GRETA
Project Status

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.. based on presentation given to project review committees

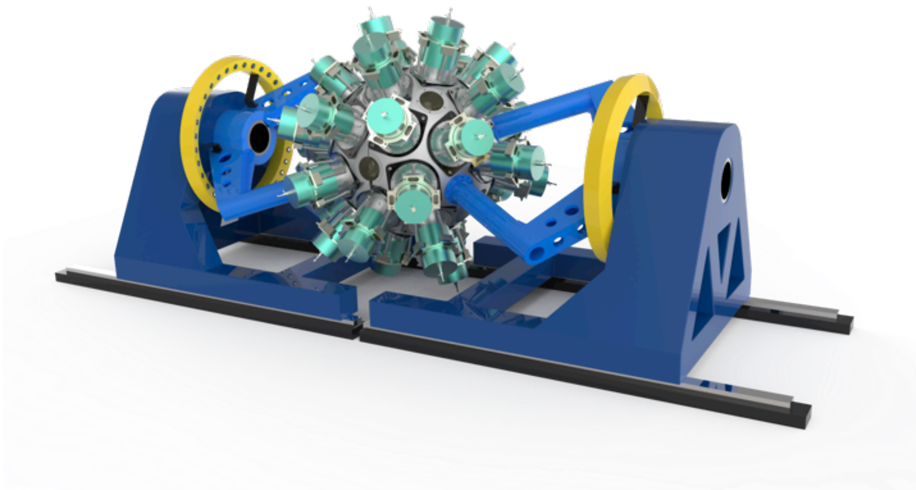
Outline

- GRETA up to now
  - CD-0 to CD-1
- GRETA Project Plan
  - Science drivers (examples), properties and predicted performance
  - Plan to deliver GRETA
    - scope, design, schedule
- What's next

GRETA: A premier γ-ray tracking detector for FRIB

A high resolution, high efficiency γ-ray detector array is an essential instrument for FRIB, required to leverage the full scientific capabilities.

The Gamma-Ray Energy Tracking Array (GRETA) is the realization of a 4π tracking detector, capable of reconstructing the energy and three-dimensional position of γ-ray interactions within a compact sphere of high-purity germanium crystals.

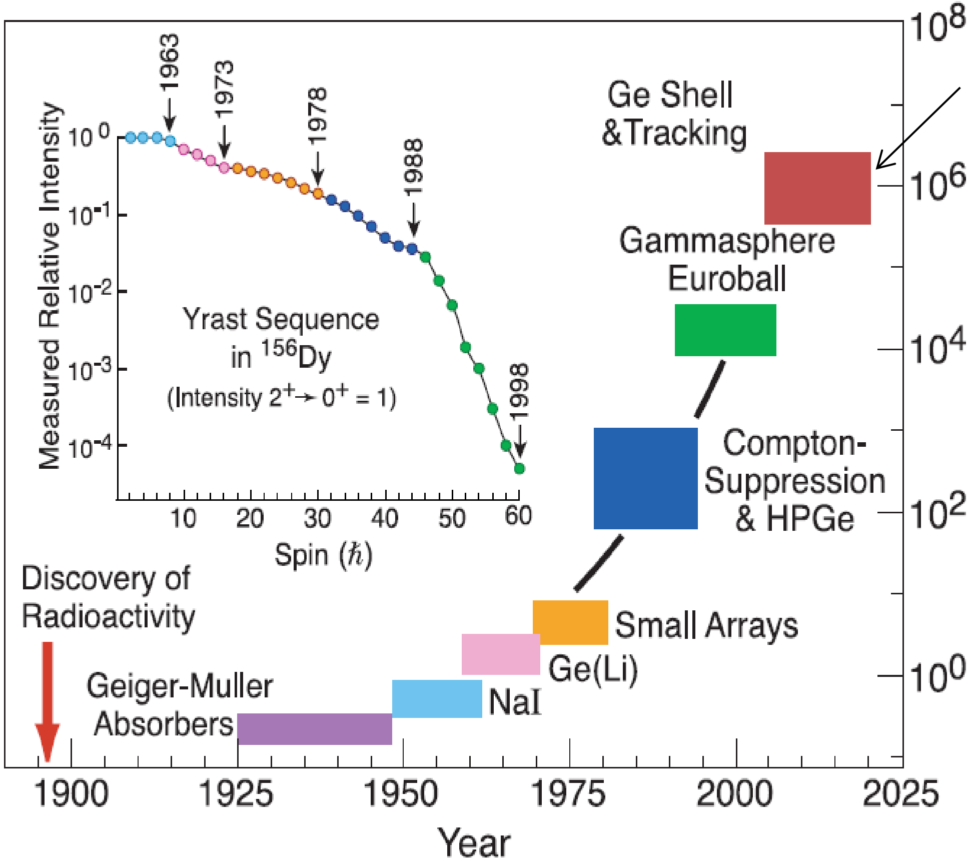


It extends and completes the technical developments demonstrated by GRETINA, a 1π tracking detector optimized for rare isotope science

γ-ray detection plays a central role in nuclear physics

- Nuclei are complex many-body systems exhibiting diverse phenomena and much of what we know about them comes from measurements of excited states
- Of the many experimental tools and techniques developed for these studies, high-resolution γ-ray spectroscopy has proven to be the most powerful

- Advances in detector technology extend science reach
- Past arrays reached a limit
- Next step, a “Ge-shell”, required new concepts and technologies



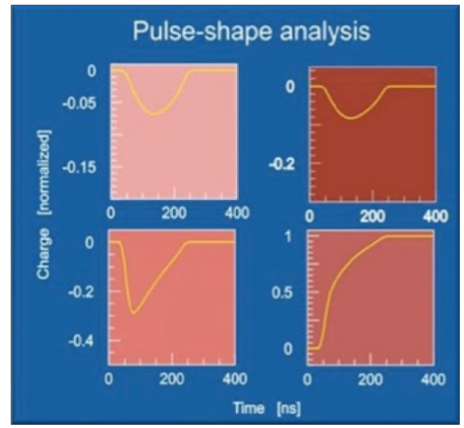
Gamma-Ray Energy Tracking

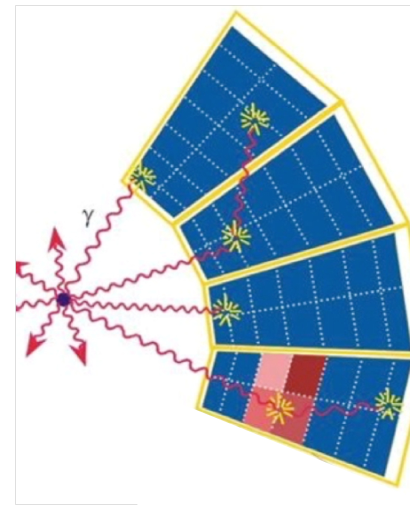
GRETA concept for a shell of closely packed Ge crystals

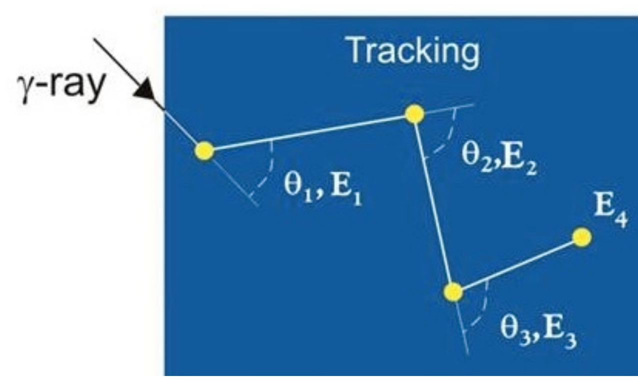
- Combines highly segmented, hyper-pure germanium crystals with advanced digital signal processing techniques

- Identify the position and energy of γ-ray interaction points within a compact "shell" of detectors

- Track γ-ray path both within and between detector elements, using the angle-energy relation of the Compton scattering process







Maximizes and Optimizes

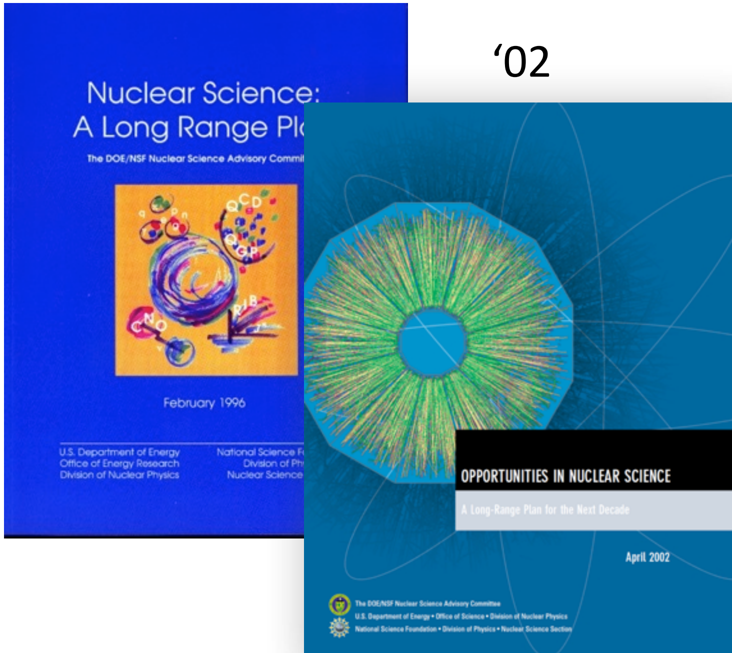
- **Efficiency, Energy Resolution, Peak-to-Total**

Path to GRETA

2002 NSAC LRP *"The detection of γ-ray emissions from excited nuclei plays a vital and ubiquitous role in nuclear science .."*

'96

'02



First discussed in the 1996 NSAC LRP

Path to GRETA

‘96

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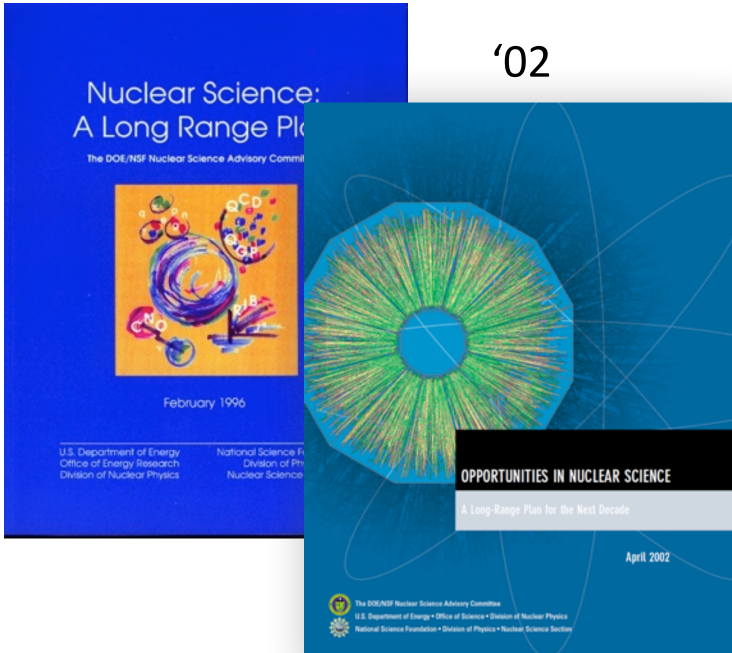


2002 NSAC LRP *“The detection of γ-ray emissions from excited nuclei plays a vital and ubiquitous role in nuclear science ..”*

First discussed in the 1996 NSAC LRP

2002 LRP launched the construction of the γ ray tracking array GRETINA

GRETINA

Gamma-Ray Energy Tracking In-beam Nuclear Array

Constructed 2003-2011: $20M funded by US DOE-Nuclear Physics Office

Optimized for rare isotope science

- Covers ~¼ of 4π solid angle with 7 Quad Detector Modules

2012-present

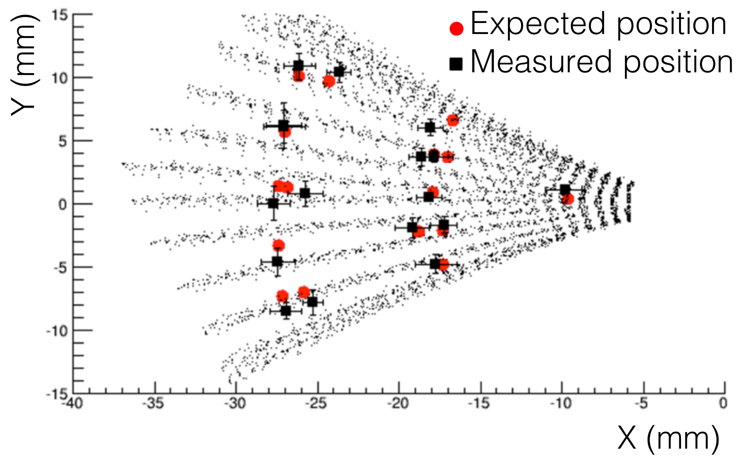
- GRETINA science operations at NSCL and ANL
- Enhancements: Quad Detector Modules added – total of 12

GRETA builds from the technical and scientific success of GRETINA

2012-2017: GRETINA "Enhancements"

GRETINA enhancements have been supported by the U.S DOE-NP Office since completion of the project with 7 quad modules in 2011.

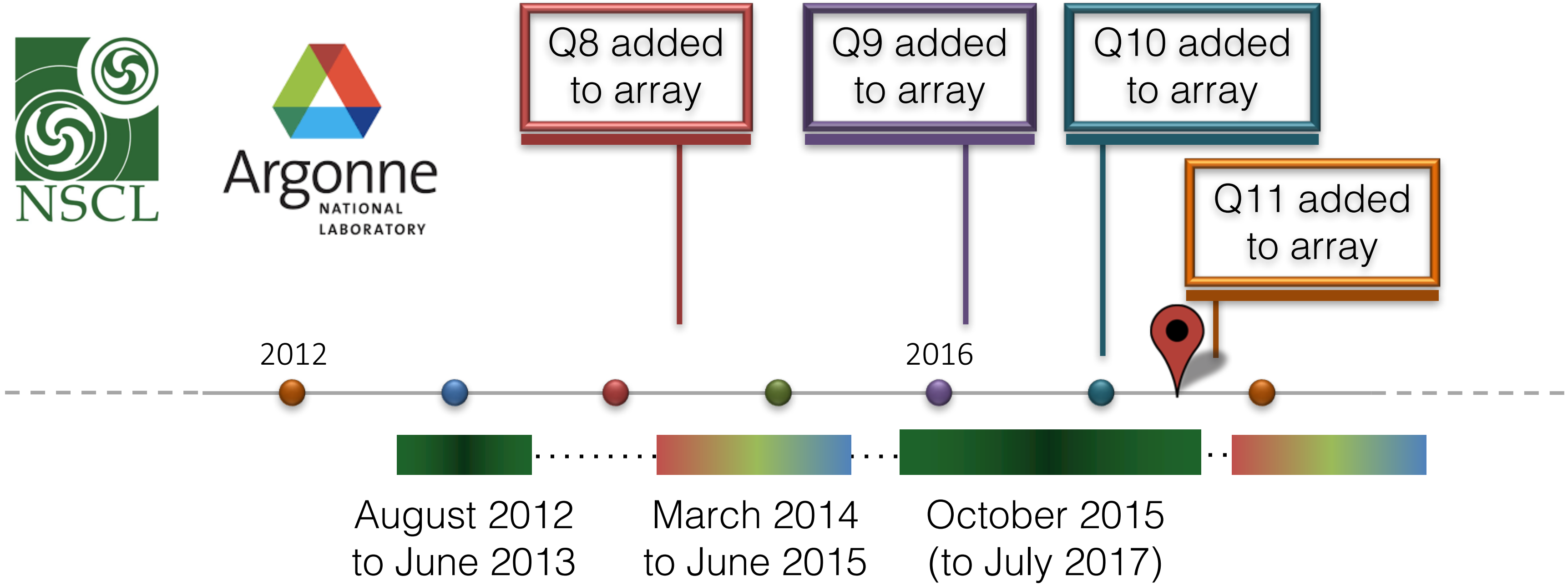
- **Growth of the array through continued procurement of quad modules (and associated infrastructure) at a rate of ~ 1 per year**
  - Purchase of Q8 - Q12
  - Electronics (digitizers, trigger modules, cables and power for each module)
  - Supplementation of the computing cluster to support the increased data rates of the larger array
- **Firmware development and modifications**
  - Improved DAQ stability
  - High-rate energy resolution performance improvements
  - Refined timing performance
- **Signal decomposition and tracking**
  - In-depth coincidence scanning of Q4 at LBNL
  - Extended capabilities in signal decomposition algorithms (single interaction, etc.)
  - Enhanced simulation including the effects of signal decomposition



GRETINA Physics Campaigns: Overview

NSCL

Argonne NATIONAL LABORATORY



- First physics campaigns at NSCL and ANL (ATLAS/CARIBU) have already produced more than *35* physics papers (incl. 12 letters)
- Second NSCL campaign is just ended, with 24 PAC approved experiments (~3600 hours).
- Up next
  - Second ANL campaign starting Fall 2017
  - Third NSCL campaign 2019

Path to GRETA

2002 NSAC LRP *"The detection of γ-ray emissions from excited nuclei plays a vital and ubiquitous role in nuclear science .."*

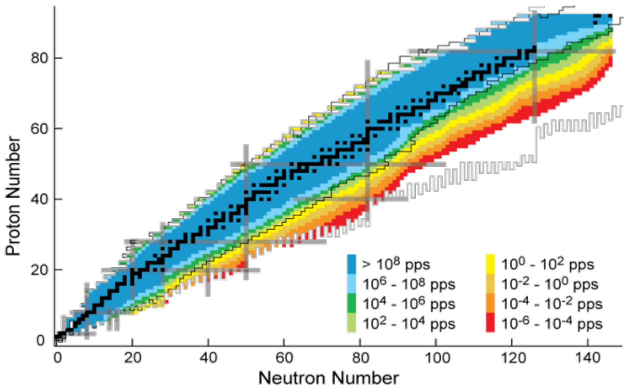
'96 '02 '07 '14 '15

2007 NSAC LRP *"Construction of GRETA should begin immediately upon successful completion of the GRETINA array"*

GRETA identified as a key instrument for FRIB

- GRETA CD-0 Sept. 2015

GRETA Science at FRIB

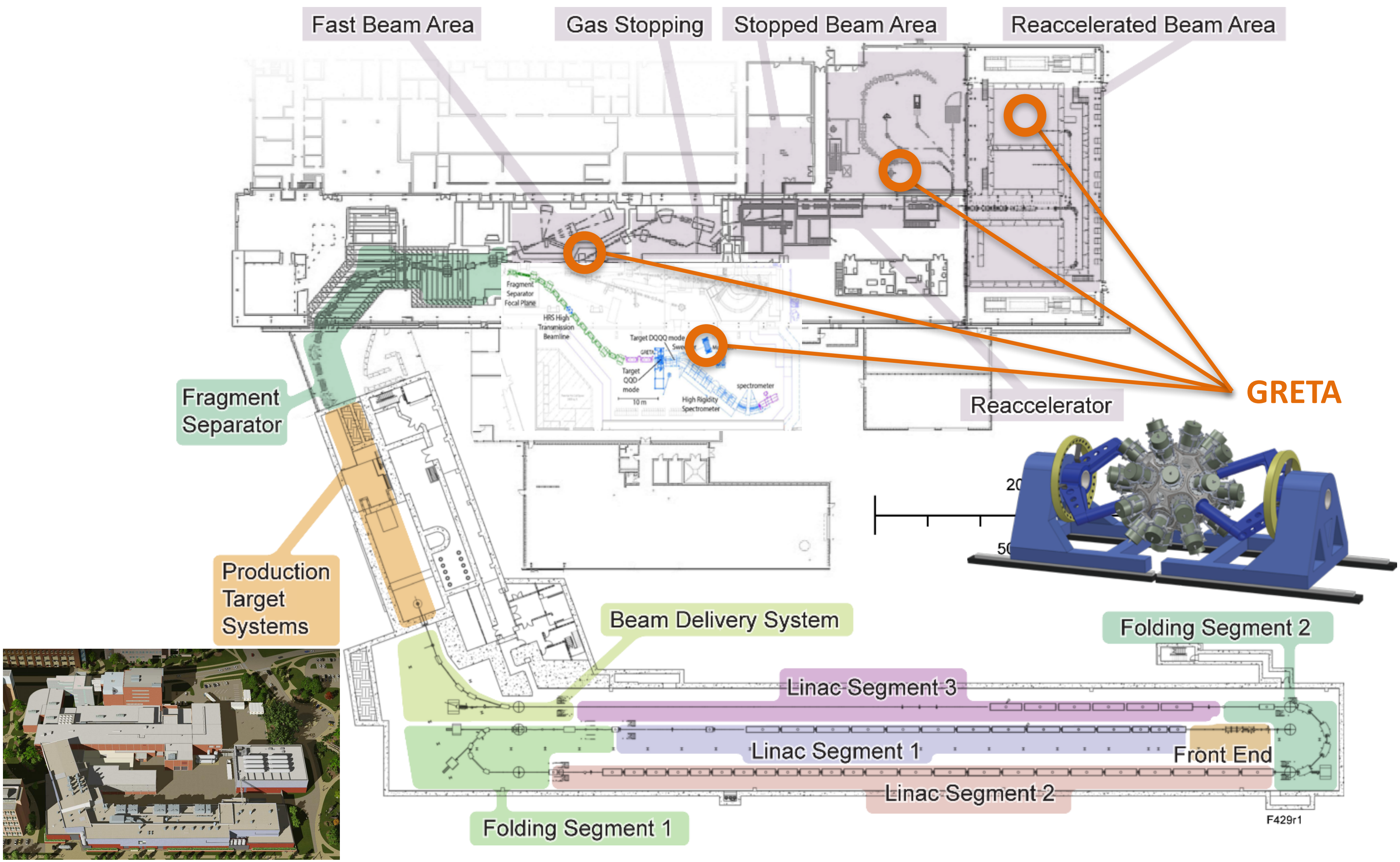


- FRIB beams will provide access to 1000s of nuclei
- GRETA will provide the sensitivity to maximize the physics opportunities at FRIB, with both fast-fragmentation and reaccelerated beams

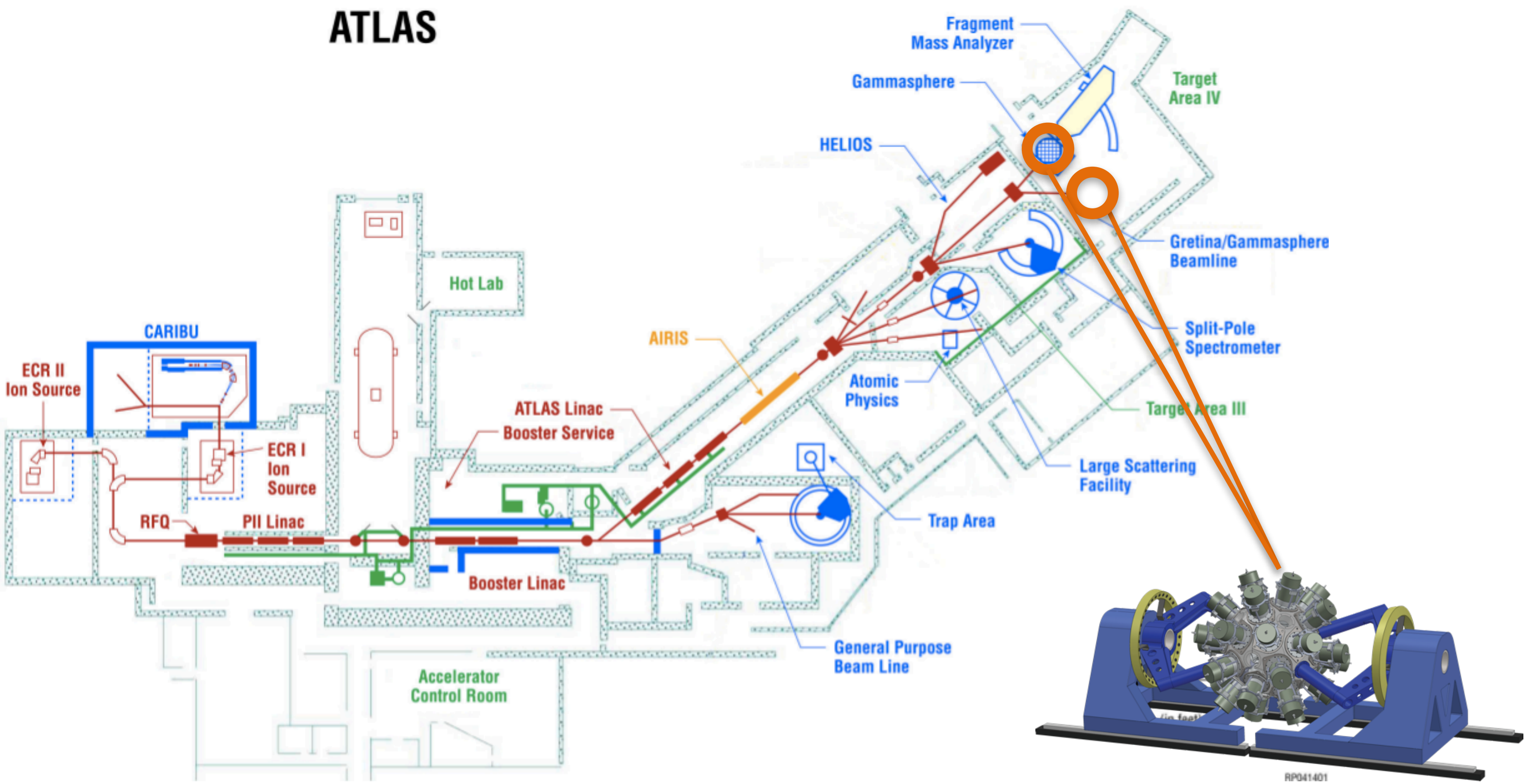
Nuclear Structure	Nuclear Astrophysics	Tests of Fundamental Symmetries	Applications of Isotopes
Intellectual challenges from NRC Decadal Study 2013			
How does subatomic matter organize itself and what phenomena emerge?	How did visible matter come into being and how does it evolve?	Are fundamental interactions 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. $^{15}O(\alpha,\gamma)$ 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)

GRETA will be used at multiple beam lines and energies



GRETA will be used at multiple beam lines and energies



Argonne NATIONAL LABORATORY

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

GRETA science case defines requirements

Key properties determining the performance of a γ-ray tracking array:

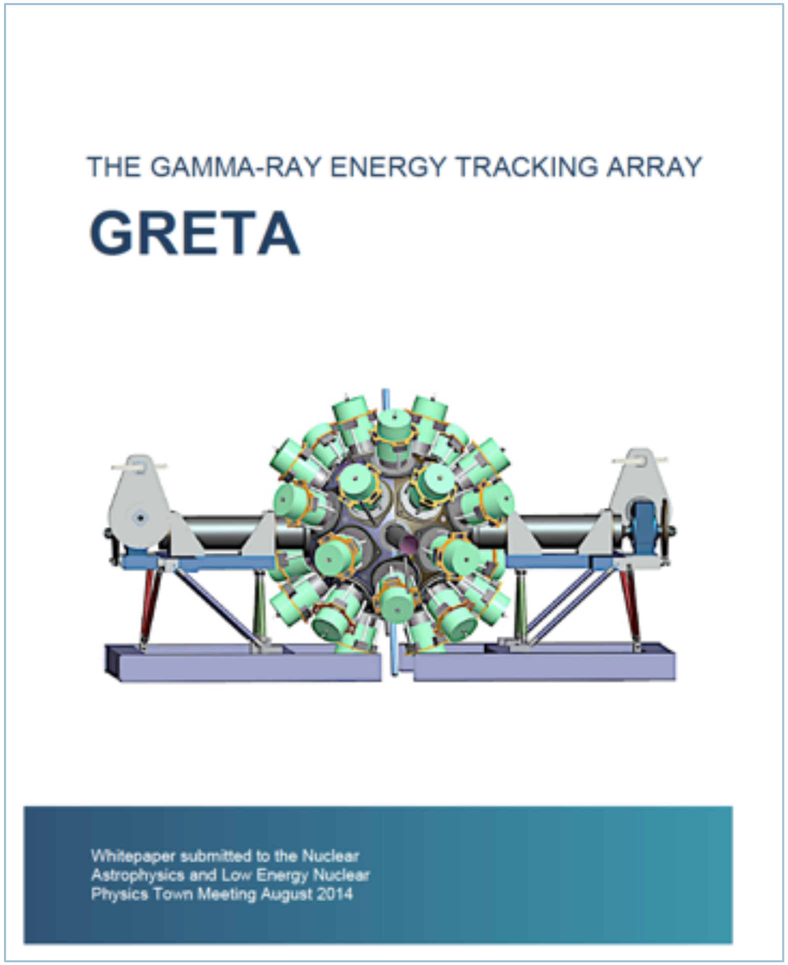
- full energy efficiency
- energy resolution
- position resolution
- background rejection (peak-to-total: P/T)
- count-rate capability

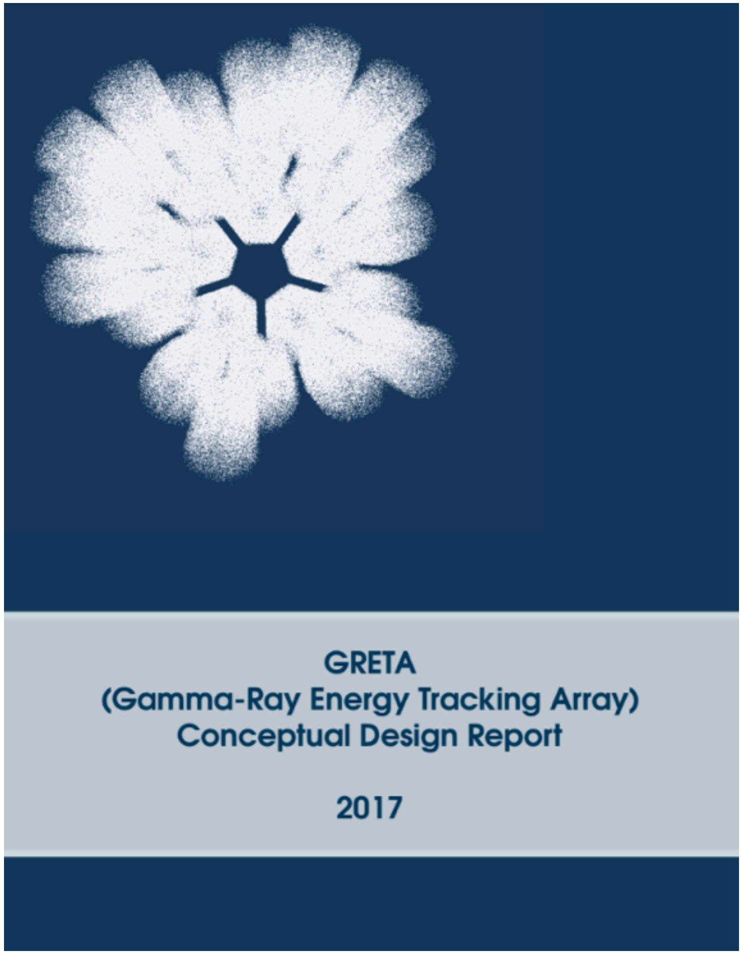
Full Energy Efficiency (Add-back)	≥ 30% at 1.33 MeV
Peak-to-Total	≥ 50% at 1.33 MeV
Intrinsic Ge Energy Resolution	≤ 2.5 keV at 1.33 MeV
Average Position Resolution	≤ 2 mm σ (x,y,z)
Count Rate (crystal)	≥ 50,000 /sec

- "flexibility" to be used in multiple locations and for a wide range of beam energies and intensities, and hence have the capability to trade-off key properties (e.g. efficiency and P/T) to optimize science

GRETA science case defines requirements

Identified specific examples to benchmark GRETA requirements and establish the science reach





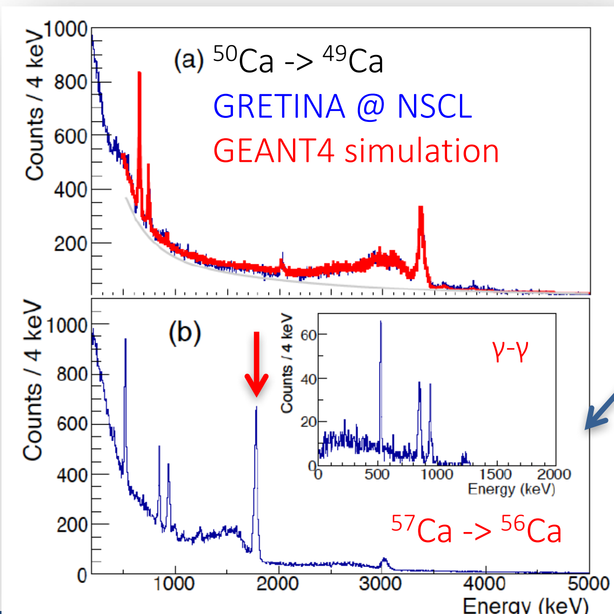
http://greta.lbl.gov/

Science example: fast beams (v ~ 50% c)

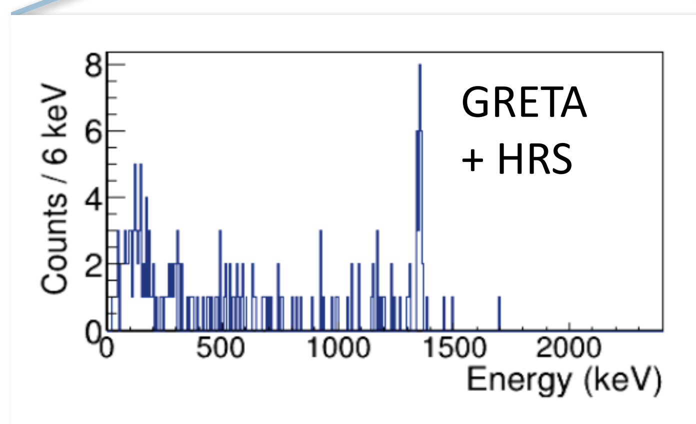
Full Energy Efficiency (Add-back)	≥ 30% at 1.33 MeV
Peak-to-Total	≥ 50% at 1.33 MeV
Intrinsic Ge Energy Resolution	≤ 2.8 keV at 1.33 MeV
Average Position Resolution	≤ 2 mm σ (x,y,z)
Count Rate (crystal)	≥ 50,000 /sec

^{48}Ca ^{49}Ca ^{50}Ca ^{51}Ca ^{52}Ca ^{53}Ca ^{54}Ca ^{55}Ca ^{56}Ca ^{57}Ca ^{58}Ca ^{59}Ca ^{60}Ca Dripline ?

Detailed Spectroscopy @ FRIB → First Spectroscopy @ FRIB



- Detailed studies of single particle structure, provide a critical test of effective interactions and 3N forces
- The structure around ^{60}Ca informs the location of the dripline at Z = 20

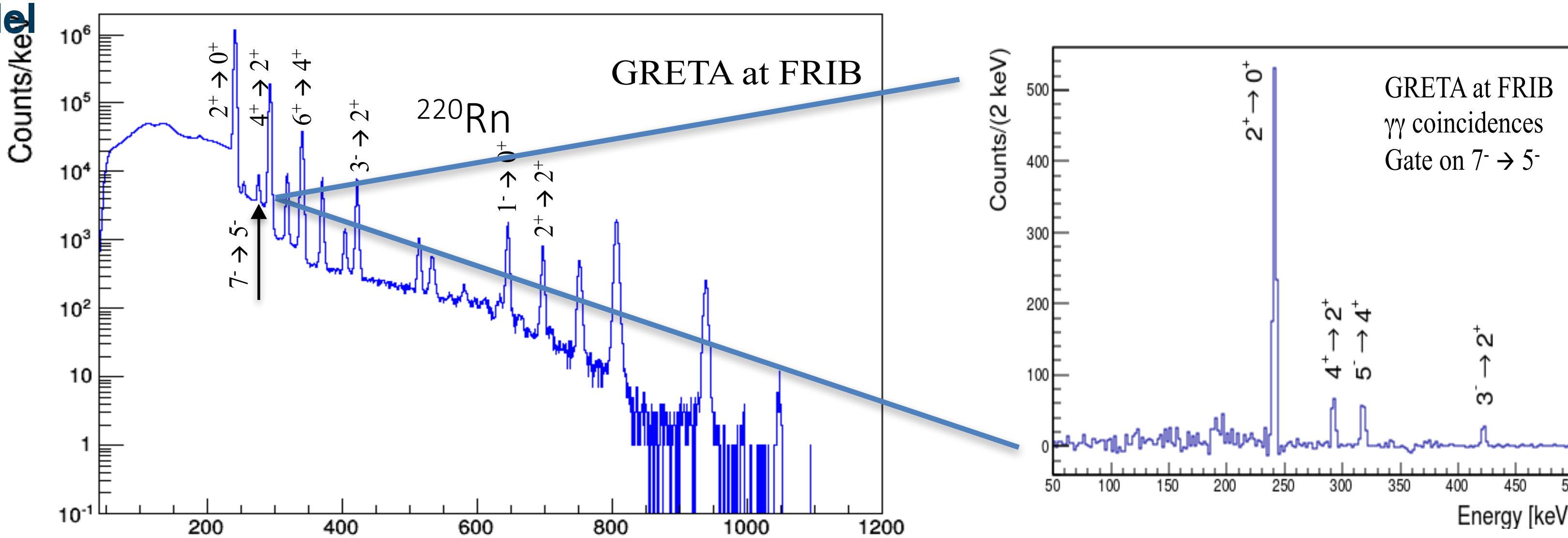


- GRETA will have superior resolving power for fast-beam experiments compared to any other γ-ray detector

Science example: reaccelerated beams (v <10% c)

Full Energy Efficiency (Add-back)	≥ 30% at 1.33 MeV
Peak-to-Total	≥ 50% at 1.33 MeV
Intrinsic Ge Energy Resolution	≤ 2.8 keV at 1.33 MeV
Average Position Resolution	≤ 2 mm σ (x,y,z)
Count Rate (crystal)	≥ 50,000 /sec

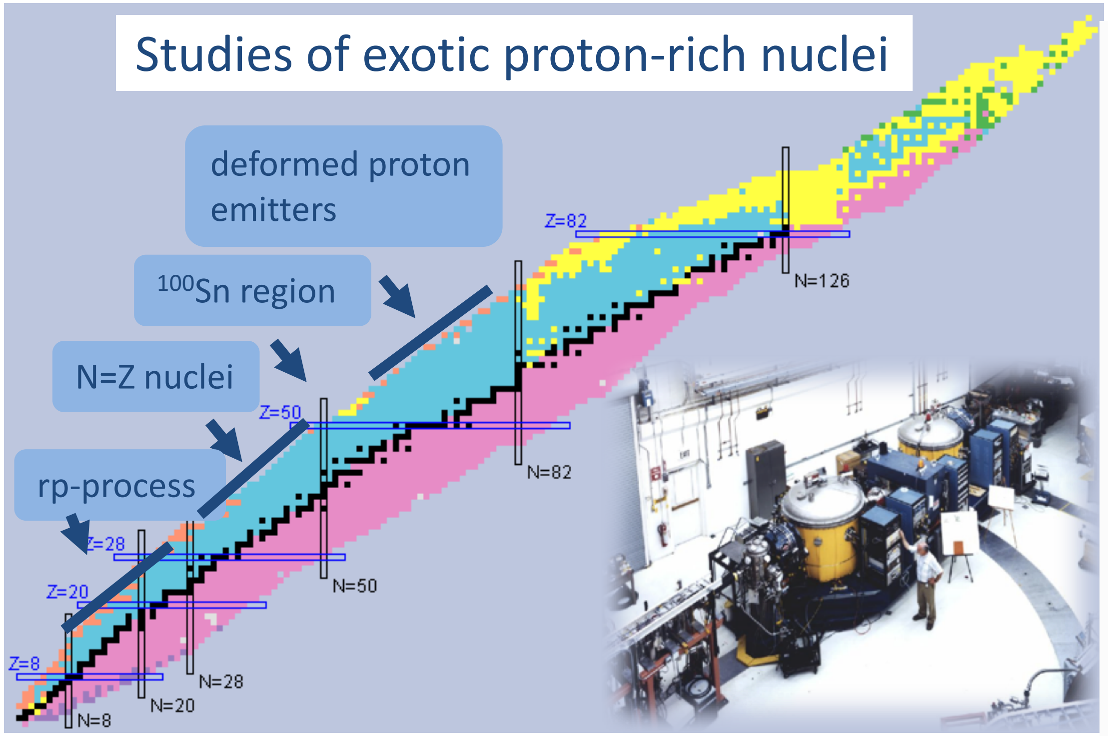
Studies of octupole collectivity to guide searches for physics beyond the Standard Model



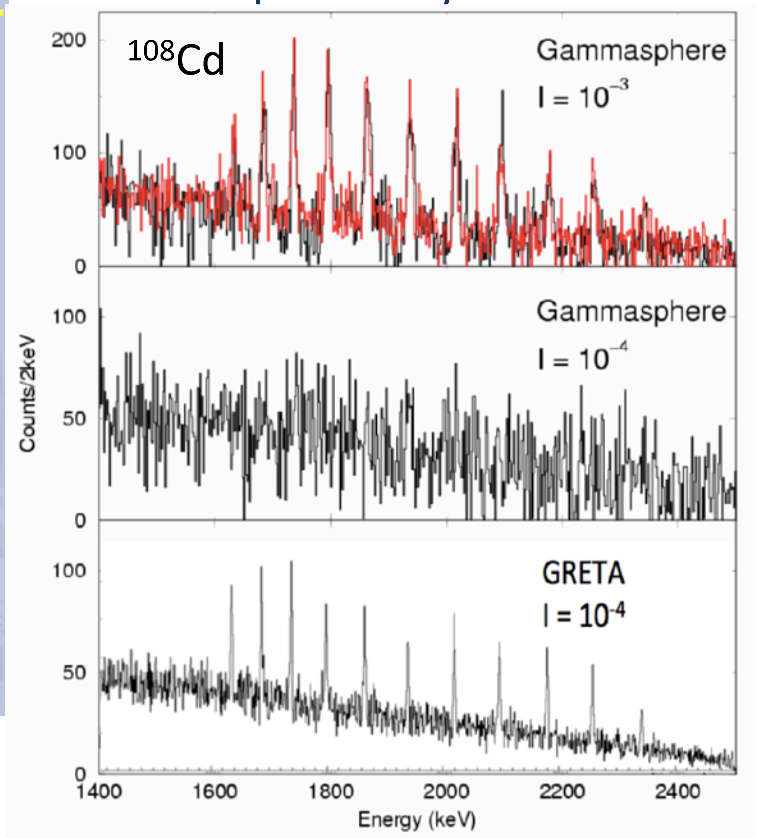
4π GRETA combined with the FRIB reaccelerated beam intensity and energy provide a 100-fold or more increase in the intensity of transitions characterizing higher-spin states

Science example: high intensity beams, high γ multiplicities

Full Energy Efficiency (Add-back)	≥ 30% at 1.33 MeV
Peak-to-Total	≥ 50% at 1.33 MeV
Intrinsic Ge Energy Resolution	≤ 2.8 keV at 1.33 MeV
Average Position Resolution	≤ 2 mm σ (x,y,z)
Count Rate (crystal)	≥ 50,000 /sec

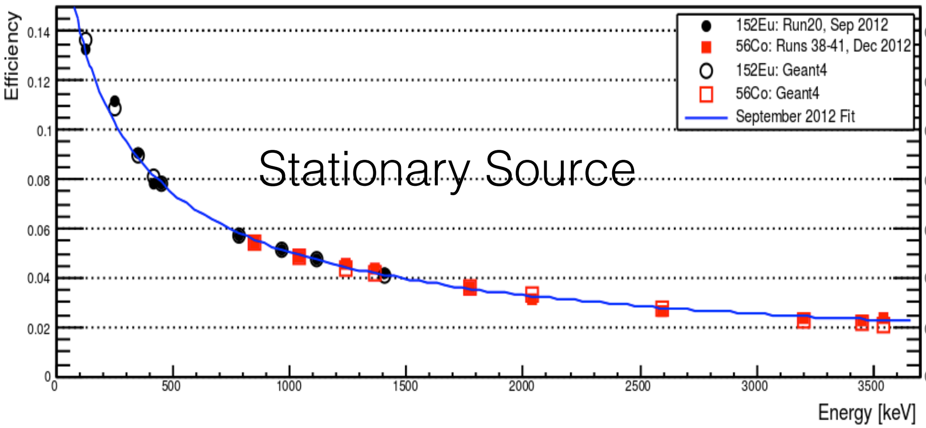


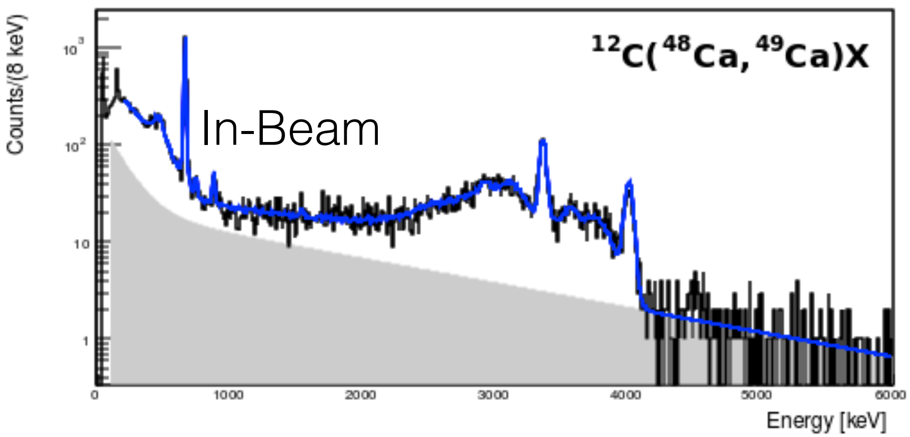
Shapes and Symmetries

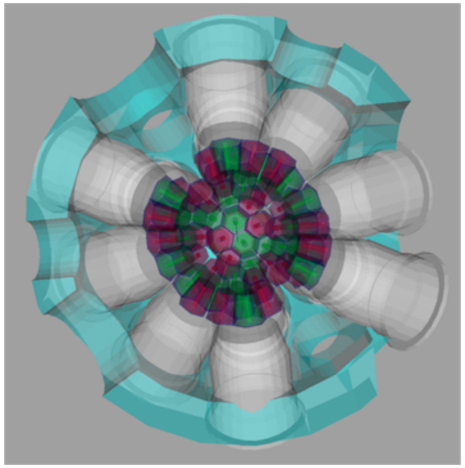


GRETA science reach based on known performance

Detailed GEANT4 simulation for GRETINA
(Lew Riley, Ursinus College)







Simulations reproduce source and in-beam spectra

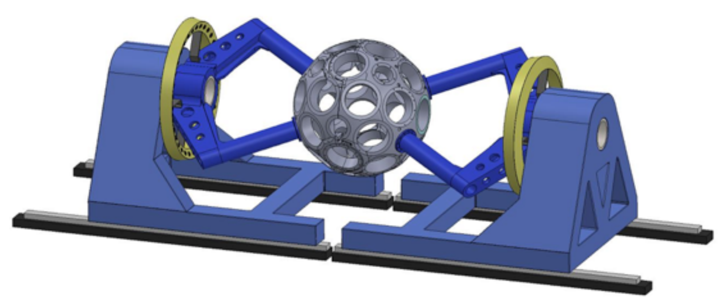
- Essential tool to extract physics with GRETINA
- Provides basis for extrapolation to GRETA

The GRETA Project

Full GRETA System (4π solid angular coverage) has 30 Quad Detector Modules – each Module has 4 crystals. These120 crystals covers 80% of a complete sphere.

The GRETA Project will deliver

- 18 Quad Detector Modules, which will be combined with the 12 Quad Detector Modules used in GRETINA
- New Electronics (digitizers, filter board), Computing (computer cluster, storage) for all 30 Detector Modules
- New mechanical structure for a full 30-module sphere



Preliminary Key Performance Parameters (KPP)

- Objective KPPs are the project goals as supported in the proposed resource loaded schedule and cost
- GRETA Threshold KPPs define the minimum performance needed to to satisfy mission need and CD-4 project completion

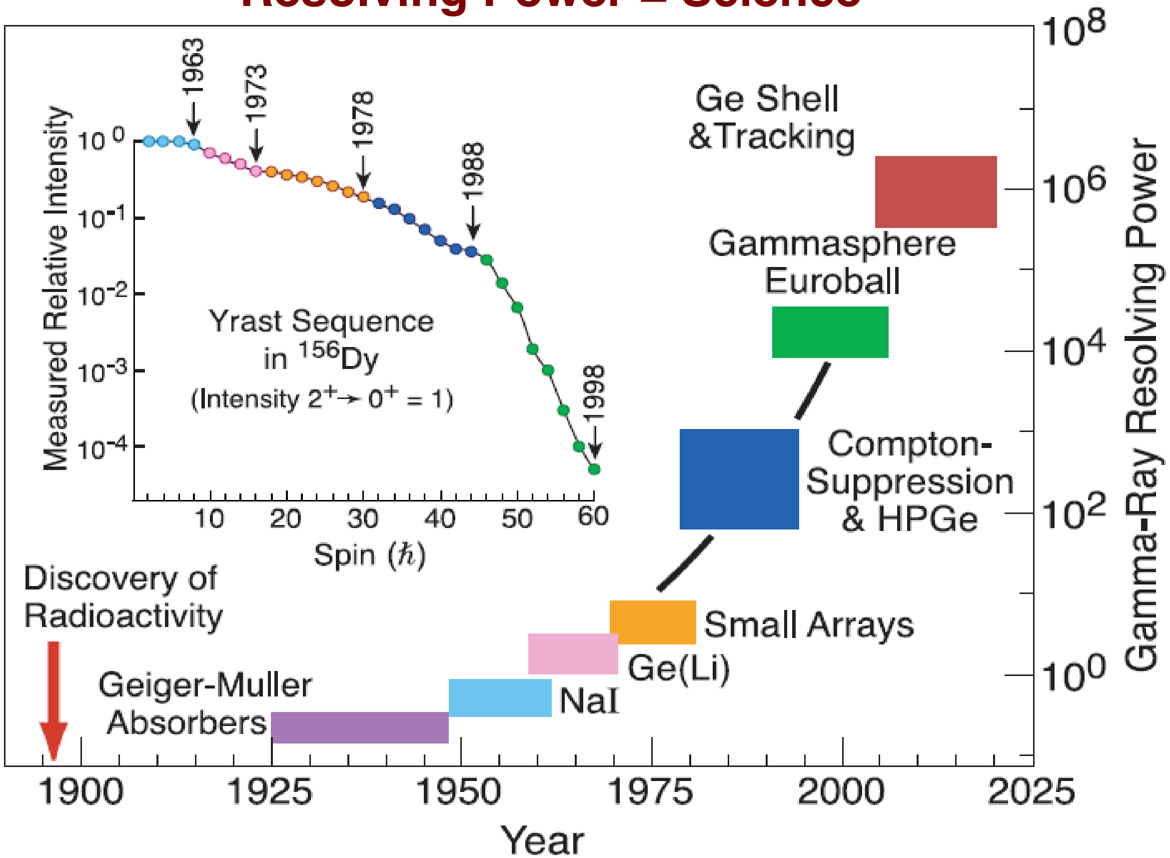
System	Parameter	Threshold KPP	Objective KPP
Detectors	Procurement and Acceptance	Accept 16 Quad Detector Modules	18 Quad Modules
Electronics	Signal Digitization	Deliver digital signal processing electronics to instrument 30 Quad Detector Modules. Provide preamplifier waveforms at ≥ 100 Mega samples/s	Same
Computing	Event Processing	2000 signal decomposition calculations per crystal/s	4000 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 sytems performance	Array energy resolution ≤ 3.0 keV	Same

Resolving power provides a quantitative measure of array capabilities and performance

The science reach of a γ-ray tracking array can be expressed in terms of the effective resolving power (RP)

Depends on Efficiency (ε); Peak-to-Total (P/T); Resolution (δE)

Resolving Power = Science



How resolving power works

Key parameters:
Efficiency (ε); Peak-to-Total (P/T); Resolution (δE)

M.A. Deleplanque et al., NIM A 430 292 (1999)

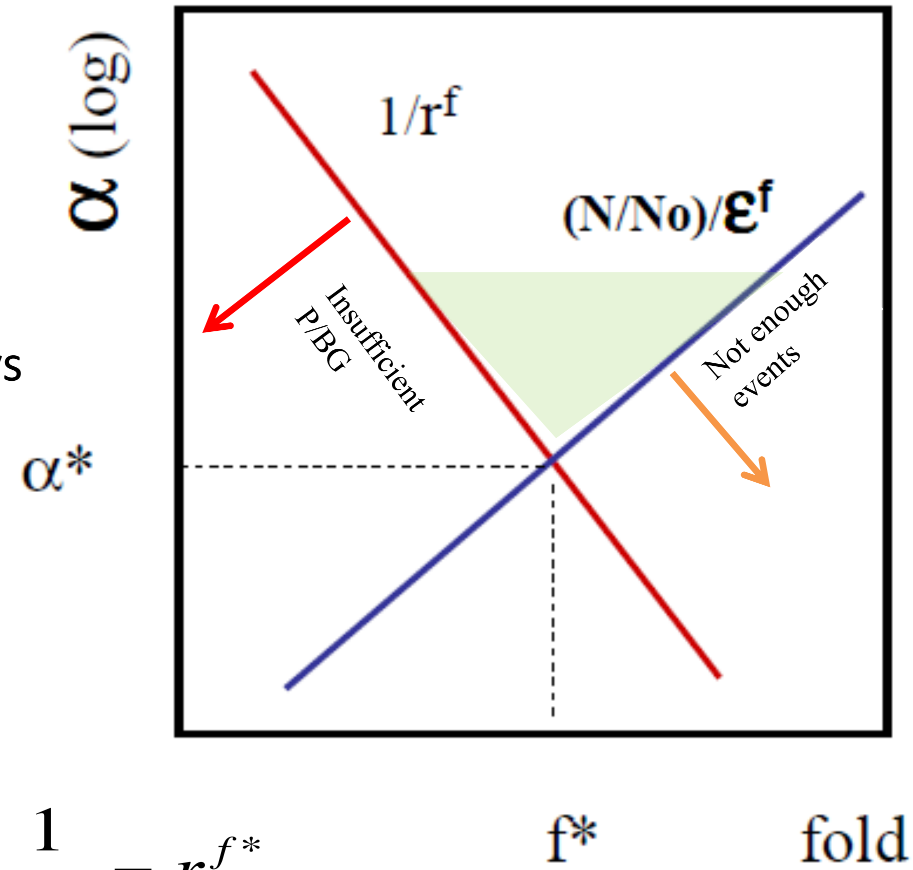
Define Array Sensitivity Parameter (*r*)

$$r \approx \left(\frac{SE}{\delta E}\right)\left(\frac{P}{T}\right)$$

$$\alpha = 1/r^f$$ f = number of γ rays

Counting Statistics

$$N = \alpha N_o \varepsilon^f$$



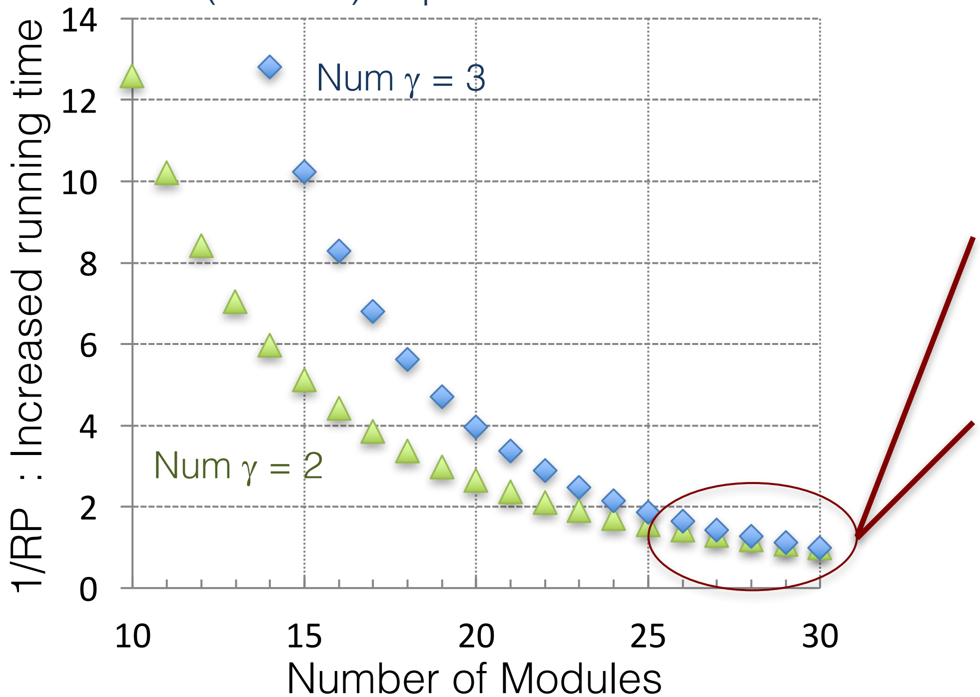
The resolving power is $$RP = \frac{1}{\alpha^*} = r^{f^*}$$

Note: r >1, ε<1

How resolving power changes with the number of detectors

Reduced resolving power directly equates to increased running time

Plot of 1/RP as a function of the number of Detector Modules for FRIB reaccelerated beam (Coulex) experiments



% Increase in experiment running time relative to the full 30 Quad Module Array

Num. γ detected	30 Quad Modules	28 Quad Modules	26 Quad Modules
1	*1*	*4%*	*8%*
2	*1*	*10%*	*20%*
3	*1*	*22%*	*51%*

18 ⟶ 16 ⟶ 14

Number of Modules delivered by the GRETA project

Threshold KPP's support full GRETA program

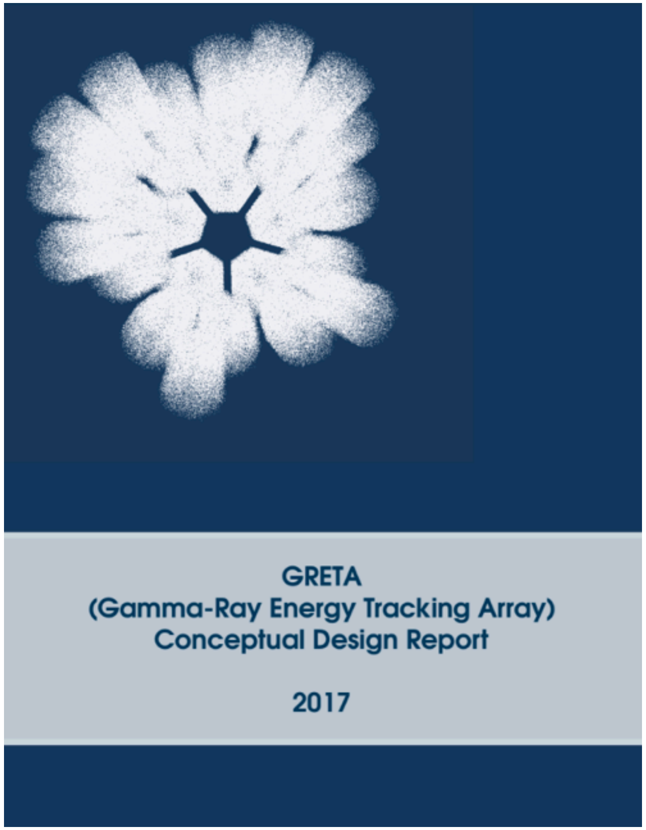
For a "2-module-reduction" (30 to 28), GRETA can meet its science capabilities, but will require longer running times per measurement

Conceptual Design

The proposed baseline design for GRETA is described in the Conceptual Design Report

- Detector Geometry and Segmentation
- Digital Electronics
- Computing
- Mechanical

- R&D and technology down-selects (alternatives) were carried out as part of the GRETINA project and verified during its operation



http://greta.lbl.gov/

Science case drives the functional requirements

- Science case for GRETA (outlined in CDR and white paper) determines the required array performance

CDR Ch. 4.2

Full Energy Efficiency (Add-back)	$\geq$ 30% at 1.33 MeV
Intrinsic Energy Resolution	$\leq$ 2.5 keV at 1.33 MeV
Average Position Resolution	$\leq$ 2 mm $\sigma_{x,y,z}$
Count Rate (per crystal)	$\geq$ 50,000/second
Peak-to-Total	$\geq$ 50% at 1.33 MeV

- Most demanding cases in each aspect were identified and evaluated
  - Fast beams (towards the neutron drip line – ^{60}Ca)
  - Reaccelerated beams (Coulomb Excitation – ^{220}Ra)
  - Intense beams (High multiplicity – ^{108}Cd)

Array performance determines system requirements

Detector Systems Requirements
- Deliver 18 Quad (4-crystal) Detector Modules with geometry, segmentation and mechanical tolerances consistent with existing GRETINA detectors.
- Ensure an average photopeak efficiency of 0.15% and 0.16% at 1.33 MeV for A-type and B-type crystal geometries respectively.
- Ensure an intrinsic detector resolution of $\leq$ 2.5 keV (FWHM) at 1.33 MeV.
- Ensure signal (preamplifier) rise-time $\leq$ 50 ns and noise $\sigma \leq 7$ keV (full bandwidth).

Detectors

Electronics System Requirements
- Deliver digital signal processing electronics to instrument 30 Quad Detector Modules, capable of digitizing detector preamplifier signals at 100 MHz sampling frequency, over a dynamic range up to 25 MeV, maintaining the intrinsic detector energy resolution of $\leq$2.5 keV (FWHM) at 1.33 MeV.
- Ensure integral (differential) non-linearity $\leq \pm$ 0.01% (1%) as measured in the final energy spectrum with a nominal gain of 0.3 keV/channel over 10 MeV.
- Ensure synchronous ADC sampling across the array.
- Provide a global timestamping mechanism to allow event reconstruction including external detector systems.
- Provide real-time energy and timing filters and waveform windowing.
- Provide a trigger system capable producing a fast trigger output (< 500 ns) to auxiliary detectors, identifying physics events for readout and incorporating trigger inputs from external detector systems.

Electronics

Array

Full Energy Efficiency (Add-back)	$\geq$ 30% at 1.33 MeV
Intrinsic Energy Resolution	$\leq$ 2.5 keV at 1.33 MeV
Average Position Resolution	≤ 2 mm $\sigma_{x,y,z}$
Count Rate (per crystal)	$\geq$ 50,000/second
Peak-to-Total	$\geq$ 50% at 1.33 MeV

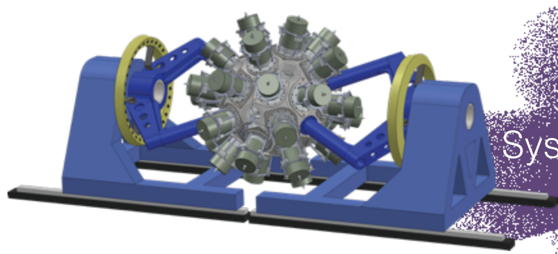
Computing

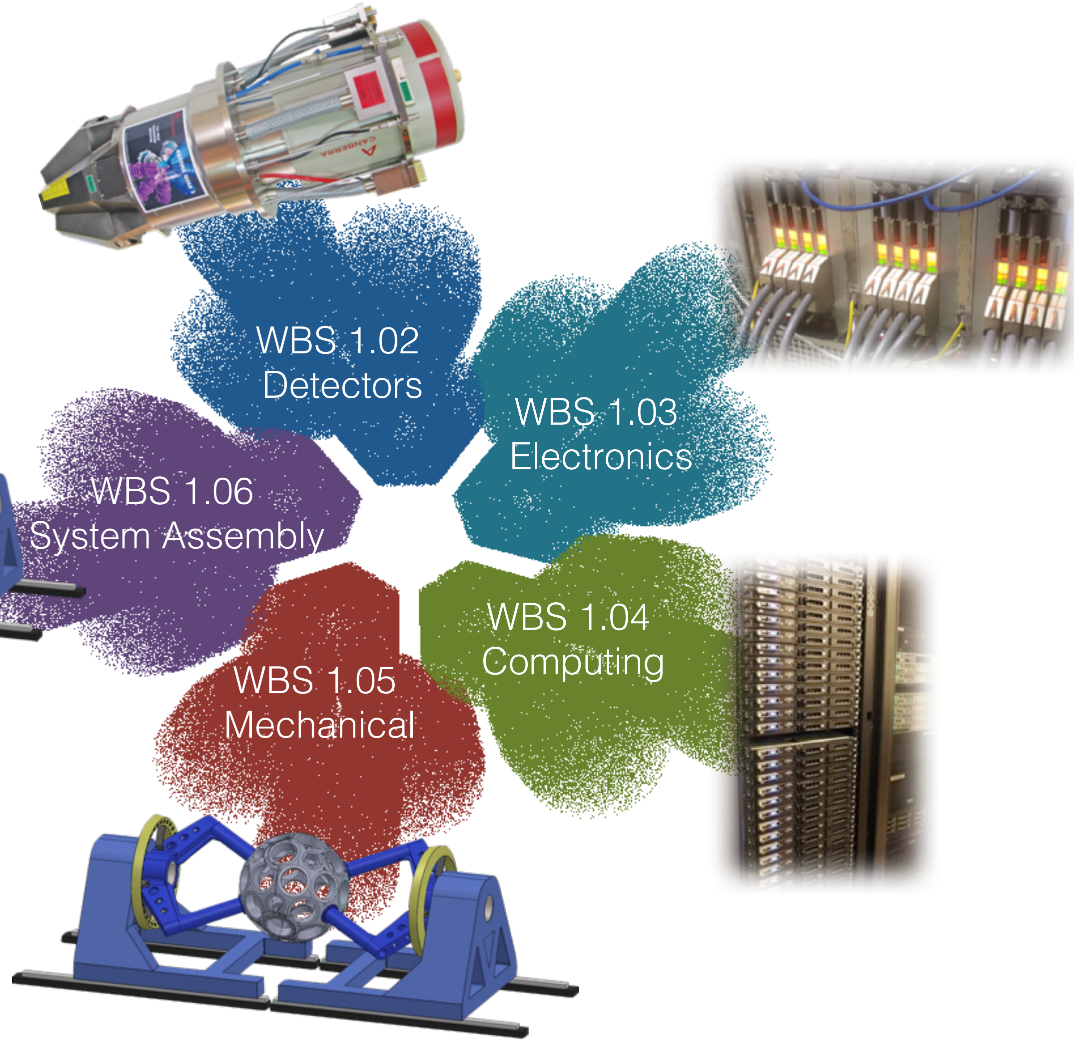
Computing Systems Requirements
- Support an incoming data rate of 32 MB/crystal/s, corresponding to a triggered data readout rate of 4000 γ-ray decompositions/crystal/s.
- Provide computing resources to perform 480,000 signal decomposition calculations per second.
- Support global event building and disk I/O at 500 MB/s.
- Provide local data storage of order 1 PB for experimental operations.
- Provide controls and monitors for approximately 50,000 channels with a nominal latency of 200 ms.

Mechanical

Mechanical Systems Requirements
- Provide a detector support structure capable of holding up to 30 detector modules, rotating, and translating perpendicular to the beam axis.
- Provide precise and reproducible placement of detector modules in all mounting positions, with tolerances and accuracy matching those obtained in GRETINA.
- Provide a detector liquid nitrogen filling system and a detector/electronics liquid cooling system.
- Ensure design compatibility with planned host sites and auxiliary instruments.

GRETA Project WBS: Technical Subsystems





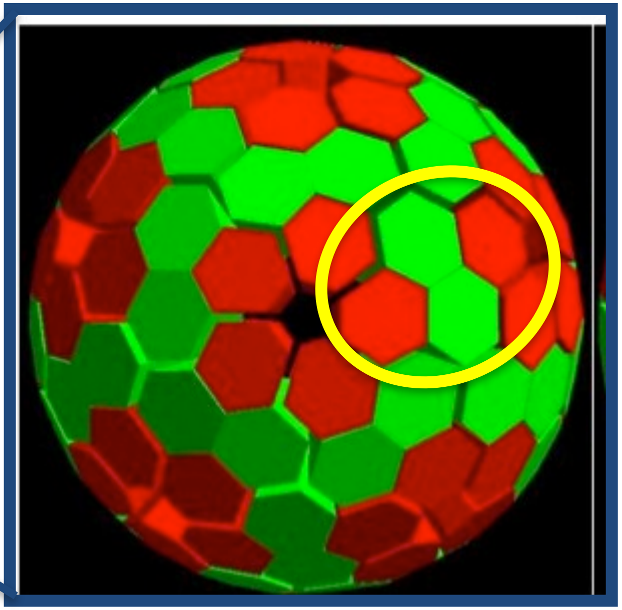
+ Interfaces with
FRIB and ANL

Why is the GRETA Module a Quad?

Geodesic Tiling

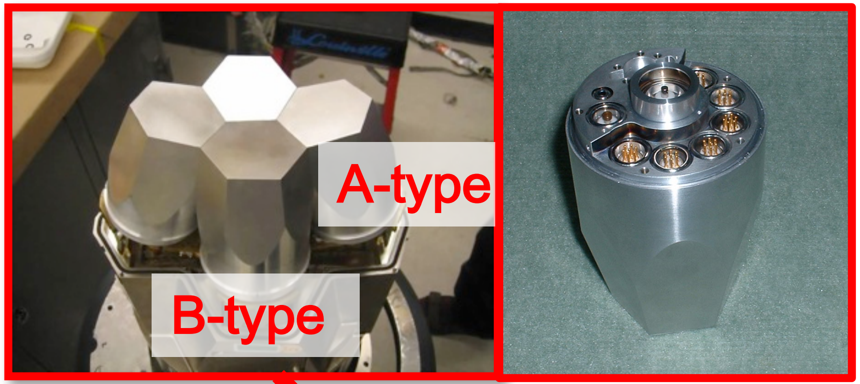
12 pentagons and …

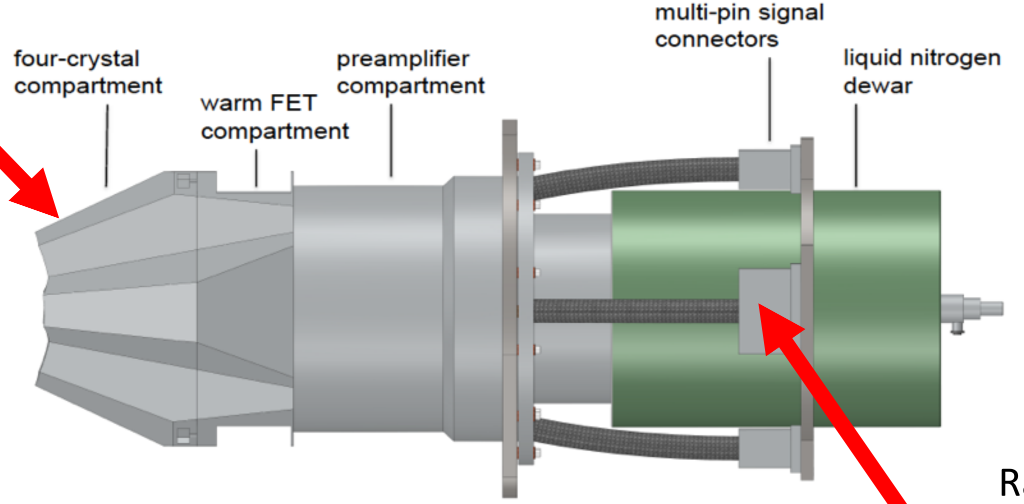
	Number of hexagons	Number of different hexagonal shapes
	80	2 (20, 60)
GS	110	3 (20, 30, 60)
	120	**2 (60, 60)**
	150	3 (30, 60, 60)
AGATA	180	3 (60, 60, 60)
	200	4 (20, 60, 60, 60)



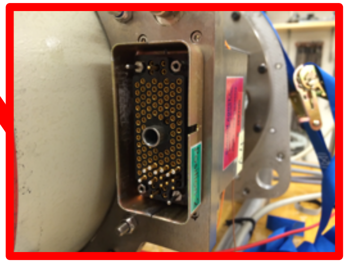
One Module type

Detector Module





Radiall connector



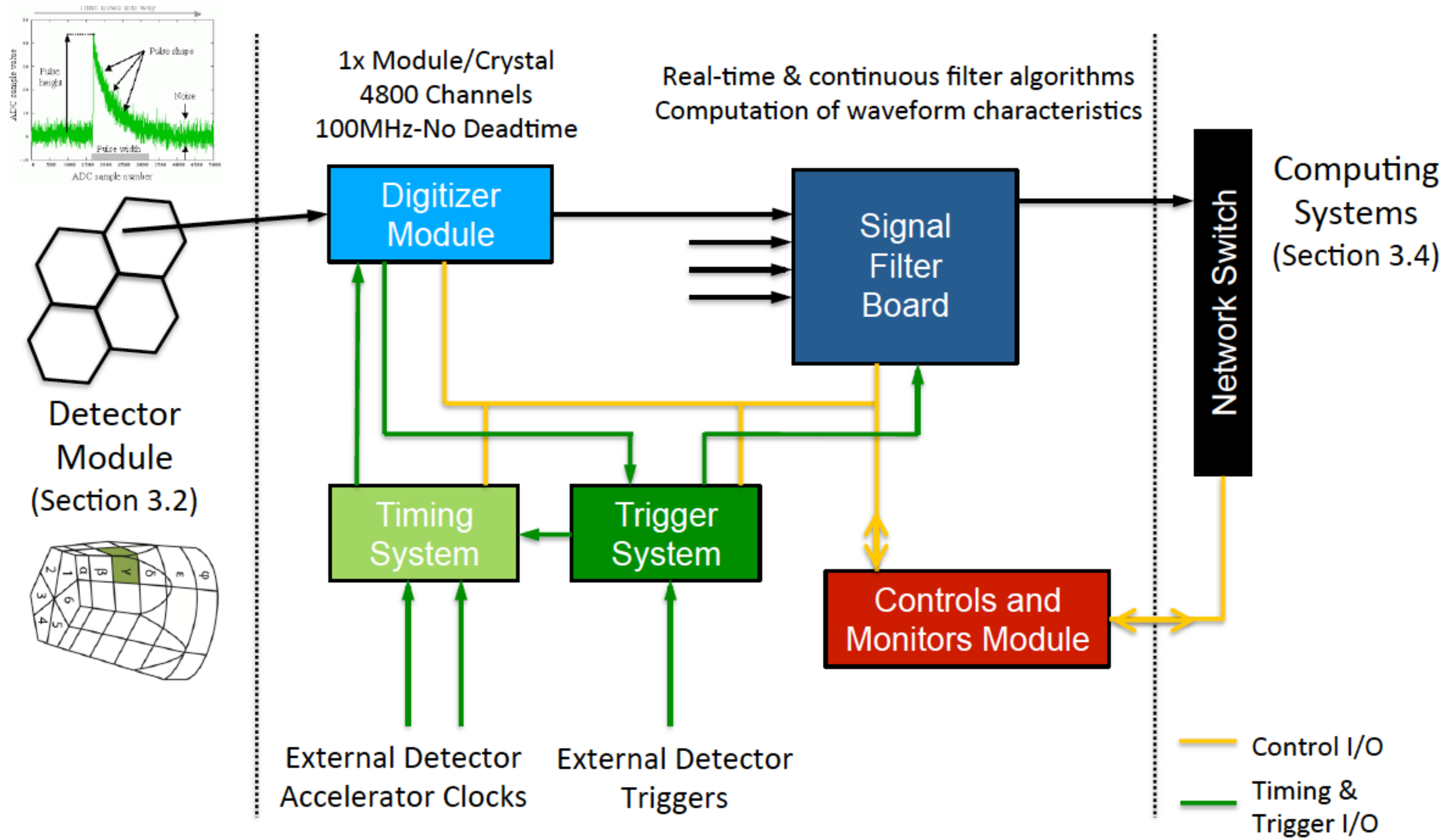
Electronics Systems

- Digitizer Modules & Interface Box
  - Instrument all segments and central contacts for 120 crystals
- Signal Filter Boards
  - Data Processing for 120 crystals
- Trigger System
  - Trigger decision for GRETA & external detectors
- Timing System
  - Synchronous timing for all
- Key Interfaces
  - Detector Modules
  - Computing Systems

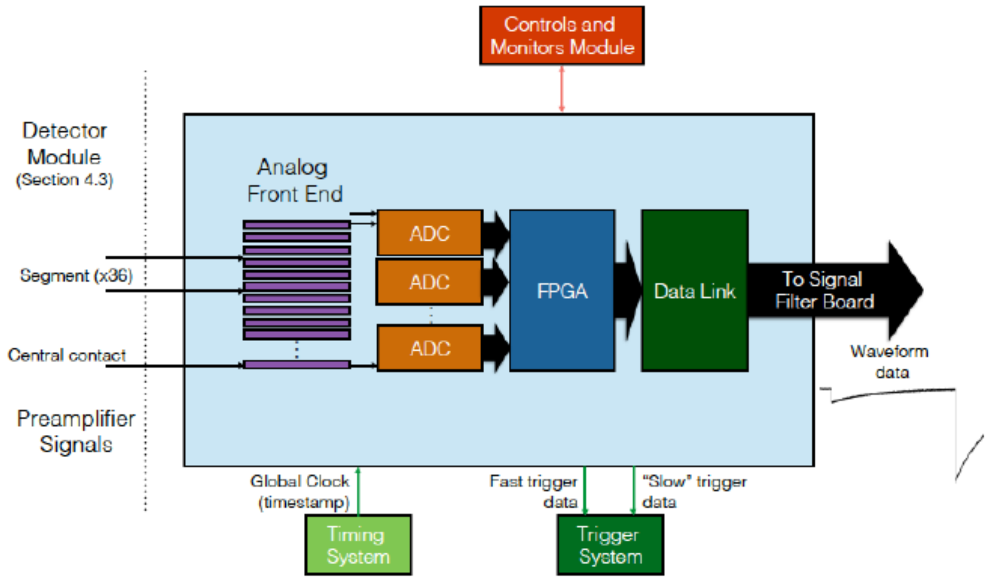
Utilize lessons learned on GRETINA in all new designs

Proposed Conceptual Design

Separate ADC and Energy Filter (FPGA) – New approach
Trigger and timing could be based on GRETINA design scaled to GRETA



Digitizer Module Design



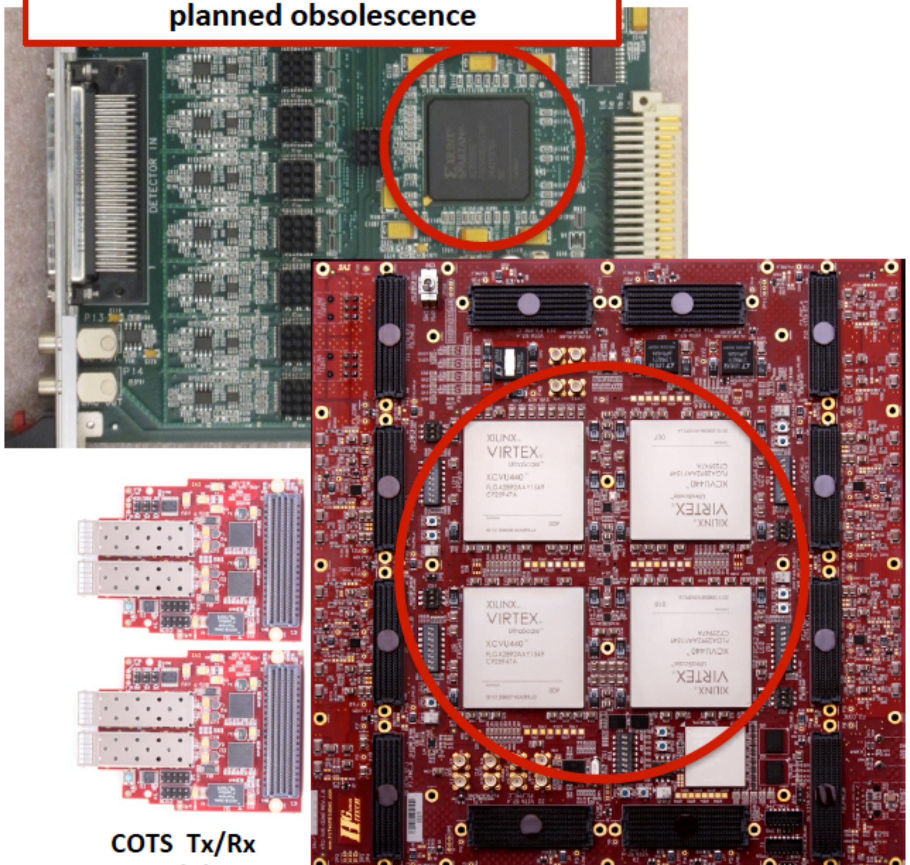
- Digitizer Module
  - Compact and low-power ADC components with good linearity performance
  - High-bandwidth fiber links for high data transfer rate to meet throughput requirements
  - Provide "fast" and "slow" trigger information to the array trigger system

Design will allow digitizer to be placed as close as possible to the detectors, minimizing transmission length of analog signals.

- Identified as the most challenging ES Subsystem
- Design starts early & ~30% of ES Design budget
- Schedule provides a full year + contingency for design of the Digitizer Module

Signal Filter Board

GRETINA: Signal filter FPGA (circa 2006) does not meet GRETA data throughput requirement and is near planned obsolescence



COTS Tx/Rx Modules

Example of COTS with 4 FPGAs per Module
Possible to implement 1 Detector Module per Board

- Signal Filter Board
  - Commercial-off-the-Shelf (COTS) hardware
  - Scalable design
  - Meets the data throughput requirement
  - Utilize existing GRETINA VHDL code base as launching platform
  - ~20% of ES Design Budget
    - Use of COTS hardware
      - Reduces fabrication risk
      - Provides upgrade path
    - Allows Firmware development independent of Digitizer development

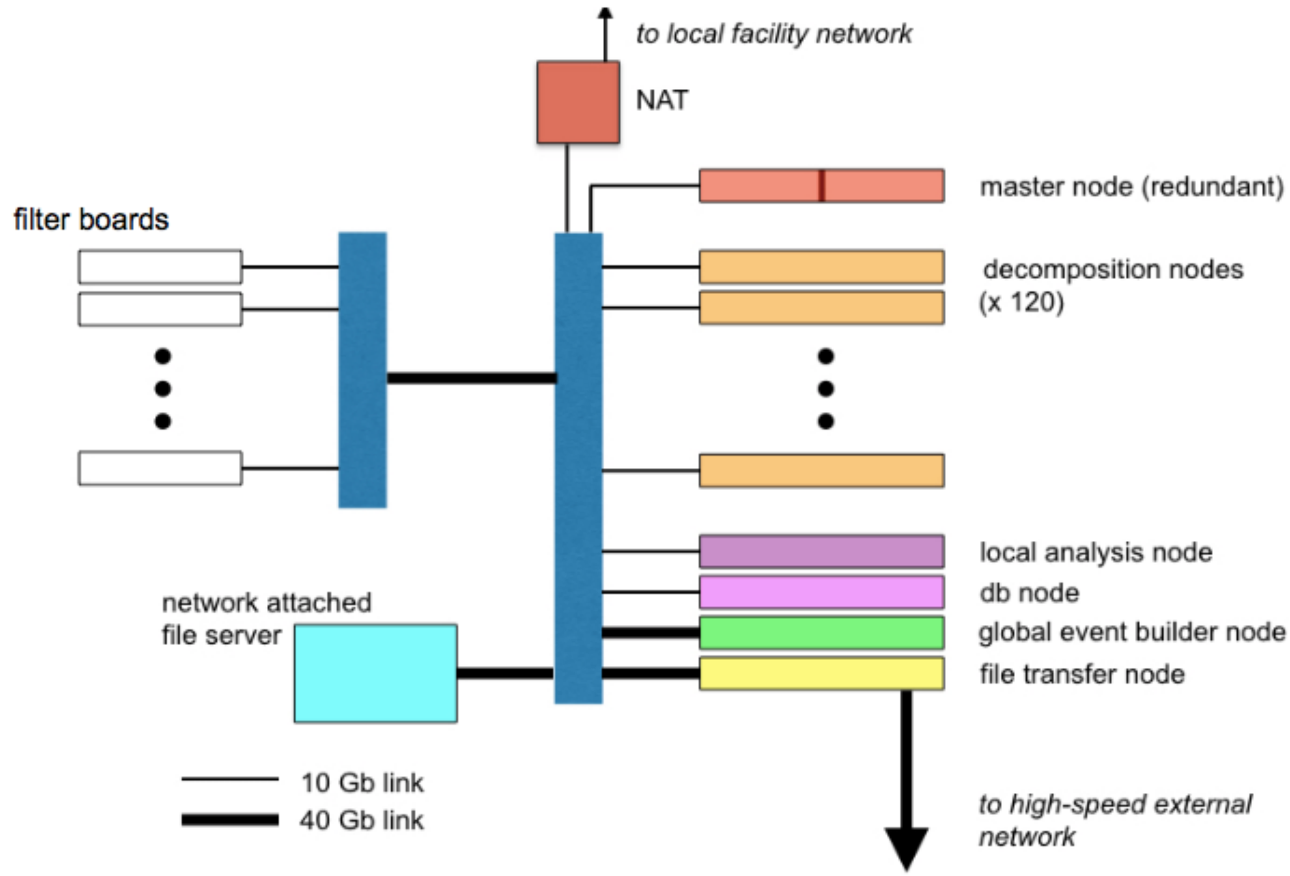
GRETA Computing – scaling from GRETINA

GRETINA cluster installation for first NSCL physics campaign

- **×3 crystals**
- **×4 readout rate/crystal**

- remove bandwidth limitations associated with VME readout bus
- higher performance computing cluster, global event builder, file store

Computing Systems

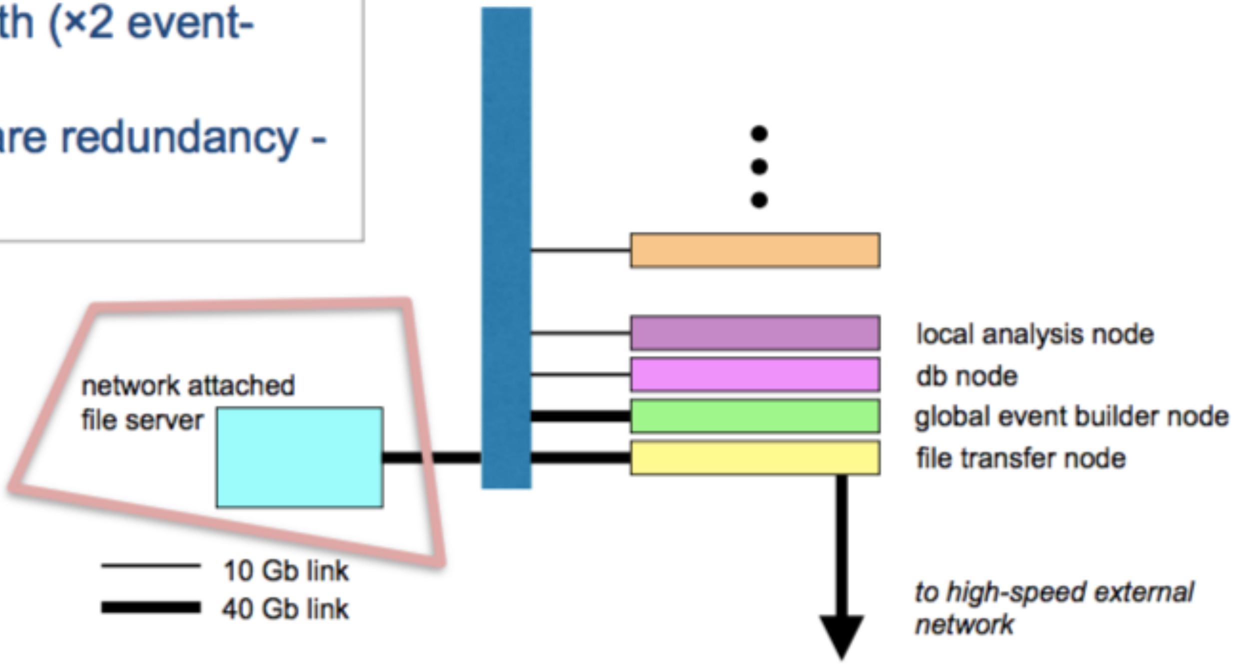


- 40 Gb point-to-point network link/switch
- HPC: ~120 nodes, ~5000 cores (Intel Knights Landing chip)
- 1 PB RAID Storage (local)

1 PB Storage: High IO bandwidth

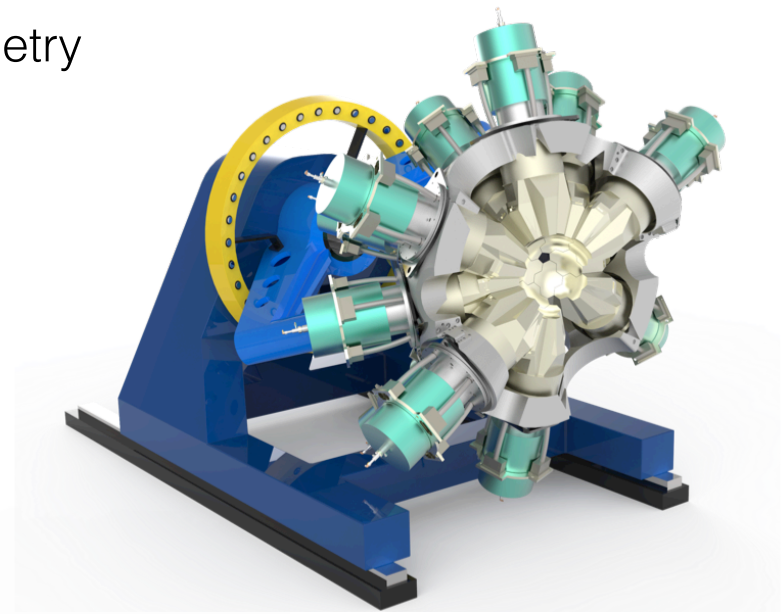
- Storage of experimental data, calibration data, basis, configuration files
- Key requirements:
  - 1 PB capacity: three 5-day mode-2 (interaction points) sets + mode-3 (waveform) sets [1 day equivalent]
  - 1 GB/s I/O bandwidth (×2 event-builder)
  - high level of hardware redundancy - vital subsystem

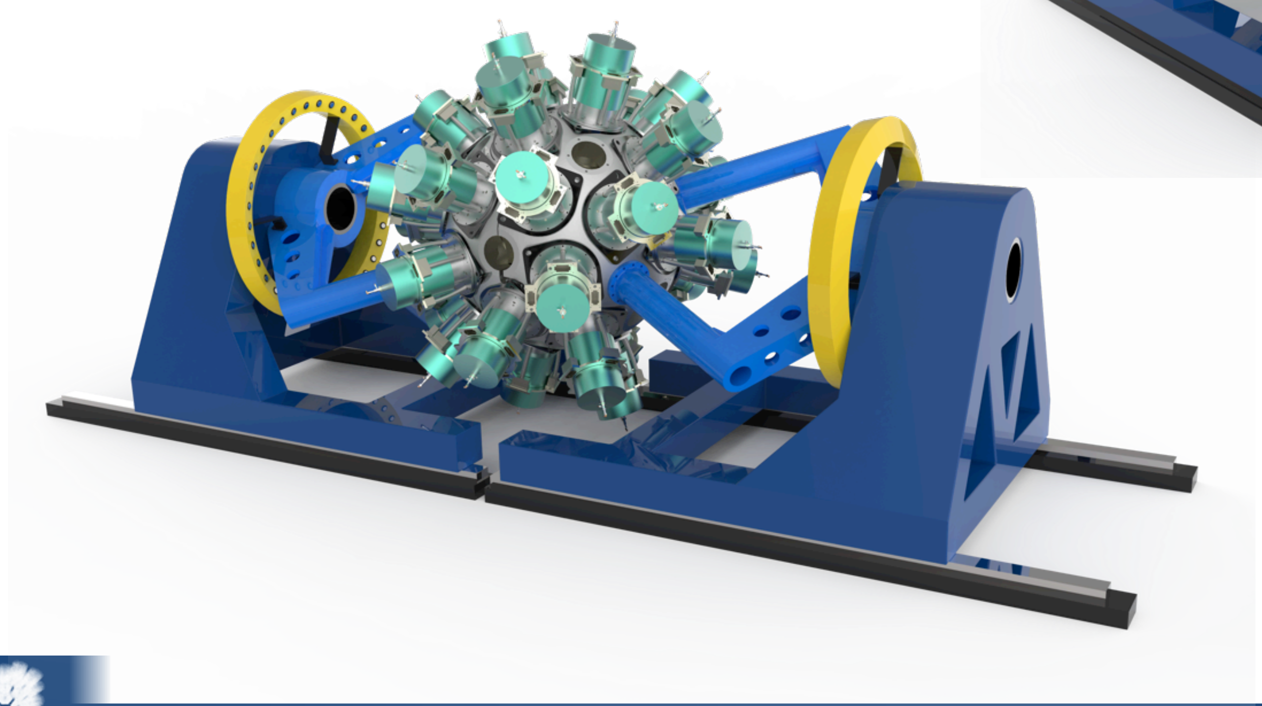
storage system similar to Dell Compellent SC8000



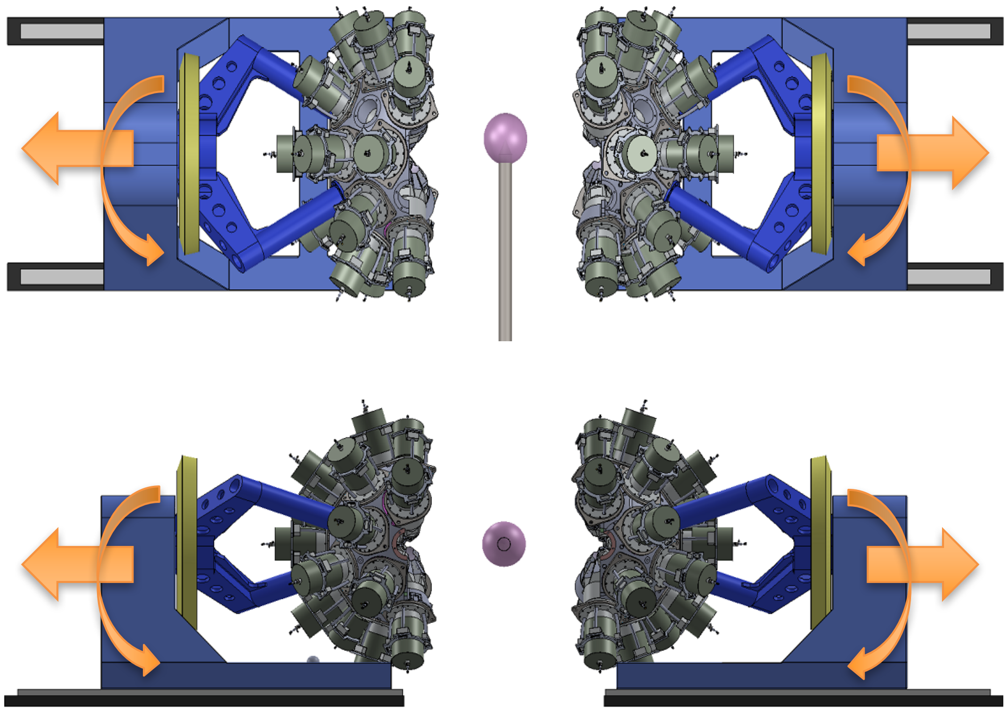
GRETA Frame and Support Structure

- 30 Quad modules in 4π compact geometry
- translation and rotation capability
- removable section for a ring of five downstream Quad Detectors.

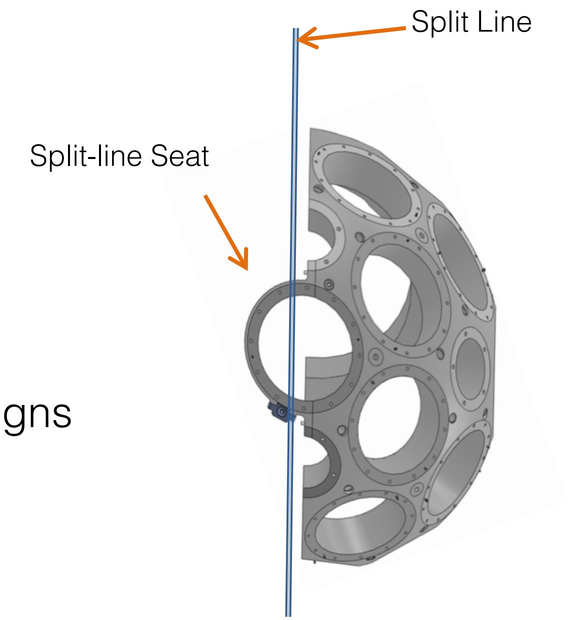




GRETA Frame and Support Structure



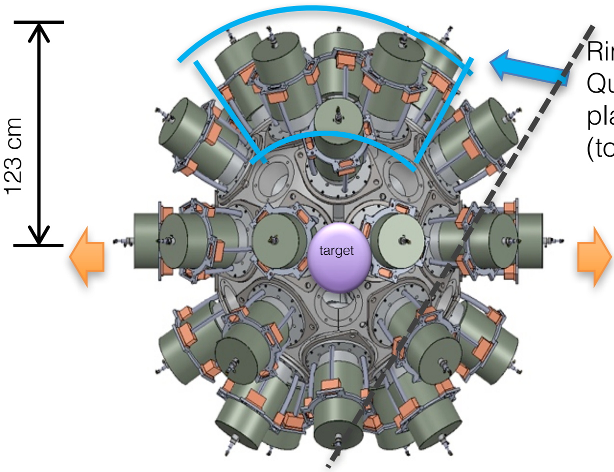
> "In summary, largely based on the substantial operational experience with GRETINA (and to some extent with Gammasphere), the design of the Mechanical Systems part of the GRETA scope appears to be mature, advanced…"
>
> *- GRETA Technical Advisory Committee Conceptual Design Report Assessment 11 April 2017*



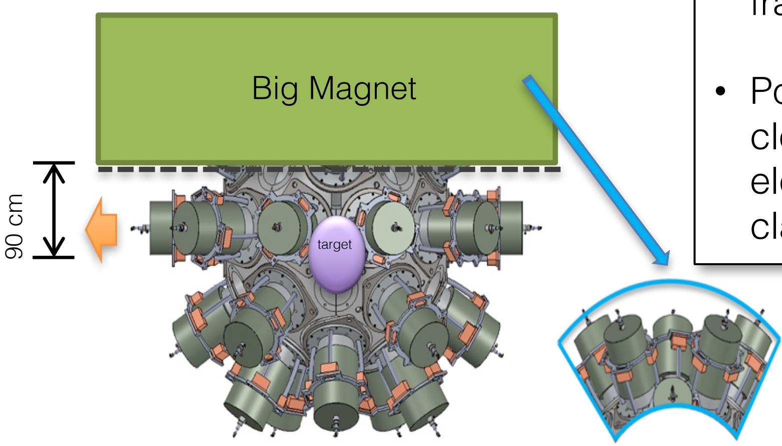
Majority of mechanical support will leverage existing designs

- Hemisphere, Translation & Rotation
- Positioning Detectors
- Alignment
- Installation & Removal

GRETA Support Structure Flexibility



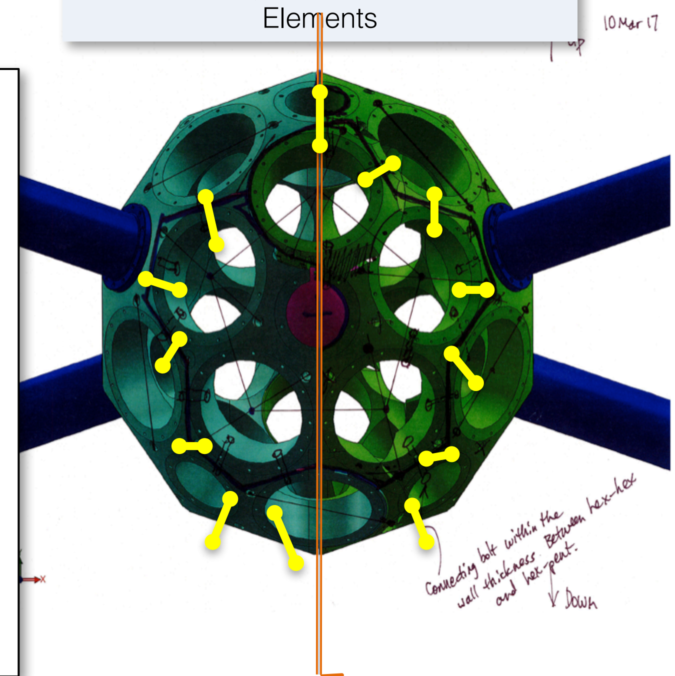
Ring of five Quads in place (top view)



Ring of five Quads removed with their Support Structure elements

- To accommodate interfaces with spectrometers where the target-magnet distance is constrained GRETA will include an option to remove the forward ring of Quad modules (akin to GRETINA frame)
- Position target ~ 33cm closer to the first ion-optical elements for specific classes of experiments

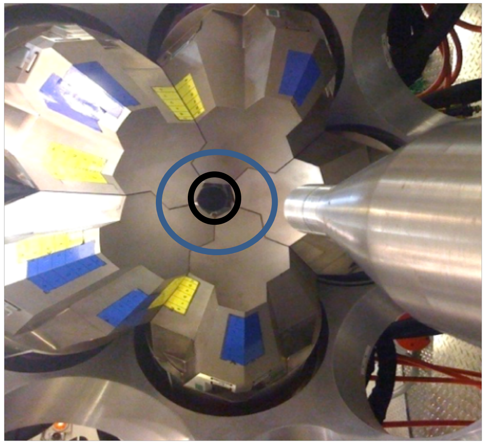
Concept for Removable 5-Quad Detector Ring and Support Structure Elements

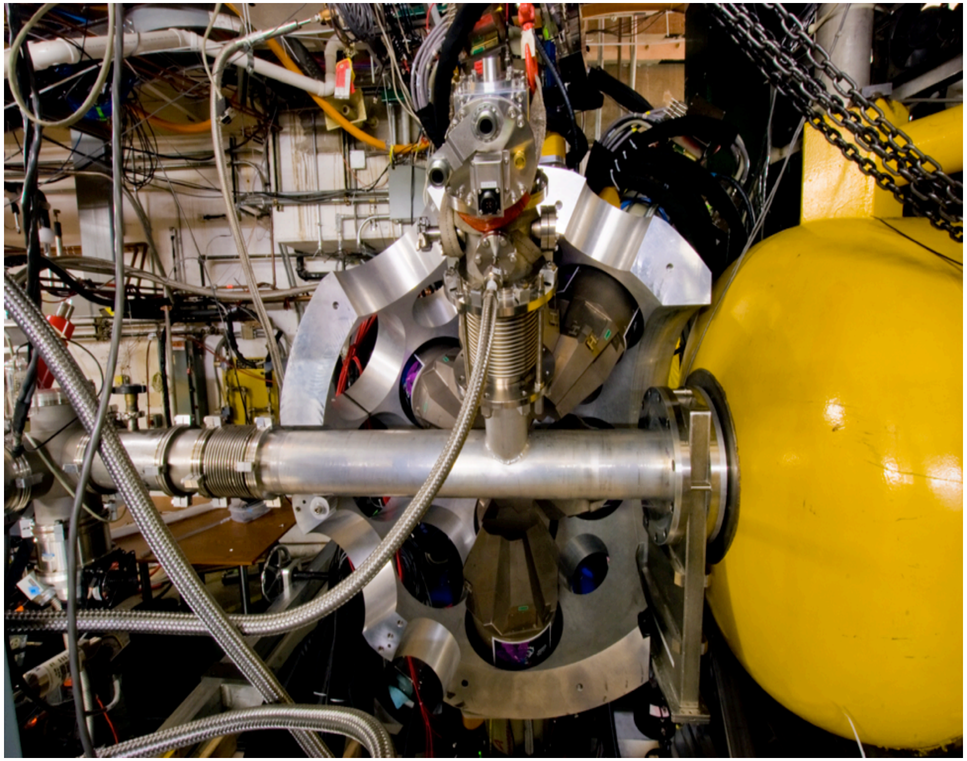


Midplane Split Line

Detectors and Interfaces: Target Location Access

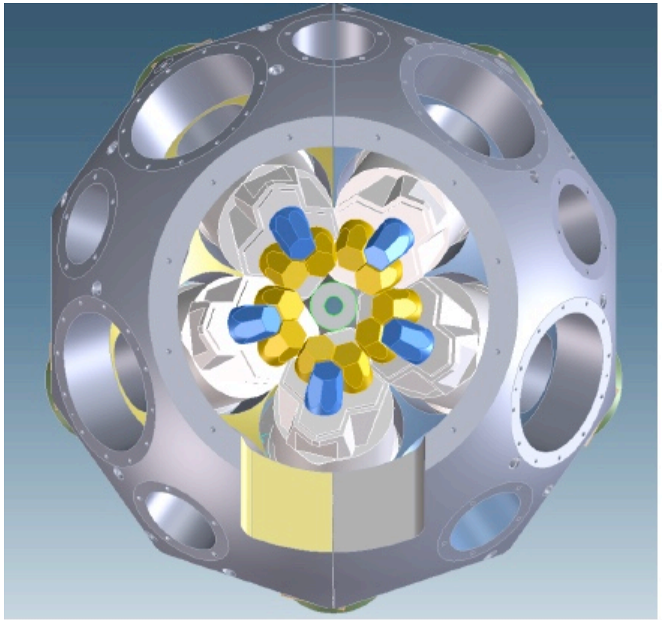
- For experiments where larger beam pipes are required (dispersion matching at the HRS) or significant infrastructure must be fed through to the target position (LH_2 target), *Quad Modules would need to be removed or pulled back*.
- In a fully-populated GRETA geometry, only access to target position (center of array) is through pentagon holes.
- Pentagon hole limits pipe diameter to 5cm

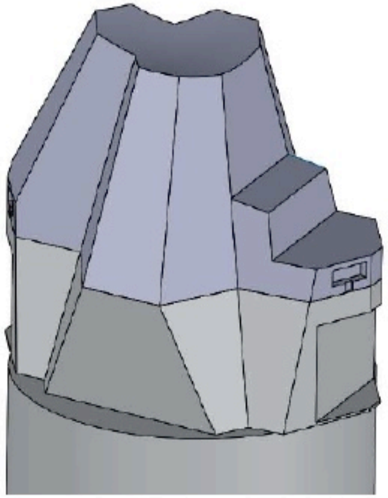




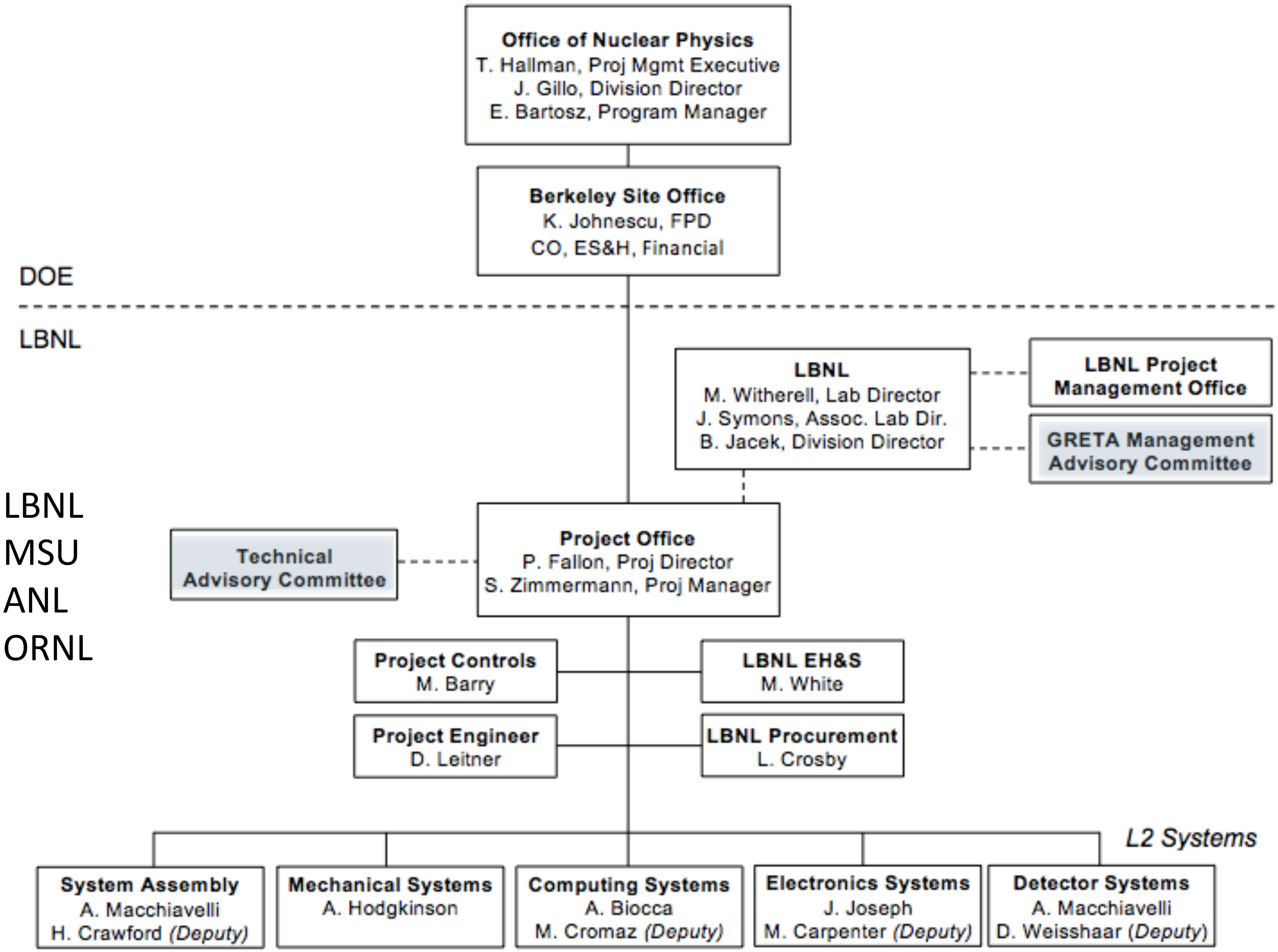
Detectors and Interfaces: Triplet End-Cap

- Demand to maintain high-efficiency of array drives inclusion of a Triplet Module end-cap for GRETA.
- With removal of only 5 crystals surrounding a pentagon hole, ~12 cm diameter pipe can be accommodated.
- Maintains efficiency while expanding and ensuring scientific capabilities.





Project Organization



- LBNL
- MSU
- ANL
- ORNL

Project Advisory Committees

NSD Director ⟷

GRETA Management Advisory Committee
Thomas Glasmacher (FRIB)
David Dean (ORNL)
Kawtar Hafidi (ANL)

GRETA Technical Advisory Committee
David Radford, chair (ORNL)
Andrew Boston (Liverpool)
Alexandra Gade (NSCL/FRIB/MSU)
Carl Lionberger (ORNL)
John Pierre Martin (Montreal)

⟷ GRETA Project

GRETINA/GRETA User Community

Over 200 active Users

GRETINA/GRETA Users Executive Committee (GUEC)

Heather Crawford, chair (LBNL)
Hiro Iwasaki (MSU/NSCL)
Darek Seweryniak (ANL)
Lew Riley (Ursinus)
Mark Riley (FSU)

GUEC is the link between the scientific community and the GRETA project

- Coordinates working groups
- Organize meetings, newsletters

http://gretina.lbl.gov/ http://greta.lbl.gov/

Technical and Community Input

GRETA Technical Advisory Committee

David Radford, chair (ORNL)
Andrew Boston (Liverpool)
Alexandra Gade (NSCL/FRIB/MSU)
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↔ GRETA Project ↔

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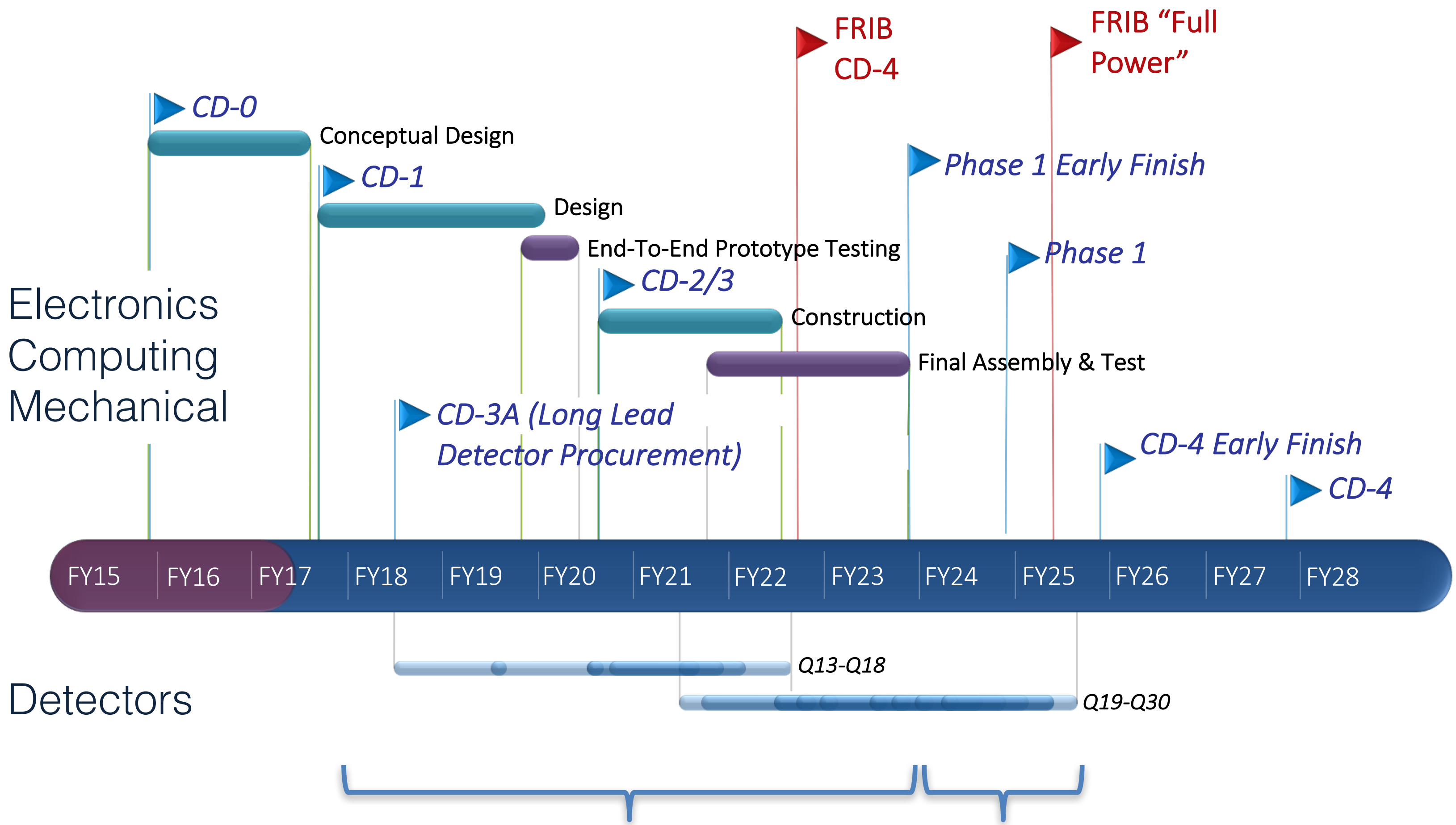
Phased approach to optimize delivery of a γ-ray tracking array capability for FRIB



Phase 1	Phase 2
• Final Electronics, Computing and Mechanical systems for 30 Quad Detector Modules • Subset of Detector Modules (6 or more)	• Accept the remaining Quad Detector Modules (For a total of 18)

Next Steps – upcoming year

- Completed conceptual design phase
  - CD-1 review held April 25-27
    - Successful, positive endorsements, and recommendations required for CD-1 have been done
    - CD-1 approval anticipated soon

- Following CD-1, key next step: Requirements and Interfaces for detailed design

- FY18 funding not yet set (large range of possibilities), nevertheless it is critical to keep moving forward and as such
  - GRETA project plans to focus on system requirements and interface control documentation and to engage the community
  - Working towards a timeframe for community input/feedback of 6-9 months – via GUEC and working group (implies workshops Fall/Winter)
  - TAC to provide advice and recommendations on design approach

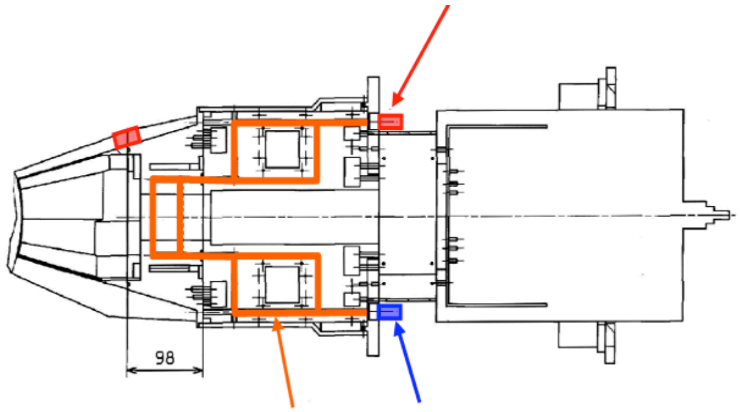
Summary

- GRETA was identified a key detector for scientific discovery at FRIB and ATLAS/CARIBU
  - scientific case has been reviewed and endorsed
  - proposed design is based on proven technology and demonstrated performance (GRETINA)
  - phased schedule optimizes delivery of a tracking array capability for FRIB

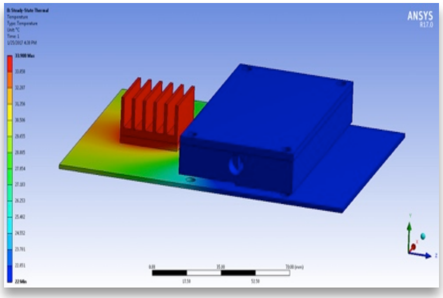
- “passed” CD-1 review (conceptual design; preliminary scope, performance, cost, and schedule), expecting CD-1 approval soon

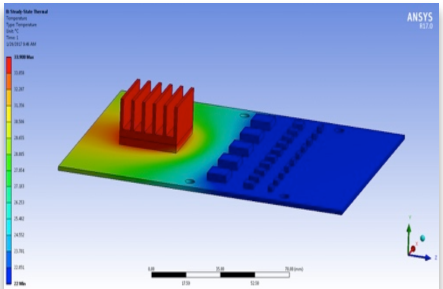
- FY18: focus on system requirements and interface control documentation

Other Mechanical Systems: Cooling



- Liquid cooling system will be used for detector preamp cooling, and expanded to Digitizer modules for temperature-sensitive components





- Detector LN_2 cooling system will be an expansion of the GRETINA fill system

- New manifold design will be required with changes to the support structure