRETA's computing architecture
- Aggregates data from electronics, serves data to decomposition cluster:
  - Allows electronics to have a simple 'push' interface using UDP
  - Signal decomposition containers can implement a 'pull' interface and self-schedule
  - Fill state of forward buffer queues allows implementation of global flow control



Eric Pouyoul (LBNL)

Event Processing

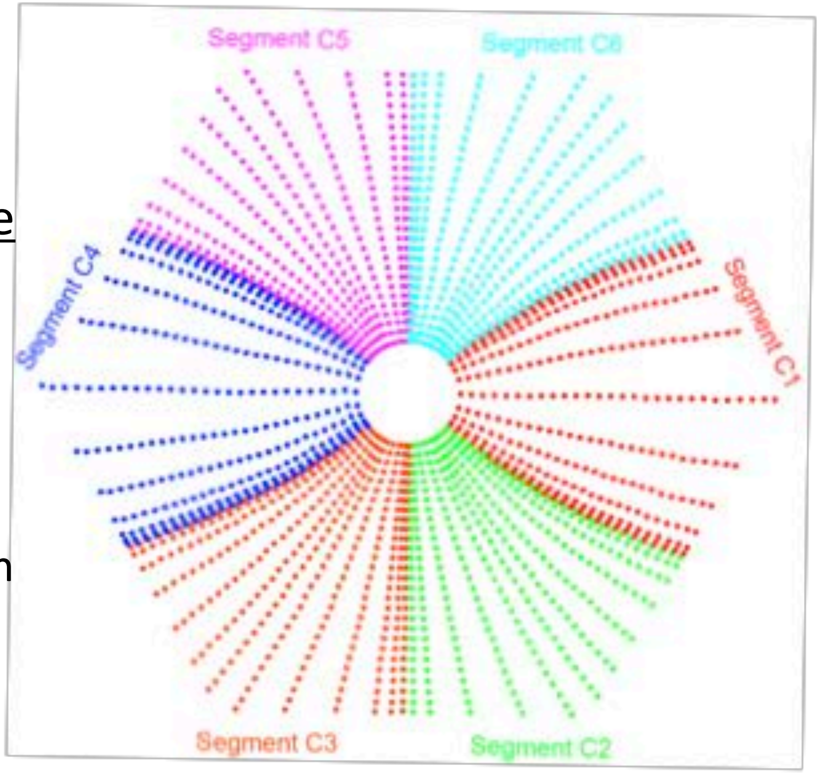
Function: Transform time-dependent electrical signals from the detector to position information of interaction(s)

- 480k events/s (15k/s per crystal)
- Sets scale of the computing cluster

<u>Refactor existing GRETINA Signal Decomp. Code</u>

- fit into the GRETA dataflow pipeline
- Decouple signal decomposition from I/O, slow control, and monitor sub systems.
- Optimize for modern processors with high core counts.
- Investigate the use of libraries in the minimization algorithm.
- Investigate the use of GPU's in the signal decomposition cluster

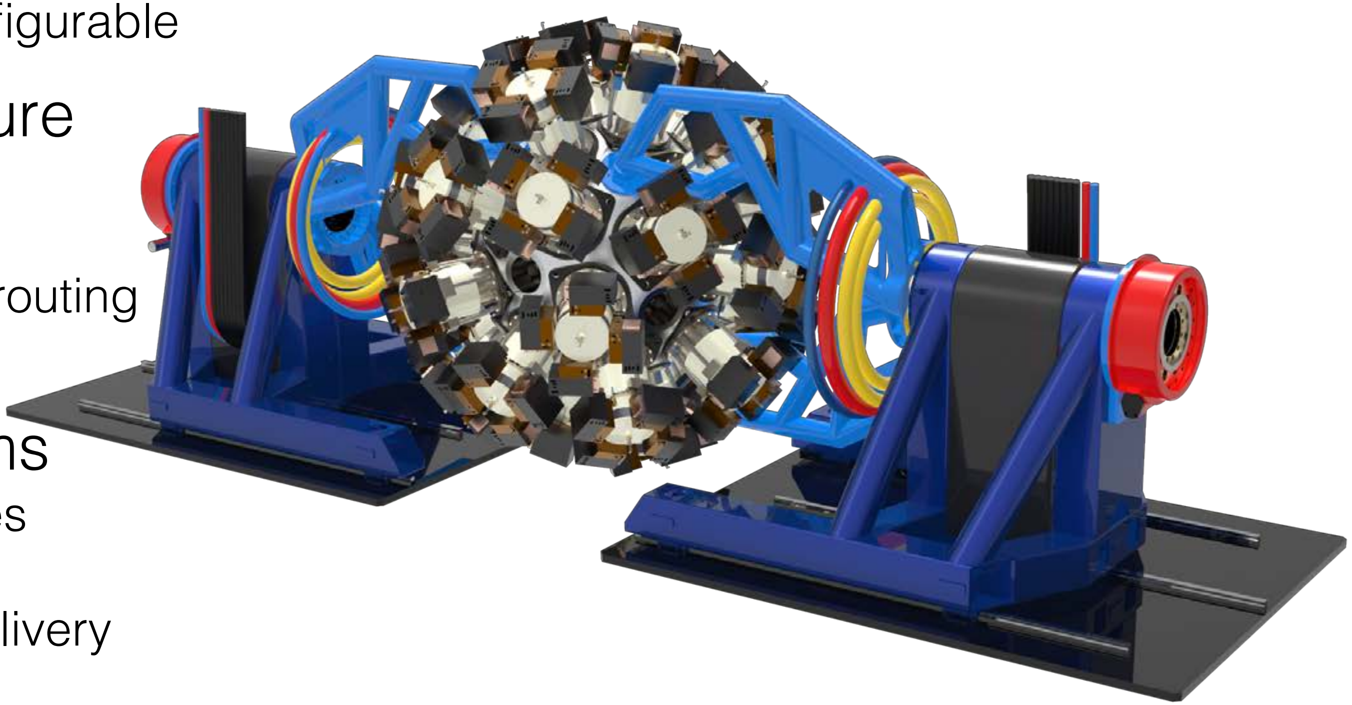
Gustav Jensen (ORNL)



Cross-section of points on equi-sensitivity grid in x-y plane for a GRETINA basis

Mechanical Systems – Technical Scope

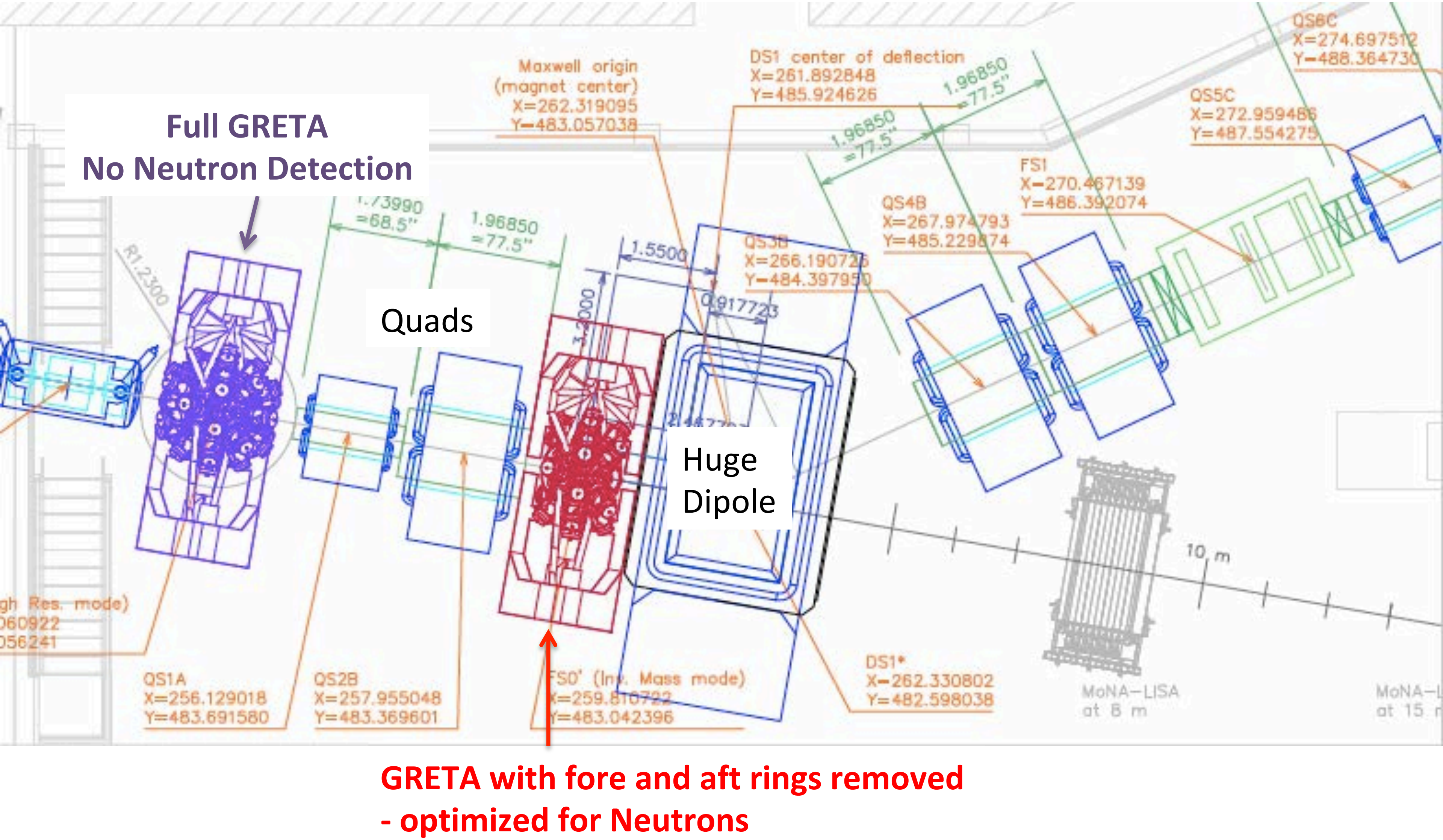
- Detector Array Sphere
  - 30 Quad Modules in a 4π arrangement
  - Experiment configurable
- Support Structure
  - Rotary motion
  - Linear motion
  - Cable & Piping routing
  - Alignment
- Cooling Systems
  - Digitizer Modules
  - Pre-Amplifiers
  - Detector LN_2 delivery
- Controls System
  - Motion controls
  - Cooling controls (Electronics & LN_2)
  - User Interface
  - Interlocks & Machine safety



Adrian Hodgkinson (LBNL)

Locations for GRETA on HRS Beam Lines

An example of the requirement for a “flexible”, movable support structure

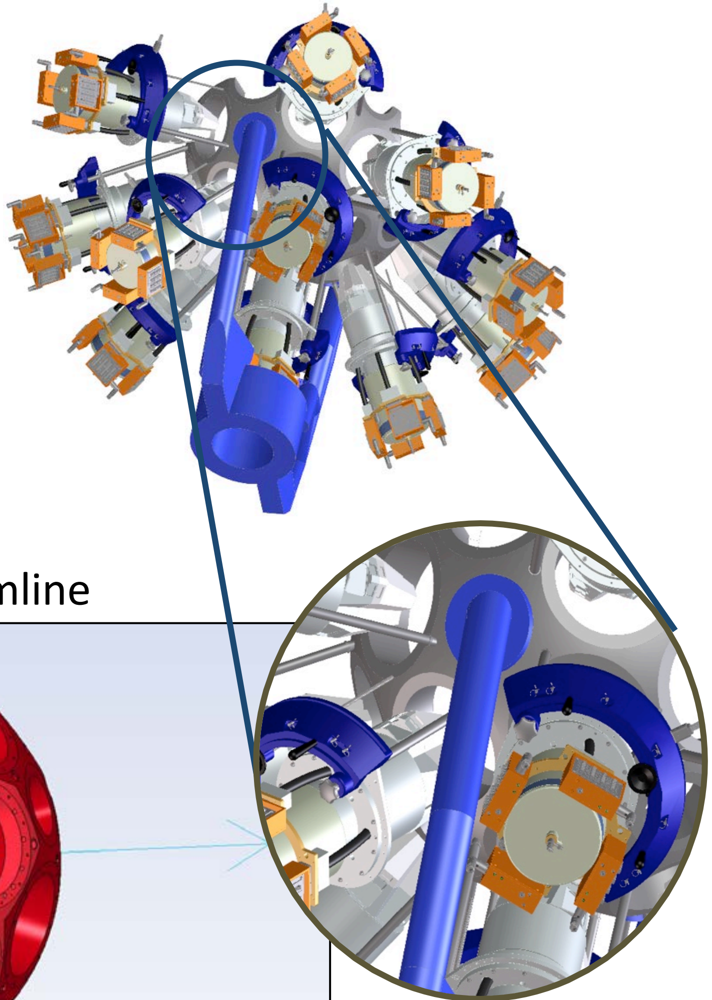


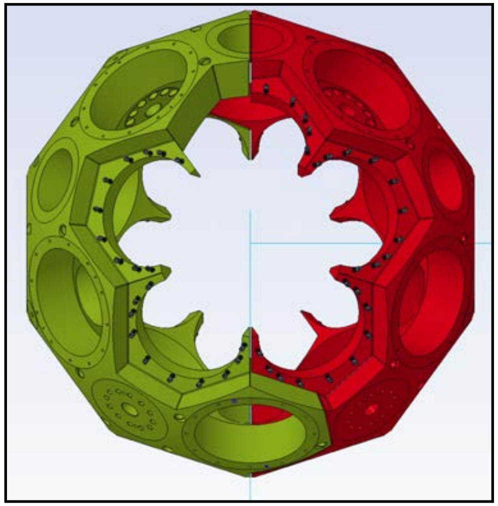
Detector Support Sphere

- Detector Sphere Final Design was completed end of July
- Engaged experienced vendors early (GRETINA and Gammasphere)

- **6 parts (left, right hemis, removable Fore & Aft rings**

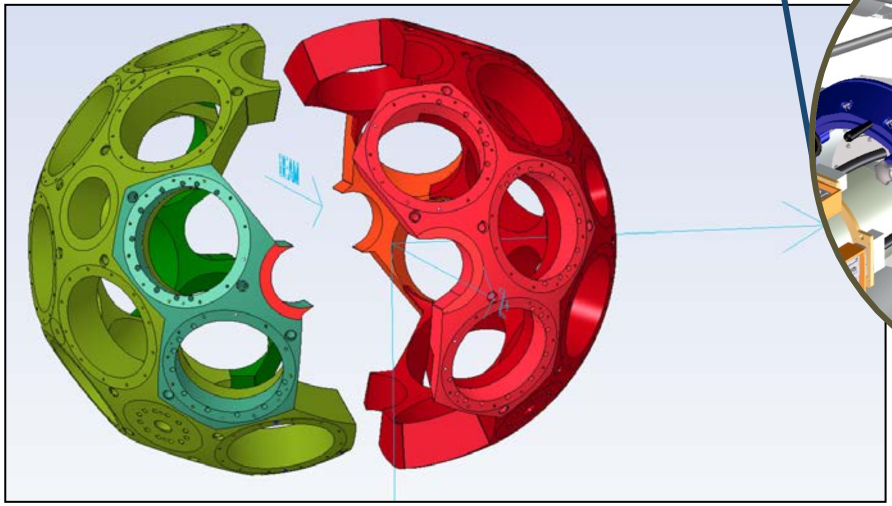
Support Arm Mounting Positions





Fore & Aft Removal

Hemispheres Split at Beamline

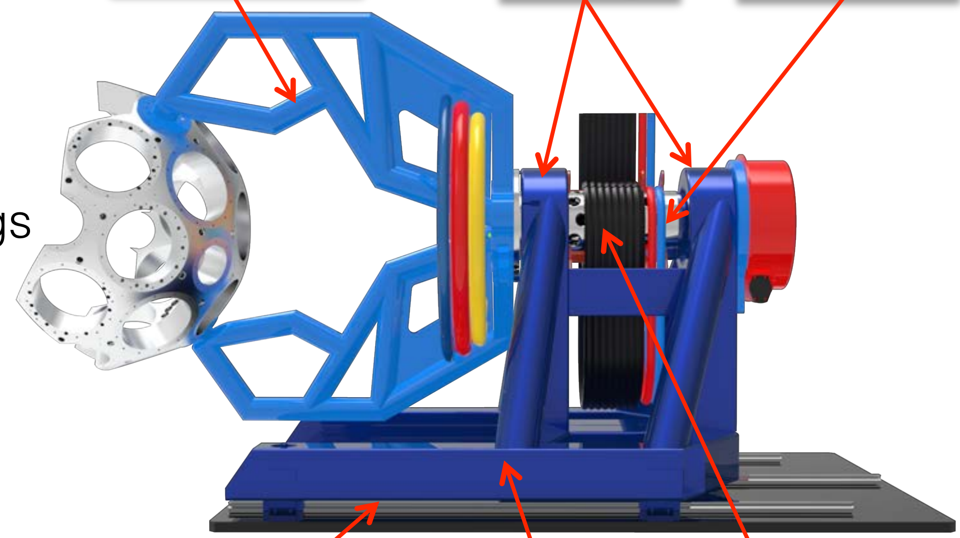


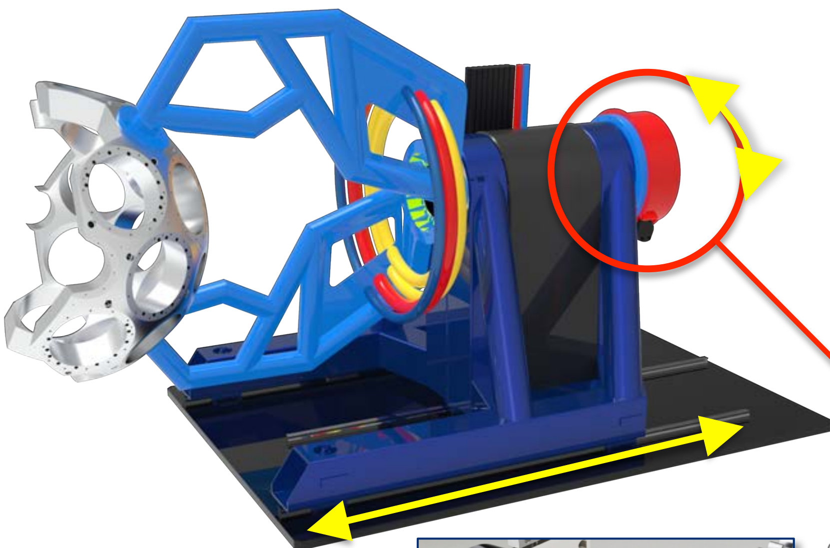
Tim Loew (LBNL)

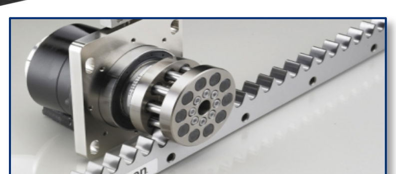
Overall Support Structure

Preliminary Design Complete

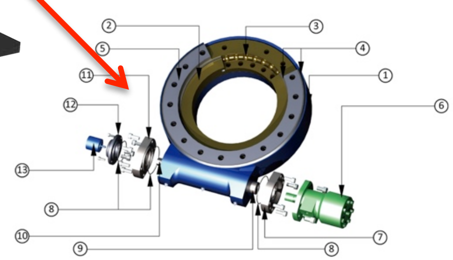
- Support Arms attached to Sphere
- Rotary shaft for manipulation
- A-Frame Support Structure
- Slew drive unit & pre-loaded bearings
- Linear Rails for manipulation
- Alignment Feet



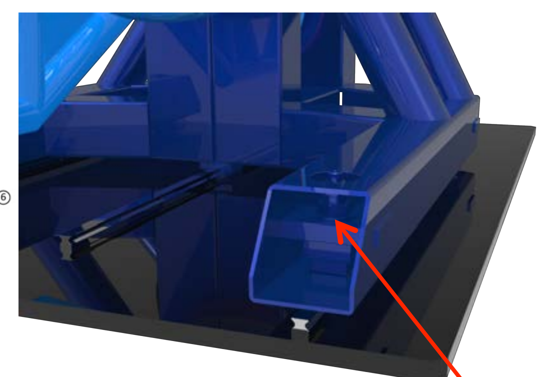




Linear Drive



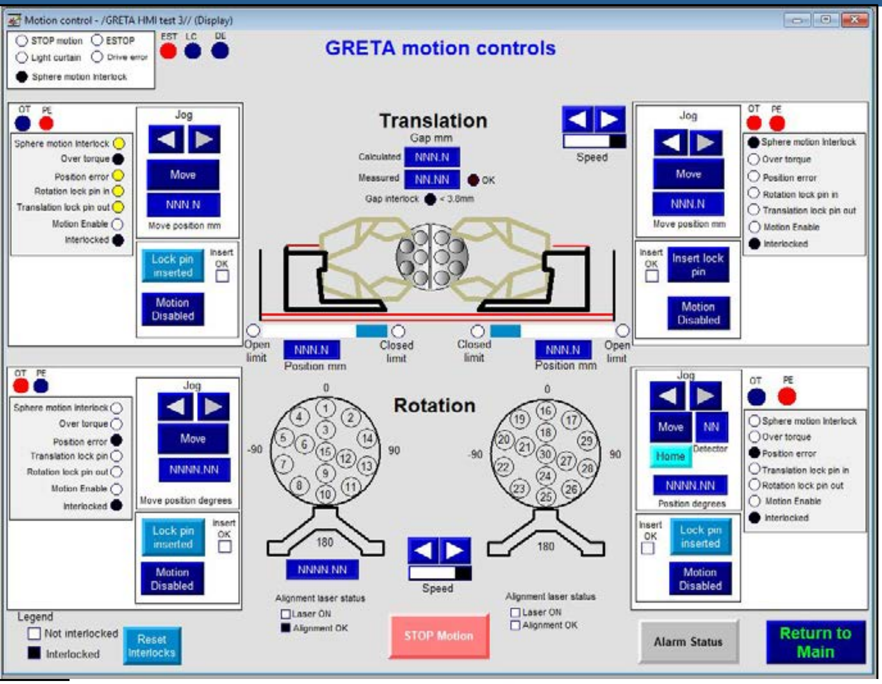
Slew Drive



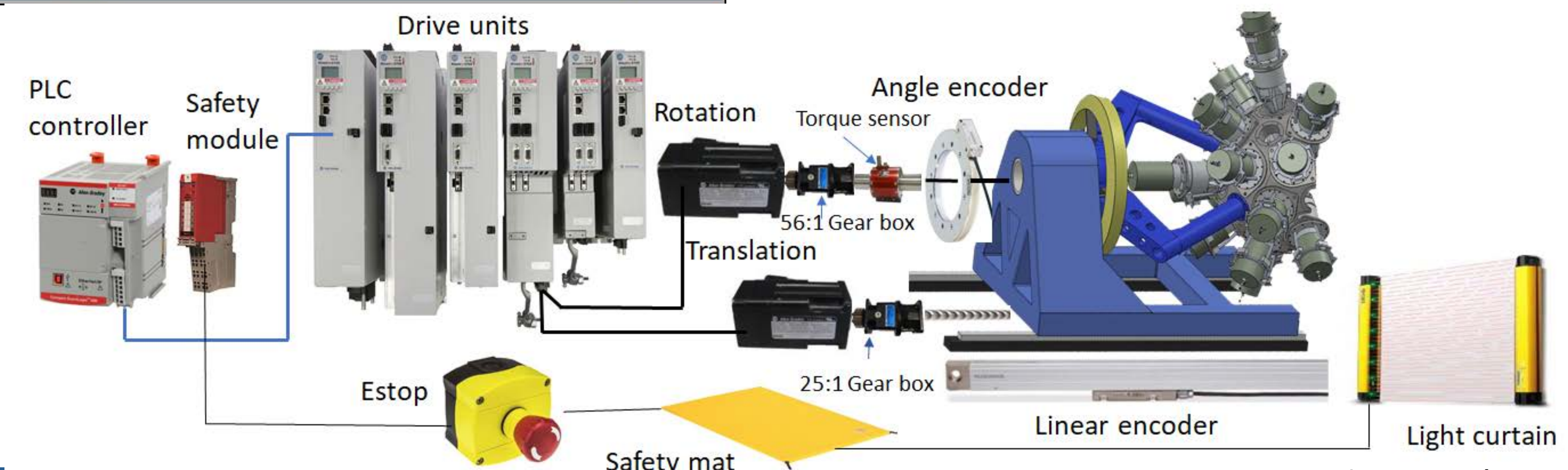
Alignment

Jennifer Doyle (LBNL)

Motor Driven Translation and Rotation

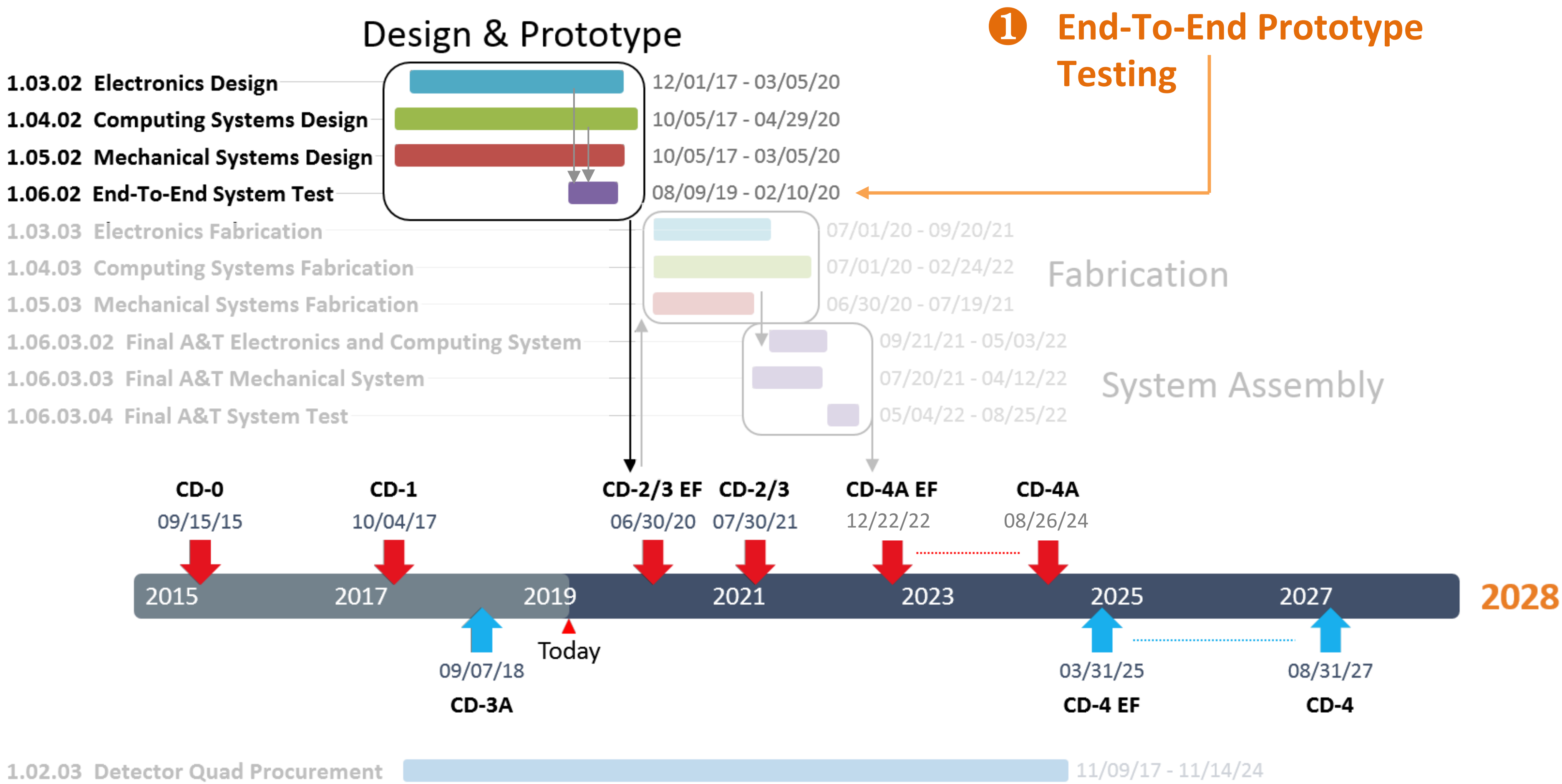


- Absolute linear encoders for translation and rotational axes
- Light curtain and/or safety mat for personnel protection
- Motion locking pins and position sensors to prevent unwanted motions



Mark Regis (LBNL)

System Assembly



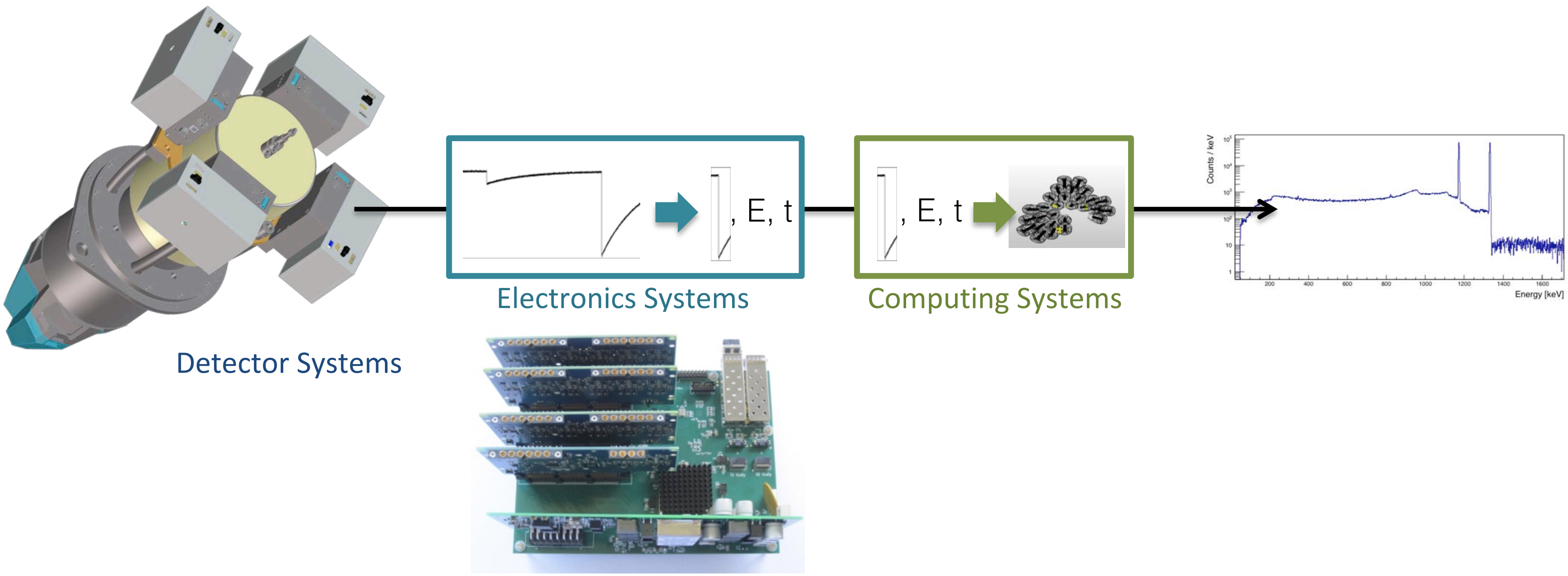
Integrating Systems to Verify Performance

- **Prototypes and Final**

Heather Crawford (LBNL)

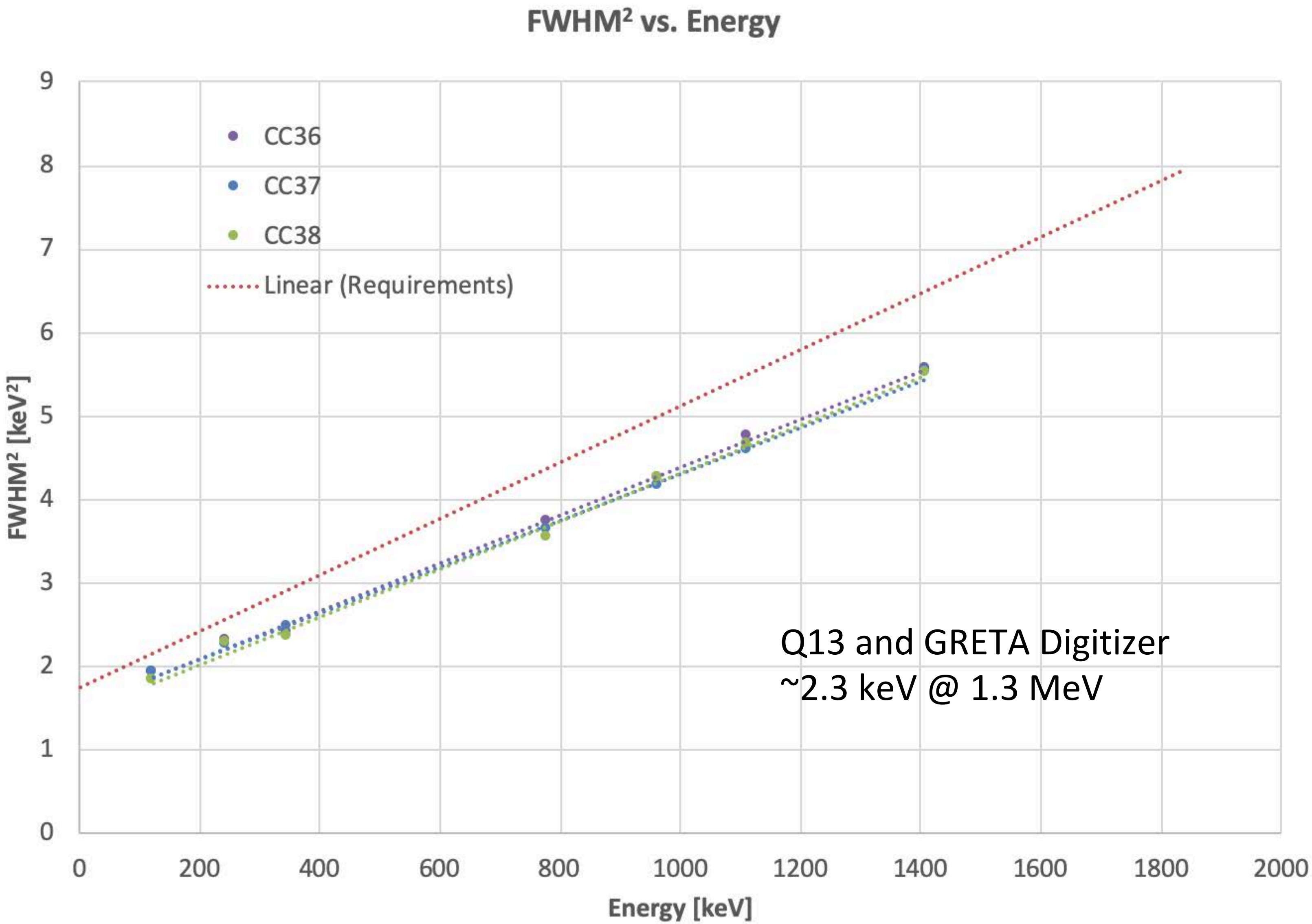
End-to-End Prototype Integration and Testing

Connect a fully functional prototype Detector Interface Box and Digitizer Board to a GRETINA/GRETA Quad and stream data to the prototype FPGA Board then through the Computing Development System (August – December 2019)

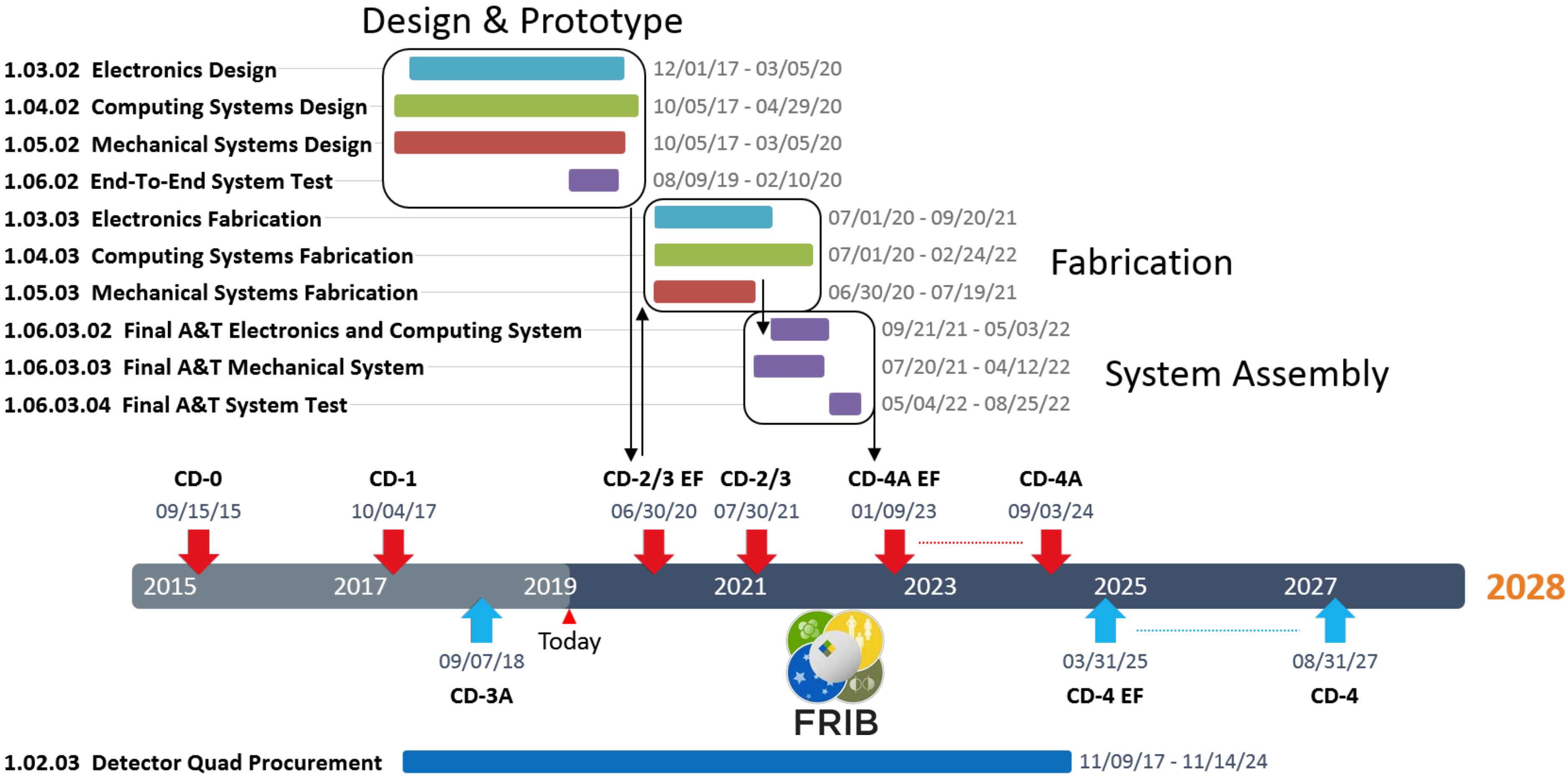


Demonstrate resolution, linearity, stability, for core and segments, ready for CD2/3

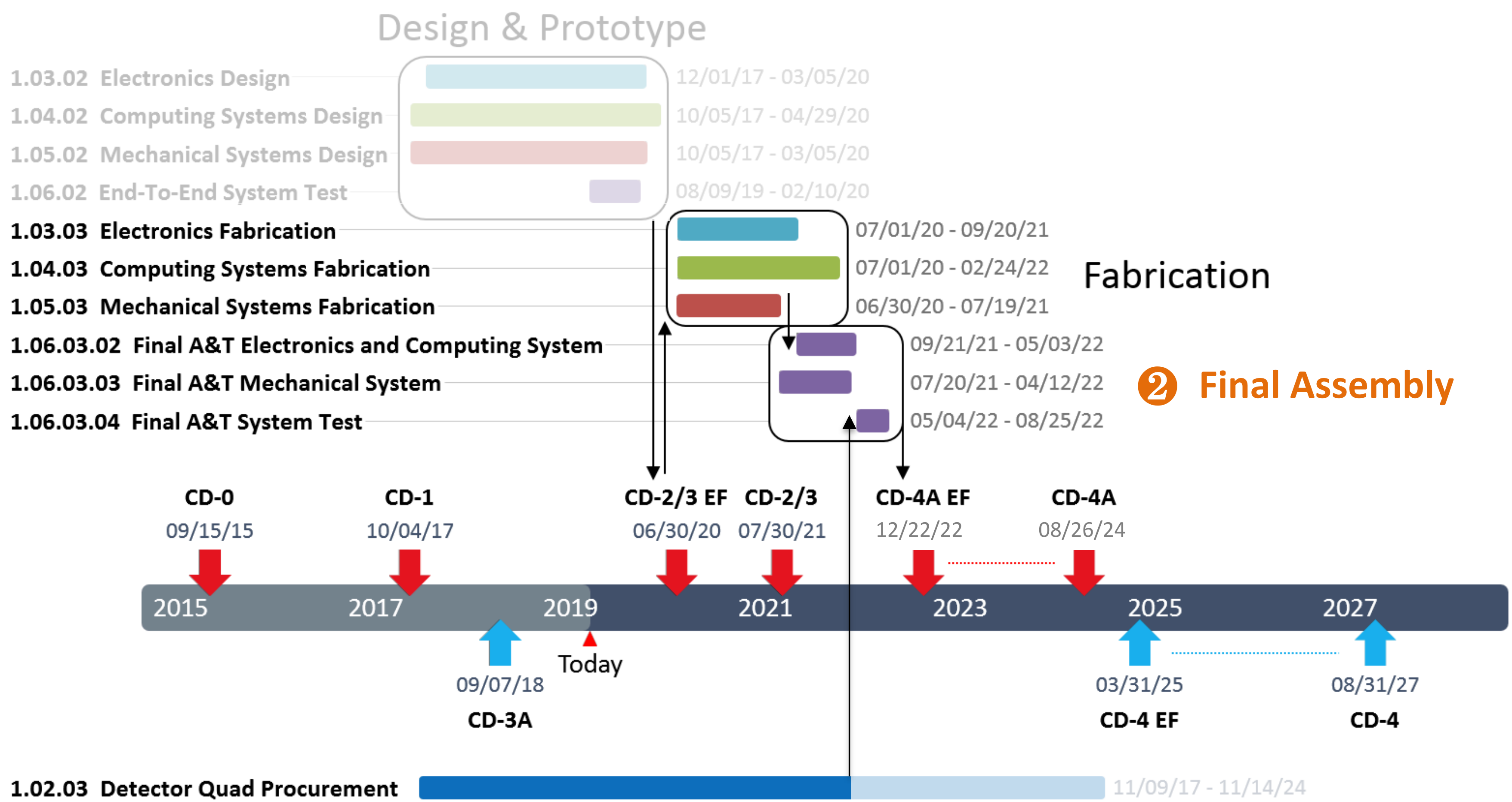
End-to-End Test – First results ☺



What's Next


Design & Prototype
1.03.02 Electronics Design
12/01/17 - 03/05/20
1.04.02 Computing Systems Design
10/05/17 - 04/29/20
1.05.02 Mechanical Systems Design
10/05/17 - 03/05/20
1.06.02 End-To-End System Test
08/09/19 - 02/10/20
1.03.03 Electronics Fabrication
07/01/20 - 09/20/21
1.04.03 Computing Systems Fabrication
07/01/20 - 02/24/22
1.05.03 Mechanical Systems Fabrication
06/30/20 - 07/19/21
Fabrication
1.06.03.02 Final A&T Electronics and Computing System
09/21/21 - 05/03/22
1.06.03.03 Final A&T Mechanical System
07/20/21 - 04/12/22
1.06.03.04 Final A&T System Test
05/04/22 - 08/25/22
System Assembly
CD-0
09/15/15
CD-1
10/04/17
CD-2/3 EF
06/30/20
CD-2/3
07/30/21
CD-4A EF
01/09/23
CD-4A
09/03/24
2015
2017
2019
2021
2023
2025
2027
2028
09/07/18
CD-3A
Today
FRIB
03/31/25
CD-4 EF
08/31/27
CD-4
1.02.03 Detector Quad Procurement
11/09/17 - 11/14/24

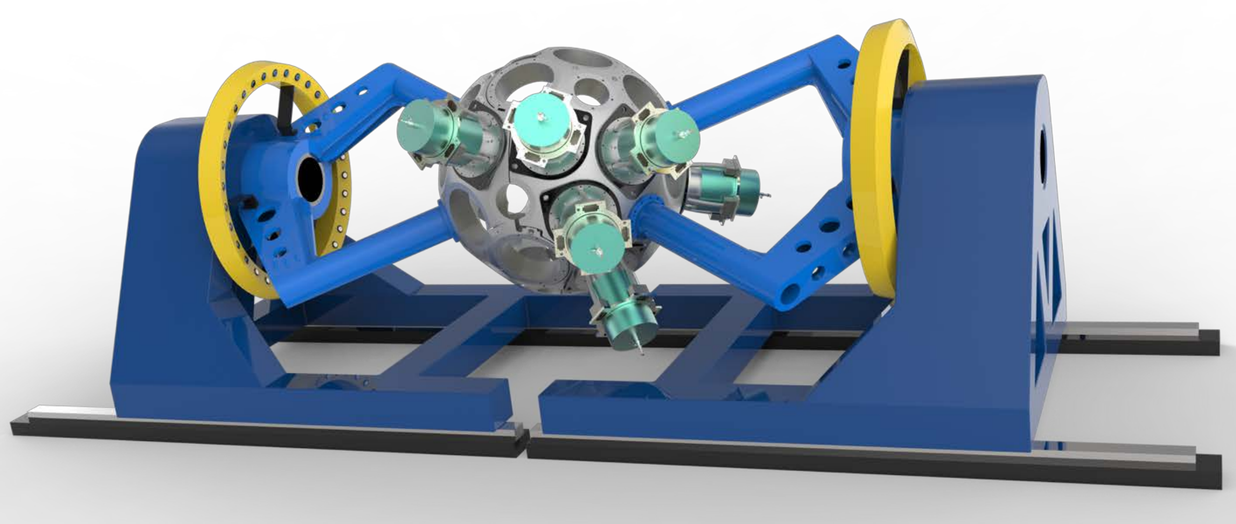
System Assembly



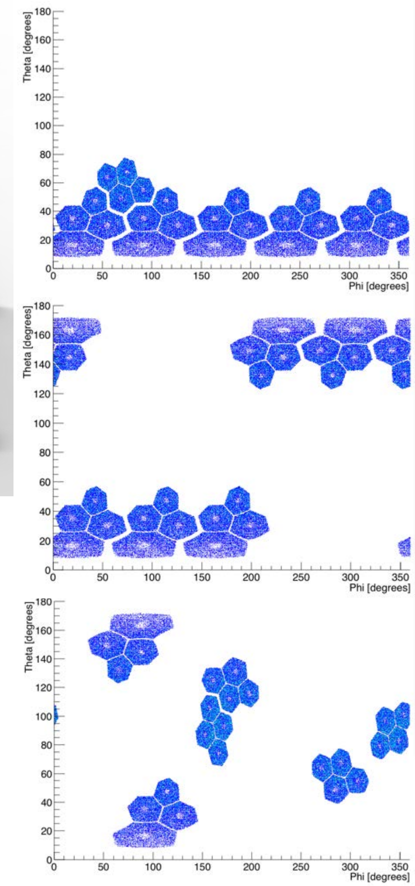
System assembly is the convergence point for the project in advance of CD-4A, and where KPPs are demonstrated.

Final System Integration

Final System Assembly and Test will integrate full mechanical, electronics, and computing systems with at least 6 GRETA Quad Modules.



- Mechanical support structure and infrastructure for 30 Quad Modules will be assembled at the 88" cyclotron (Building 88)
- Electronics and computing systems for 30 Quads will be installed
- At least 6 Quad Modules will be installed, instrumented and tested in multiple configurations



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

Summary

- GRETINA continues to deliver outstanding science at Rare Isotope and Stable Beam Facilities

- GRETA
  - A key detector for scientific discovery at FRIB
    - building on technical and scientific success of GRETINA
    - phased schedule (CD-4A) optimizes delivery to FRIB
  - Detector procurements are underway (ahead !)
  - Design and Prototyping making good progress (on track for CD-2/3 next summer)

- Looking forward to first GRETA science at FRIB

Thanks to all : GRETINA "Operations", GRETA Project, DOE NP, many users