Ultrafast Radiation-Hard Large Volume Gallium Oxide Spectroscopic Scintillators

Amlan Datta*
CapeSym, Inc., Natick, MA, USA

Project Award Number: DE-SC0021476
Period of Performance: 04/04/2022 – 04/03/2024

* datta@capesym.com

Presented Jul 30, 2025
DoE NP PI Meeting

This work was made possible by the support of the DOE Office of Science **Nuclear Physics (NP) program** under award DE-SC0021476.

Program Overview

Program Goal:

Radiation Hard Scintillators for Crystal Calorimetry

Non-Hygroscopic

High-density

Robust

Based on:

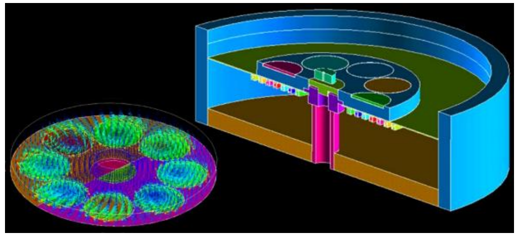
Gallium Oxide (β-Ga_2O_3) Scintillators

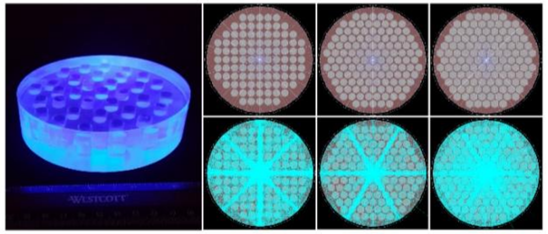
On CapeSym

- Founded 1992
- Employees: 12
- Science + Manufacturing:
  - Materials engineering and processing
  - Crystal growth
  - Materials Characterization
  - Radiation detectors and instruments
  - GEANT4 Scintillation modeling, Thermal modeling.
- Strong participation in a number of US government-supported initiatives:
  - DOE, DHS, DoD, NIH, NASA

CapeSym Commercial R&D Capabilities

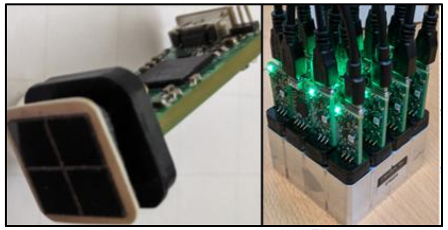
GEANT4 Scintillation Modelling



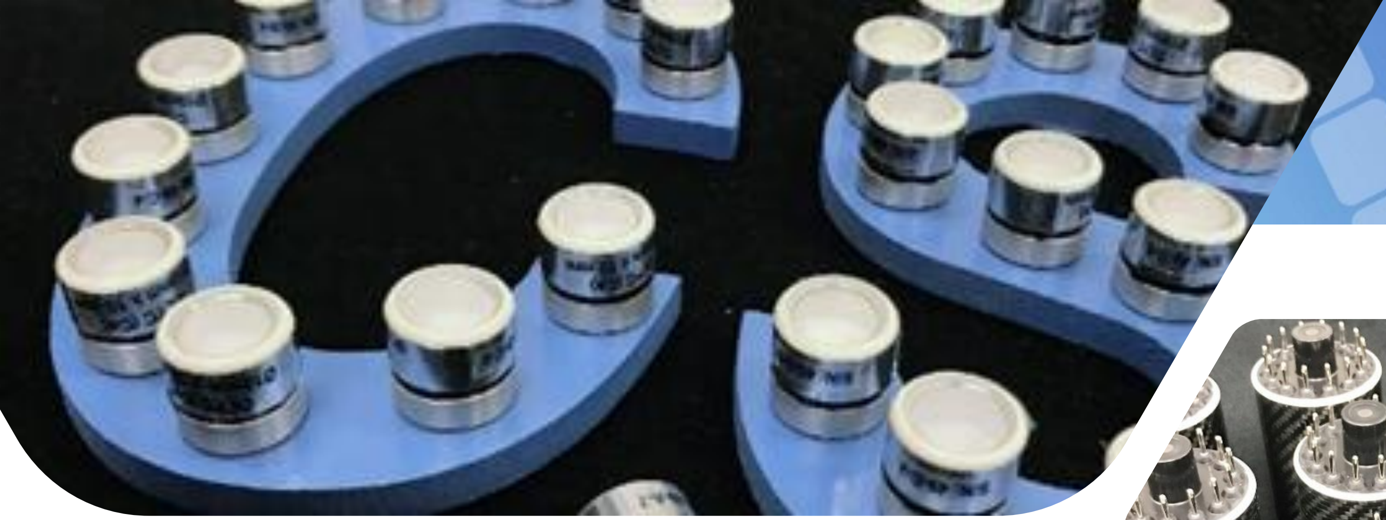


Scintillator Crystal Growth

Radiation Detection Electronics and Instruments Development



Radiation Detection Characterization



CapeSym Manufacturing Capabilities

- Today: ~1000 large size detectors/year
- All process stations + furnaces designed and built at CapeSym
  - Low cost
  - Can scale rapidly – 3 months
- Automated crystal growth, cutting and polishing
- Low moisture glove boxes, multiple gamma sources, DD neutron generator, environmental chamber, oxygen tester
- High-throughput encapsulation process
- Rugged encapsulation with PMTs and SiPM arrays
  - Meets ANSI environmental standards

Program Overview

Program Objectives:

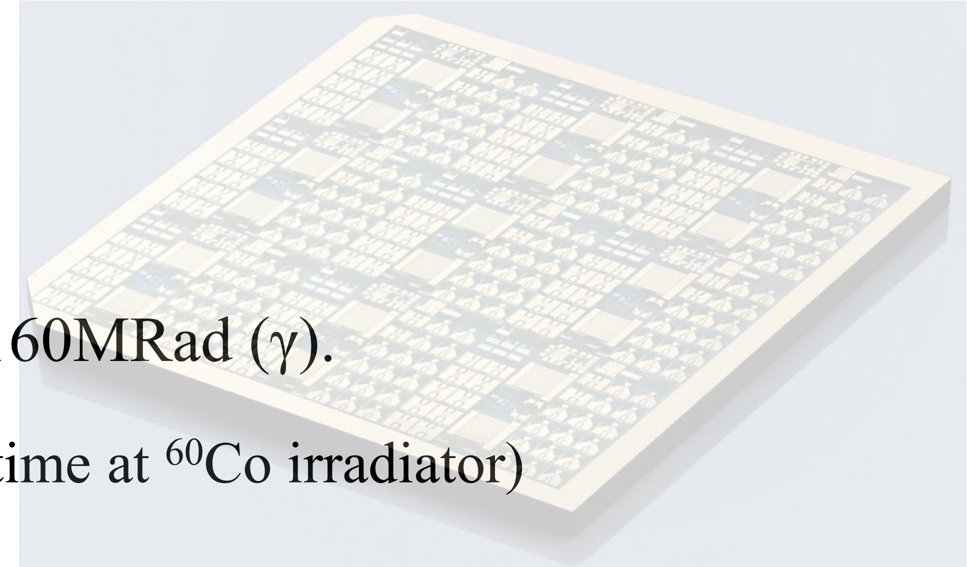
Our primary focus in this work is to pioneer the development of β-Ga_2O_3 scintillators which is expected to redefine the benchmark scintillator properties of current detectors used for crystal calorimetry experiments in nuclear physics:

Next Generation of Scintillators

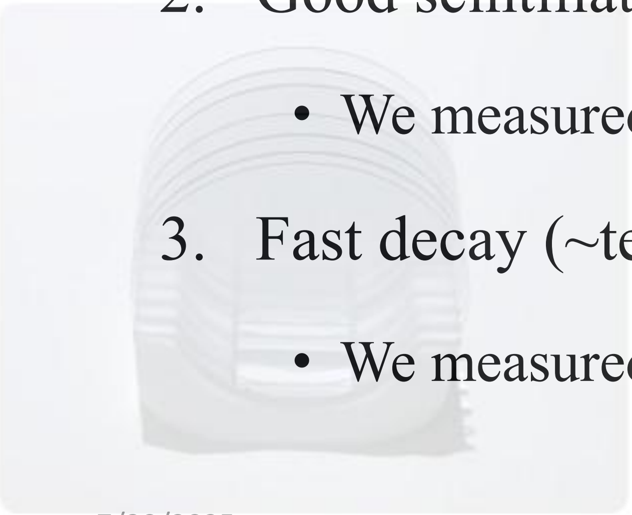
- 01 Radiation Hard
- 02 Ultrafast (<10ns)
- 03 Bright (>5000 Ph/MeV)
- 04 Moderate Energy Resolution (<15%)
- 05 Non-Hygroscopic and Robust

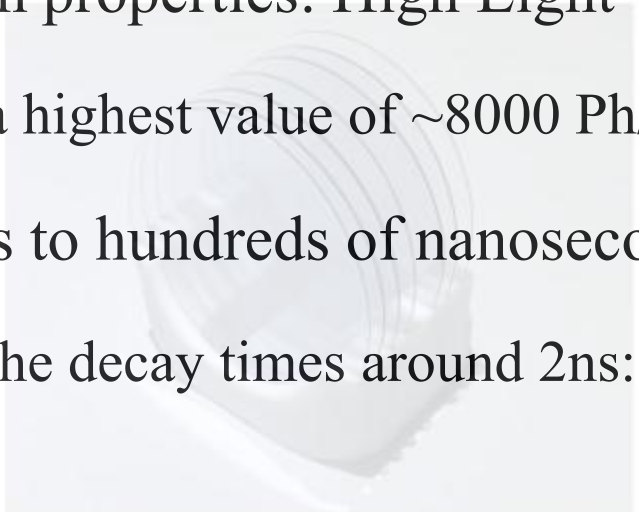
β-Ga_2O_3: Advantages & Promise

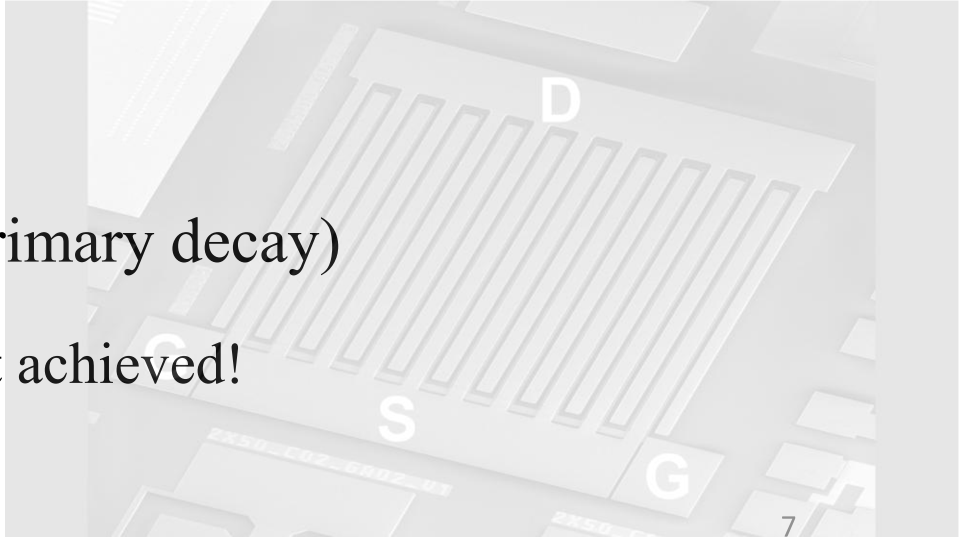
<u>Why β-Ga_2O_3 Scintillator:</u>



1. Extremely radiation hard, demonstrated up to 160MRad (γ).
   - We tested up to 2MRad (About 8 days of beamtime at ^{60}Co irradiator)
2. Good scintillation properties: High Light Yield
   - We measured a highest value of ~8000 Ph/MeV
3. Fast decay (~tens to hundreds of nanosecond primary decay)
   - We measured the decay times around 2ns: target achieved!



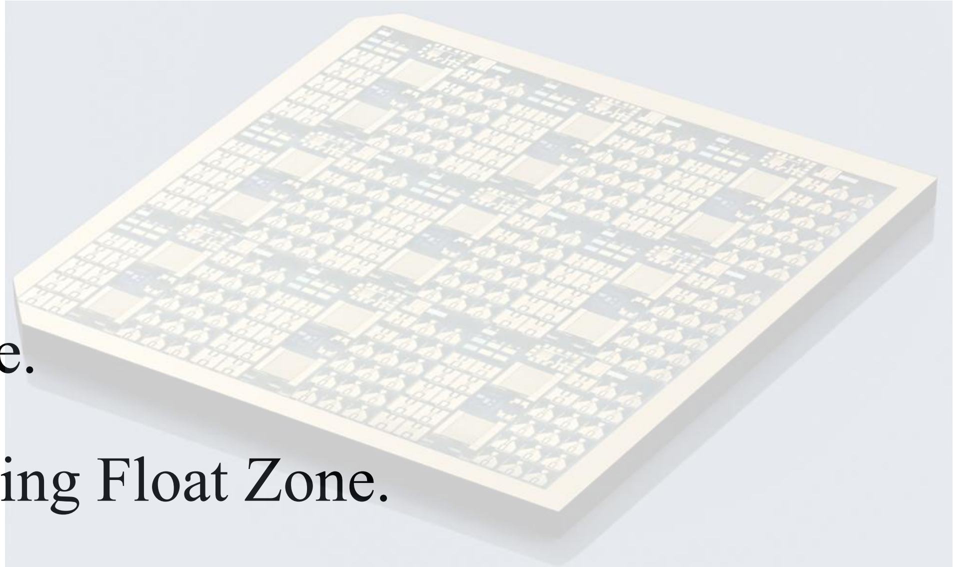


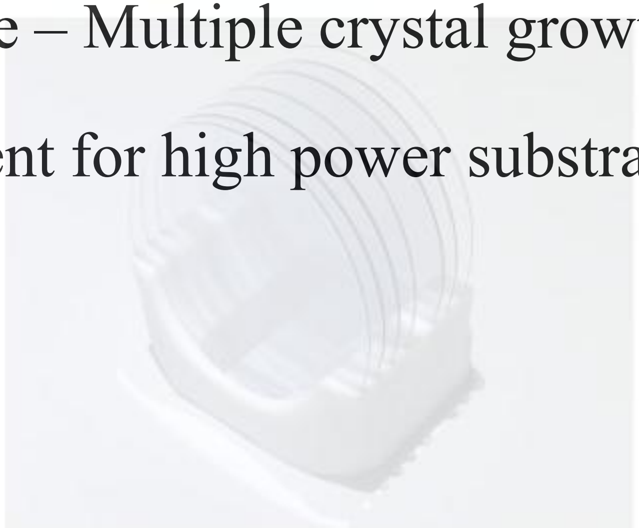


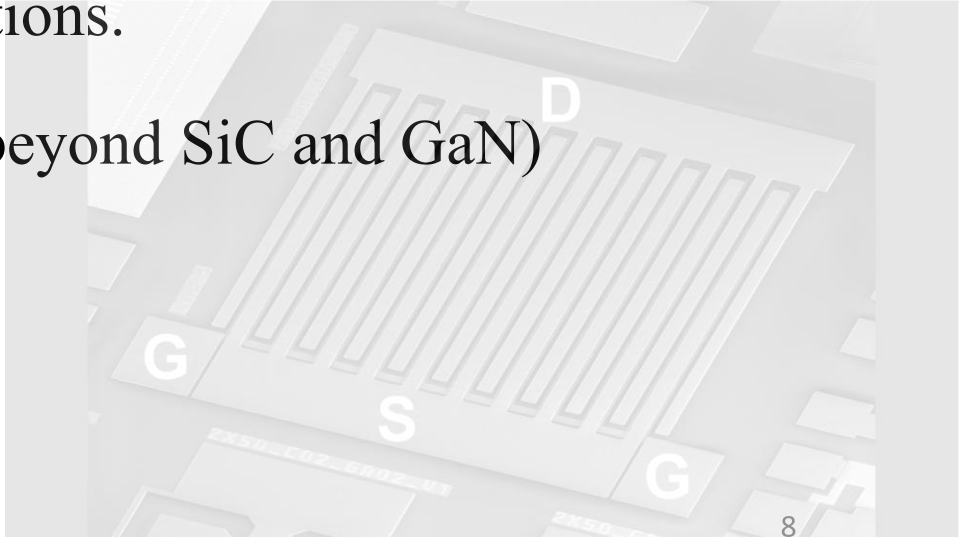
β-Ga_2O_3: Advantages & Promise

Why β-Ga_2O_3 Scintillator:

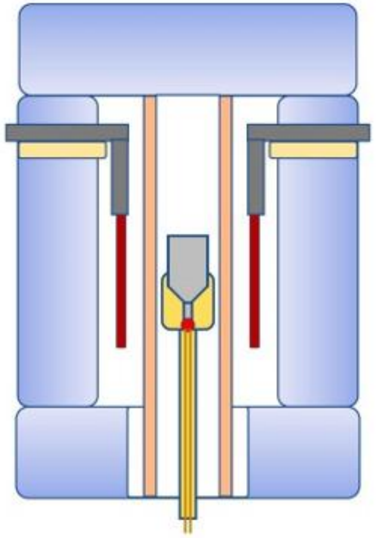
4. Robust, temperature- and moisture-insensitive.
5. Low cost and high yield manufacturability using Float Zone.
6. Highly scalable – Multiple crystal growth options.
7. R&D investment for high power substrates (beyond SiC and GaN)



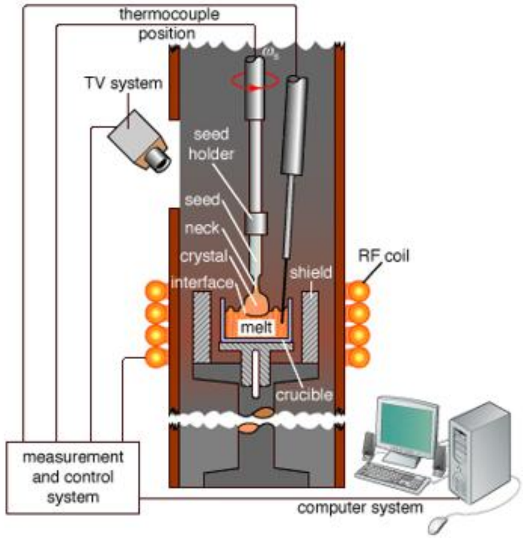




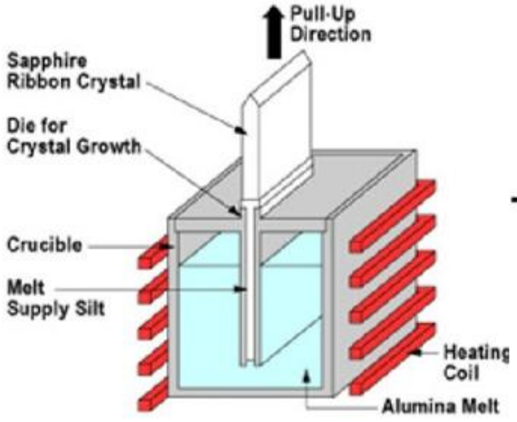
β-Ga_2O_3: Crystal Growth techniques



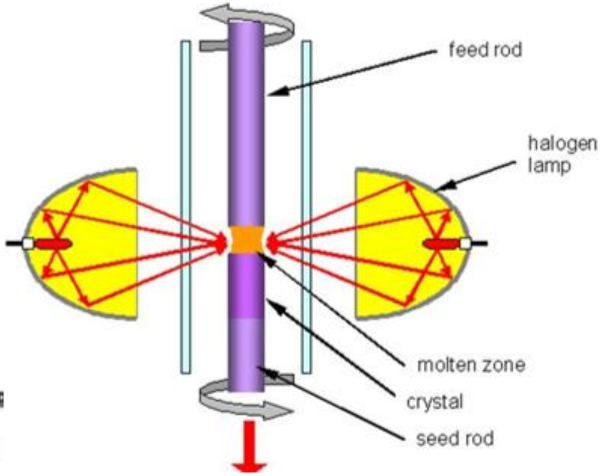
Vertical Bridgman



Czochralski



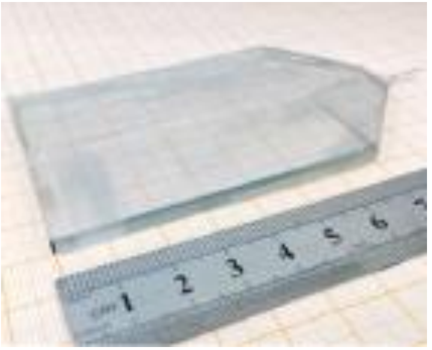
Edge Defined Film Fed Growth



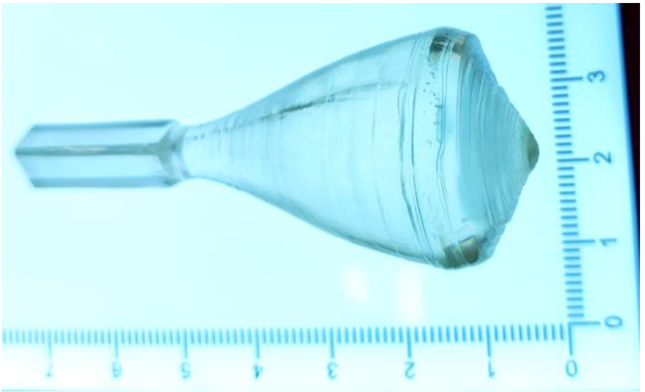
Float Zone

Tamura

IKZ



Tamura



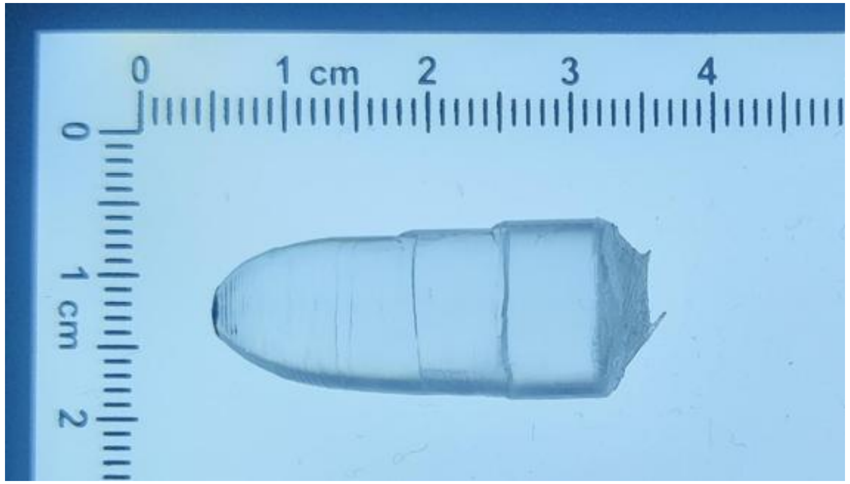
CapeSym

1. Establishment of FZ Growth Capability at CapeSym

Ultrahigh Temperature Crystal Growth facility
At CapeSym

<u>Advantages of FZ:</u>

- No containment issues
- Process materials with melting temperature up to 3000°C
- Relatively quick turnaround time – Cost-effective!
- Low capital cost and short learning curve

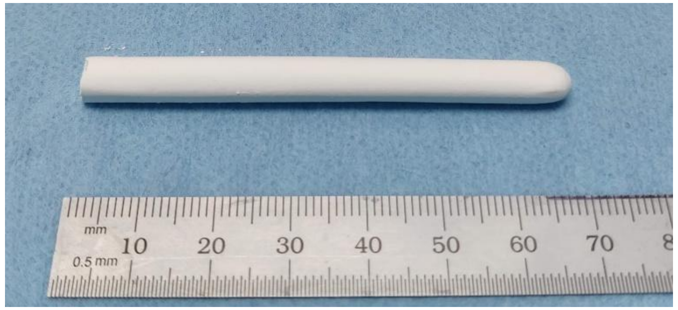


First β-Ga_2O_3 CapeSym Crystal May 2023

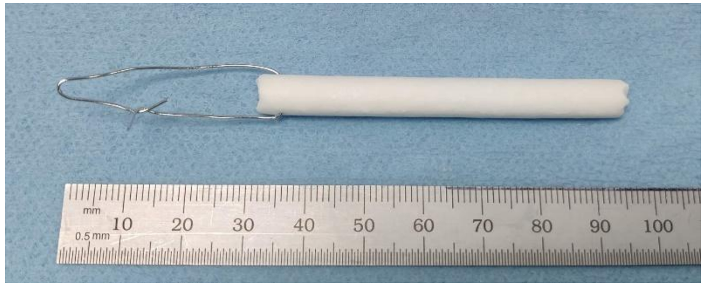
2. Optimization of the Crystal Growth Process

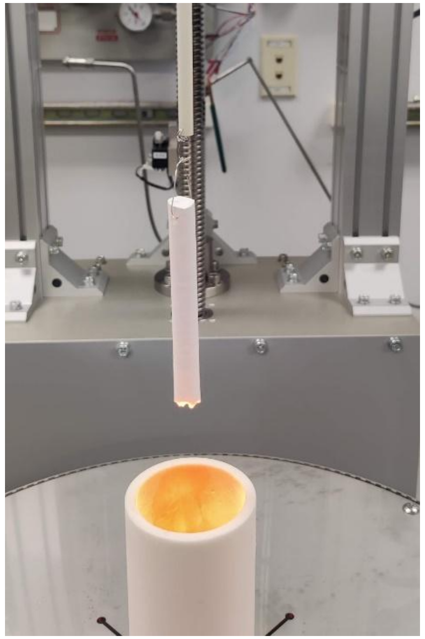
Feed Rods Optimization

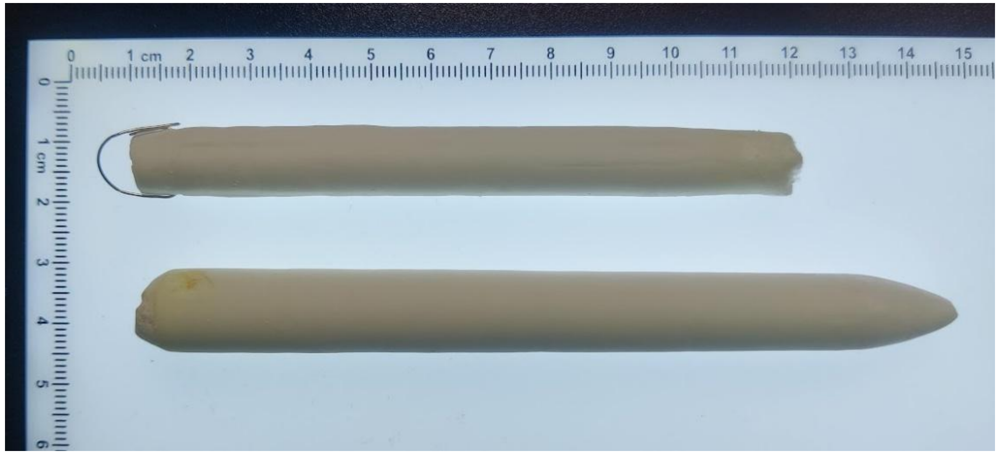
Feed Rod Pressing



Feed Rod Annealing

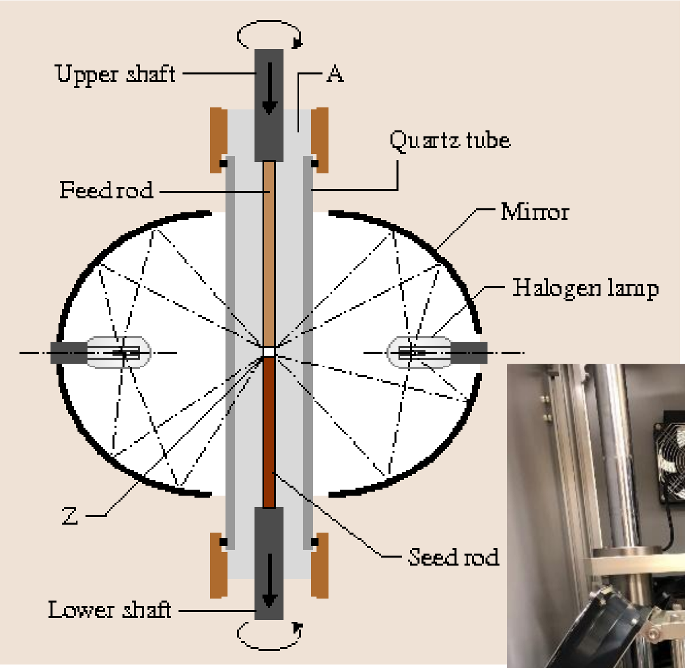


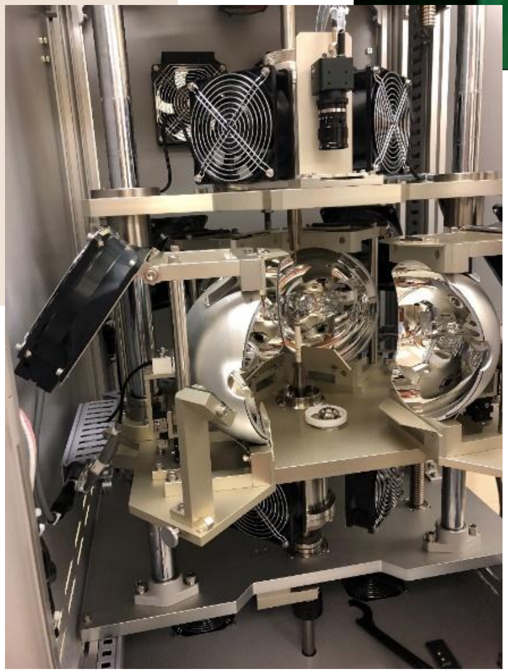


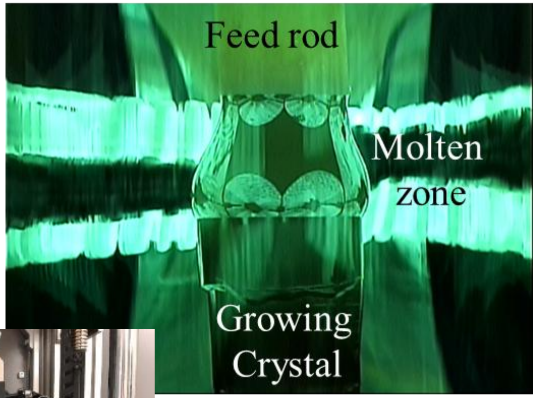


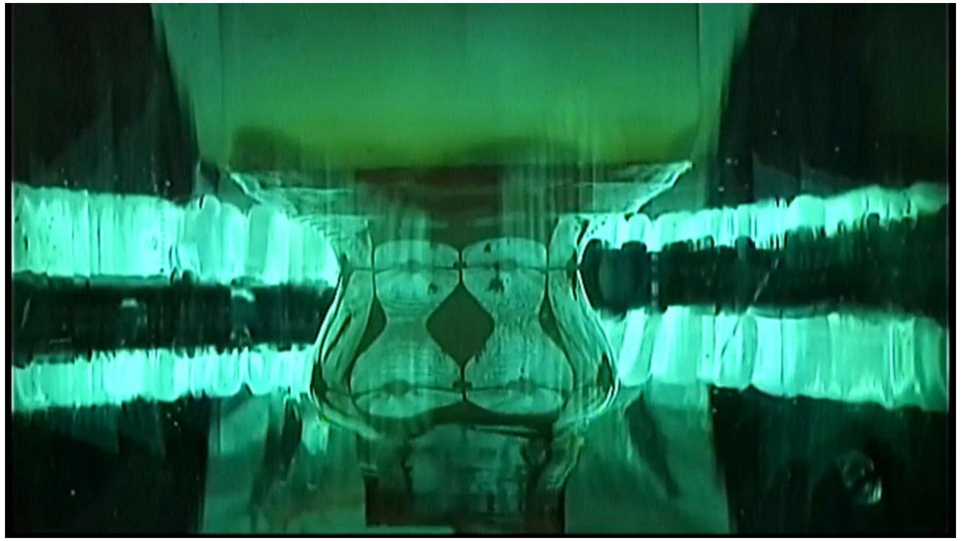
2. Optimization of the Crystal Growth Process

Crystal Growth using Float Zone technique







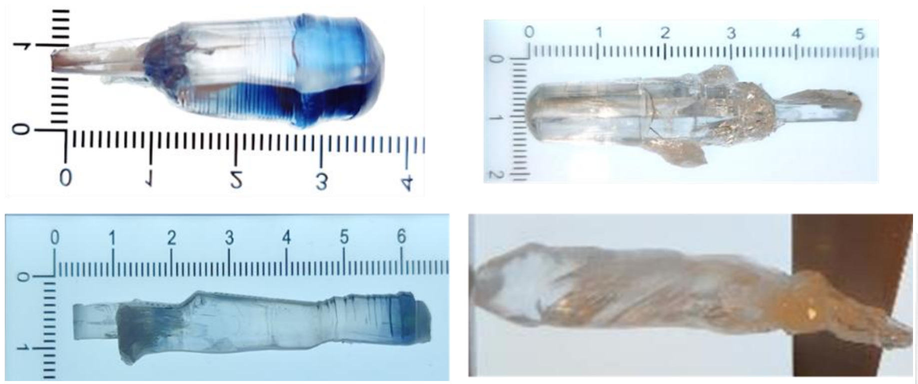


In situ video of β-Ga_2O_3 growing crystal in the FZ furnace at ~1900°C.

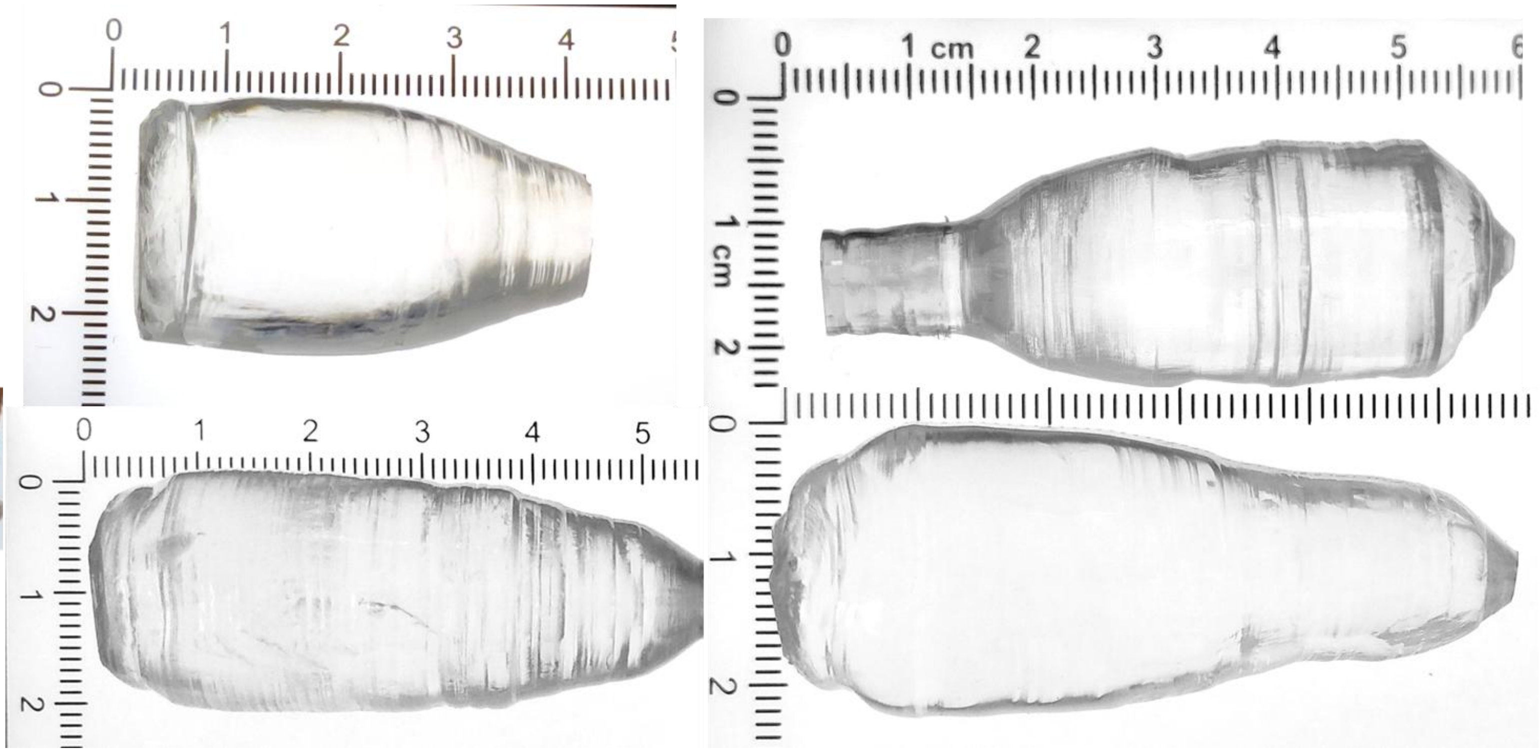
2. Optimization of the Crystal Growth Process

β-Ga_2O_3 Crystal Growth Optimization over ~1.5 years

2022-2023



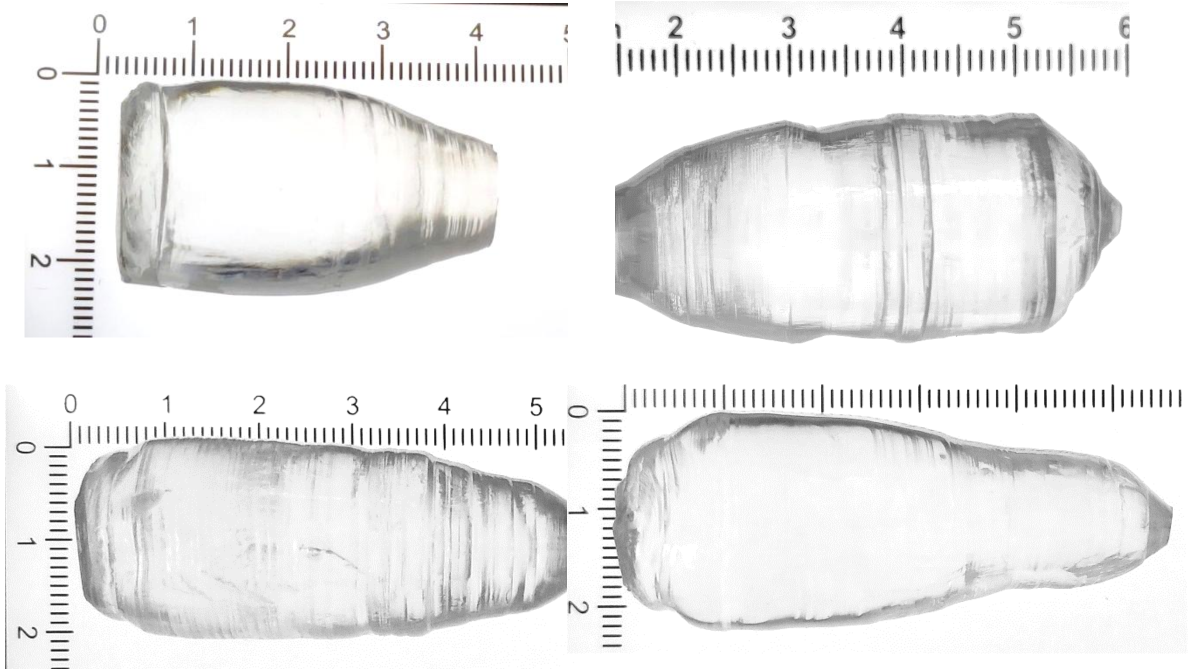
2023-2024



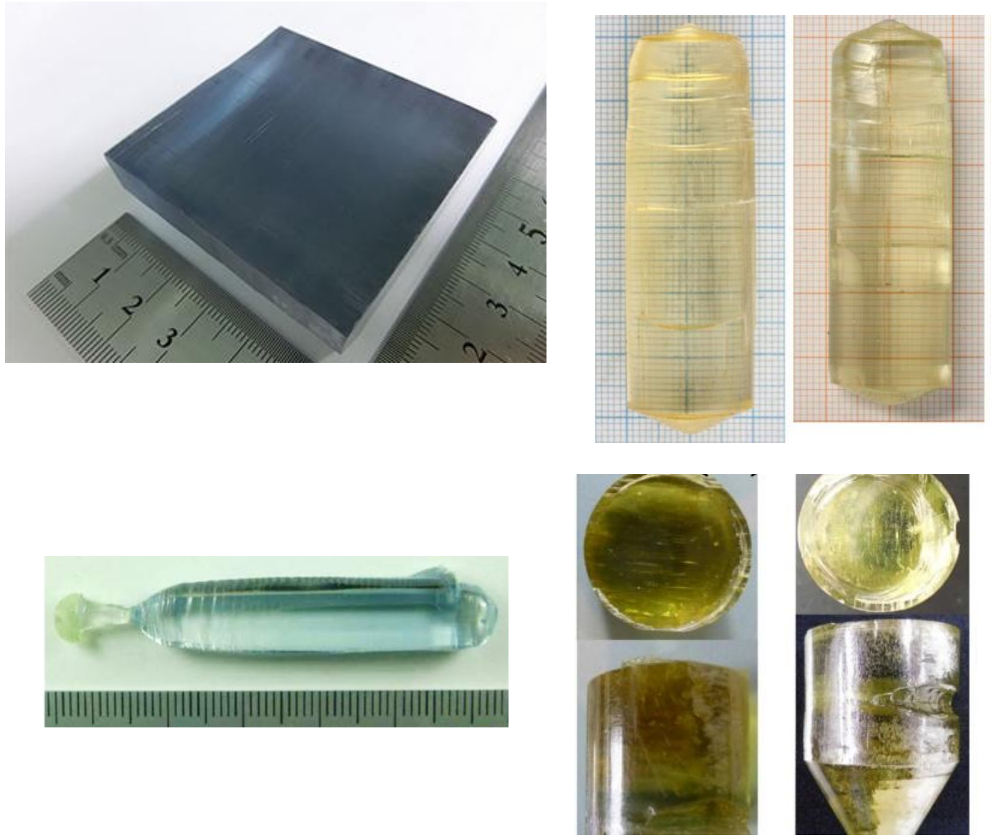
Excellent Scintillation Properties

Effect of Bandgap Defects

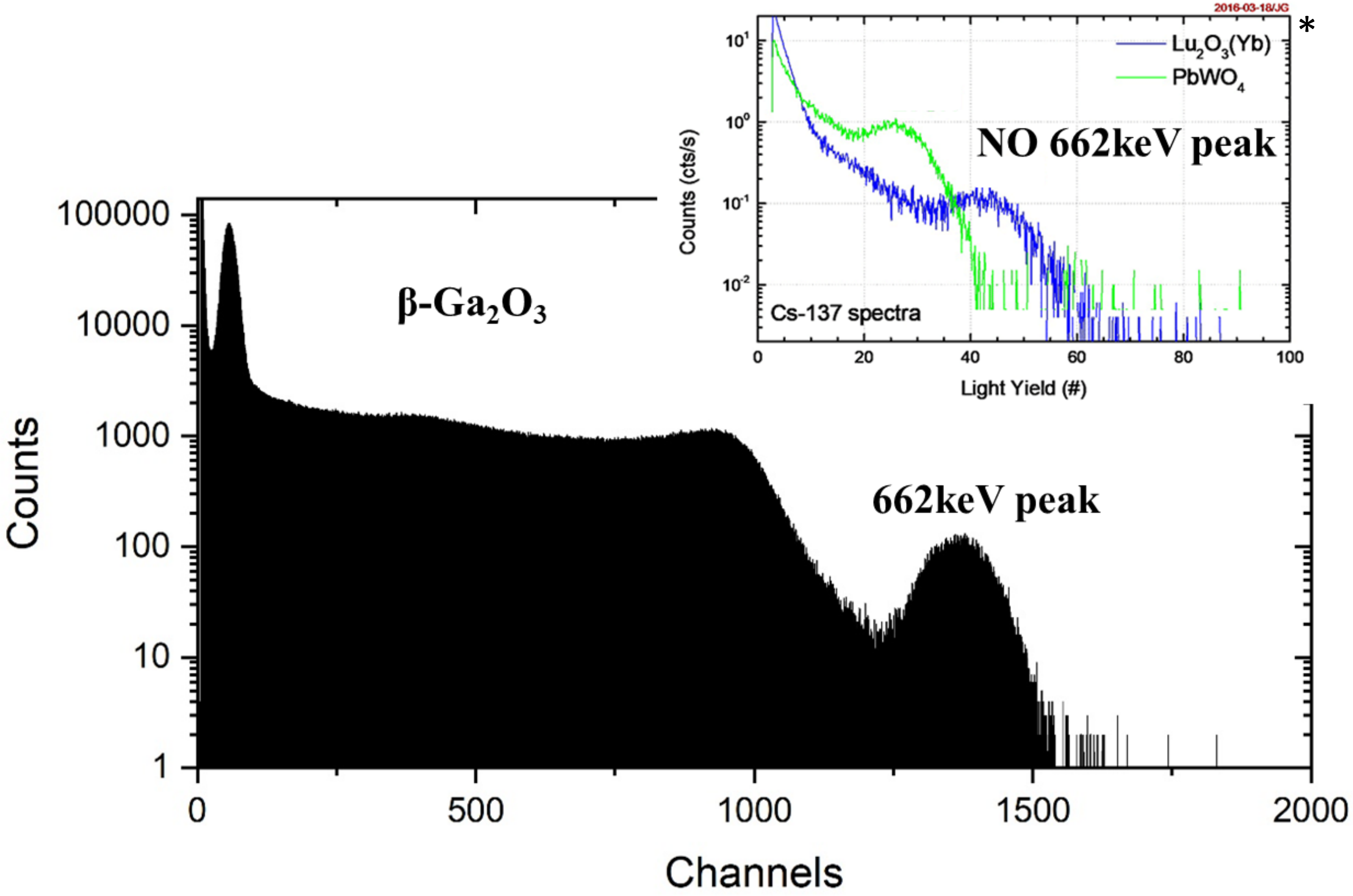
β-Ga_2O_3 Crystals Grown at CapeSym



β-Ga_2O_3 Crystals Grown Worldwide



3. β-Ga_2O_3 Crystal Characterization



Optimized high-purity transparent β-Ga_2O_3 crystal grown after parameter optimization.

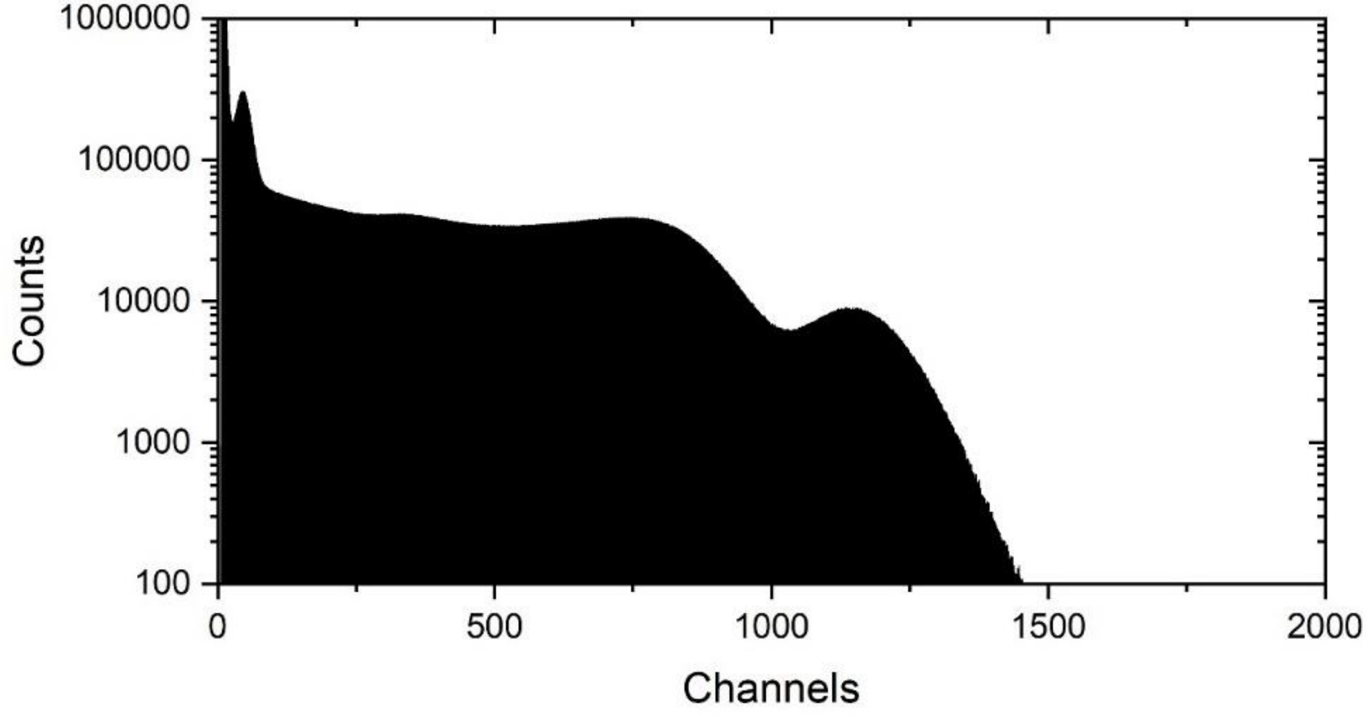
7% Energy Resolution at 662keV

^{137}Cs Gamma spectra yielding a light yield of 8000 Ph/MeV.

*Glodo et al. "New Developments in Scintillators for Security Applications", Phys. Procedia 90, 285-290 (2017).

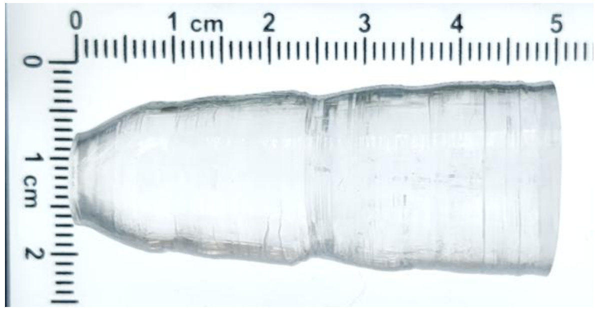
3. β-Ga_2O_3 Crystal Characterization

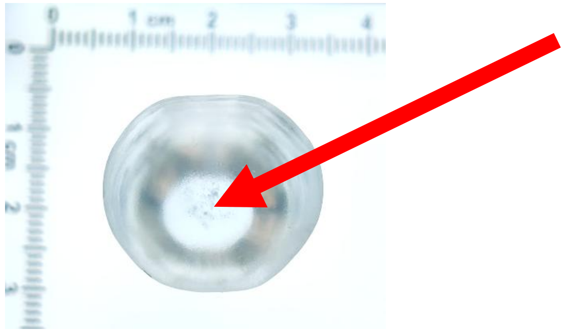
Spectroscopic Response from a 2-cm Thick β-Ga_2O_3 Scintillator



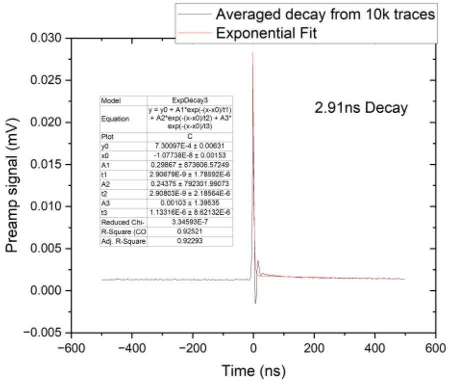
12% Energy Resolution at 662keV

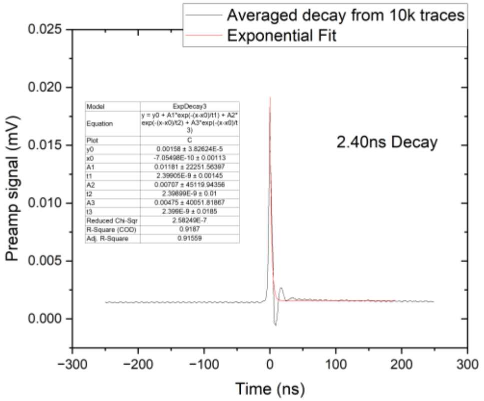
^{137}Cs Gamma spectra yielding a light yield of 5200 Ph/MeV

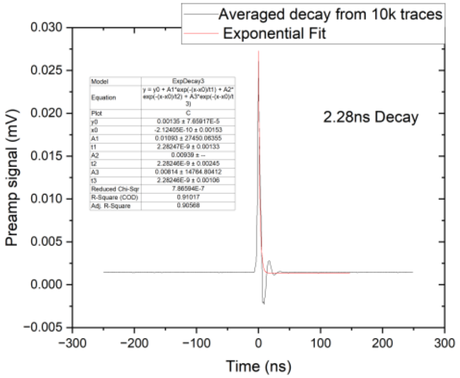


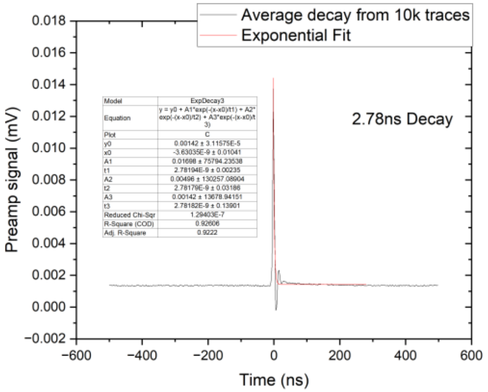


3. β-Ga_2O_3 Crystal Characterization



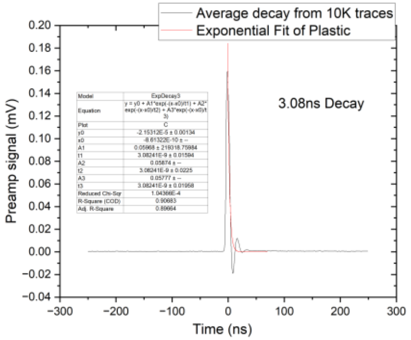


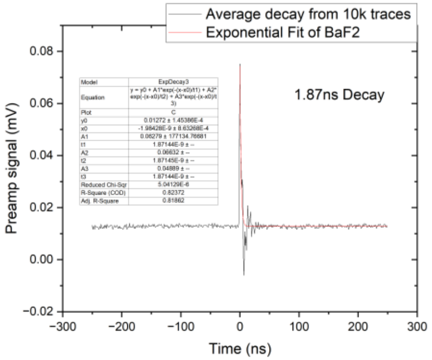


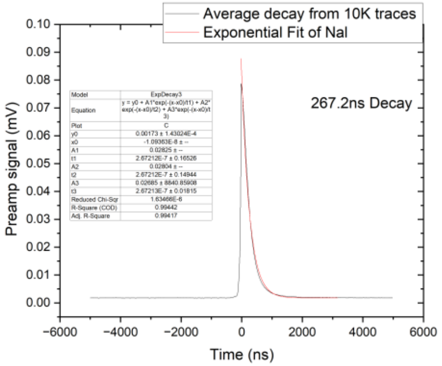


Decay curves for β-Ga_2O_3 Detectors: ~2ns Decay

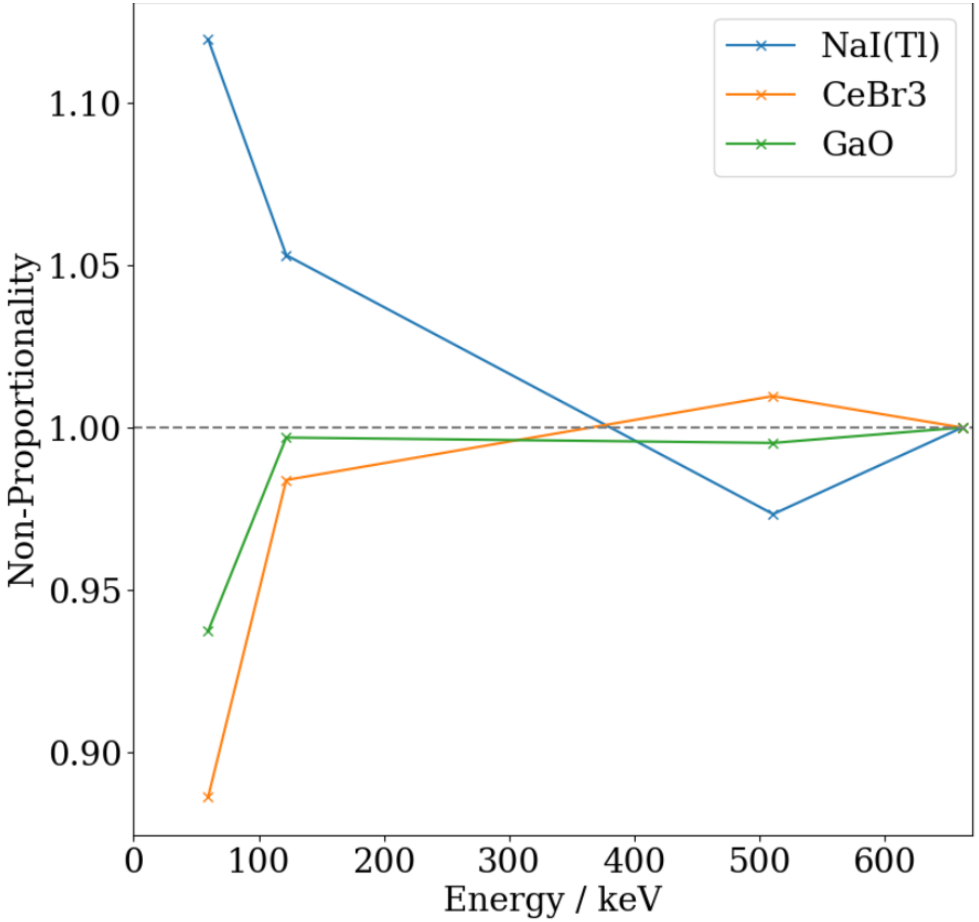
Decay curves for 3 different types of fast scintillators obtained from calibrated set up







3. β-Ga_2O_3 Crystal Characterization



Comparison with NaI and CeBr3

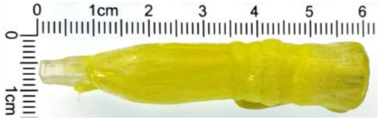
Excellent Non-proportionality β-Ga_2O_3 Detectors

Doped β-Ga_2O_3 Crystal Growth

Doped with Neodymium

Doped with Ytterbium

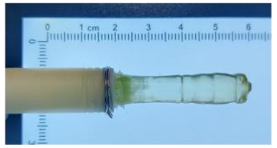
Doped with Chromium



Doped with Cerium and Gadolinium

Doped with Al and Ce

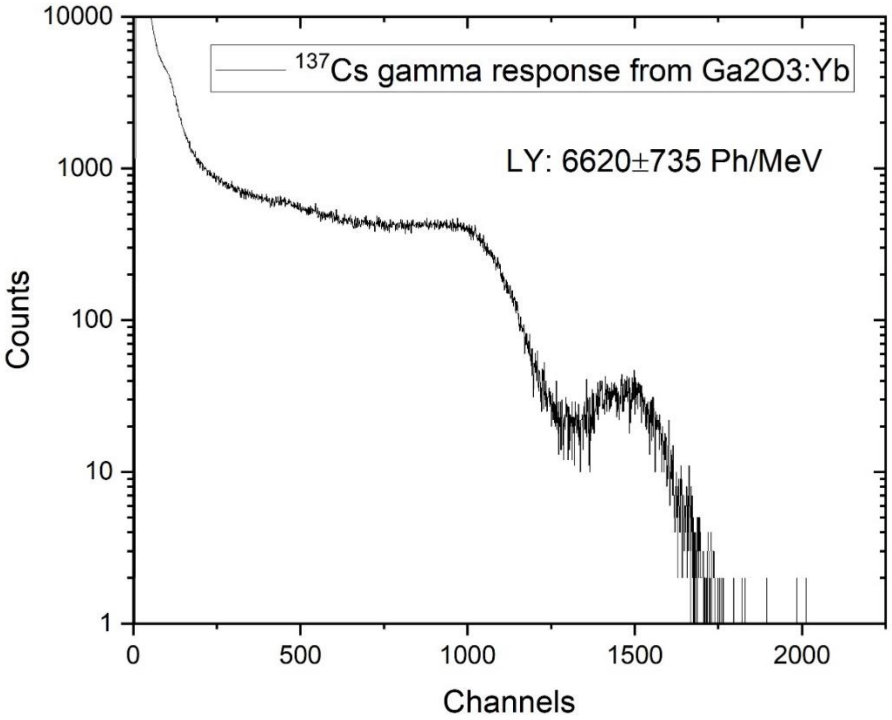
Doped with Bismuth



Doped with Lanthanum

Doped with Silicon

Doped with Cerium

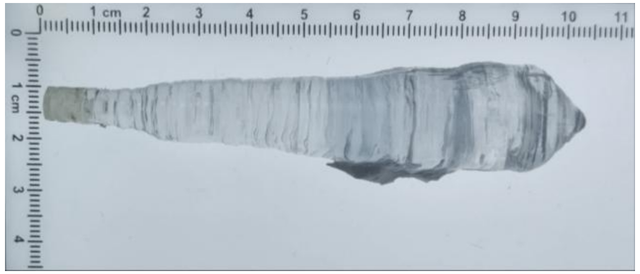


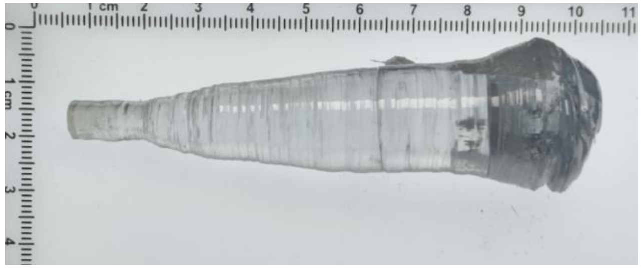
^{137}Cs Gamma spectra from β-Ga_2O_3:Yb scintillator yielding a light yield of 6620 Ph/MeV.

Large Volume β-Ga_2O_3 Crystal

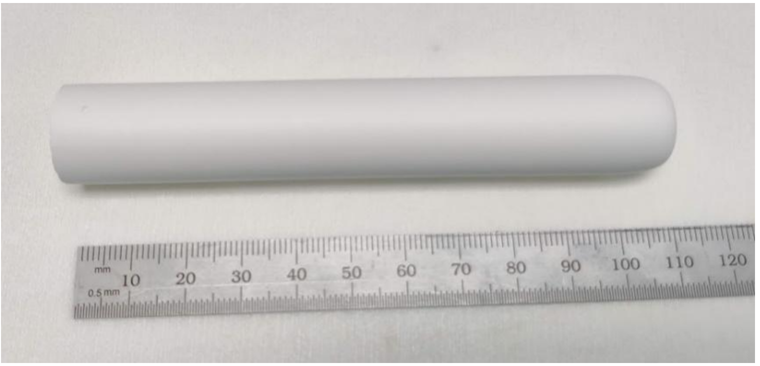
Even Larger Volume β-Ga_2O_3 Crystal Growth

Need more time for optimization

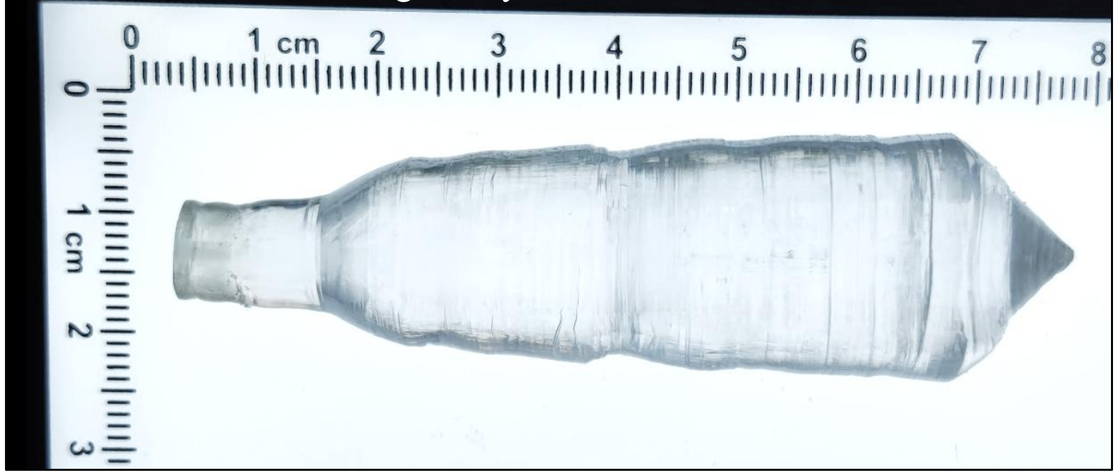




Large Diameter Feed Rods



Largest Crystal Till Date



Very Large Volume β-Ga_2O_3 Crystal

Even Larger Volume β-Ga_2O_3 Crystal Growth is Required

For larger crystals, we need to change the growth process to:
Ultrahigh power Float Zone
(12000W versus current 4000W)

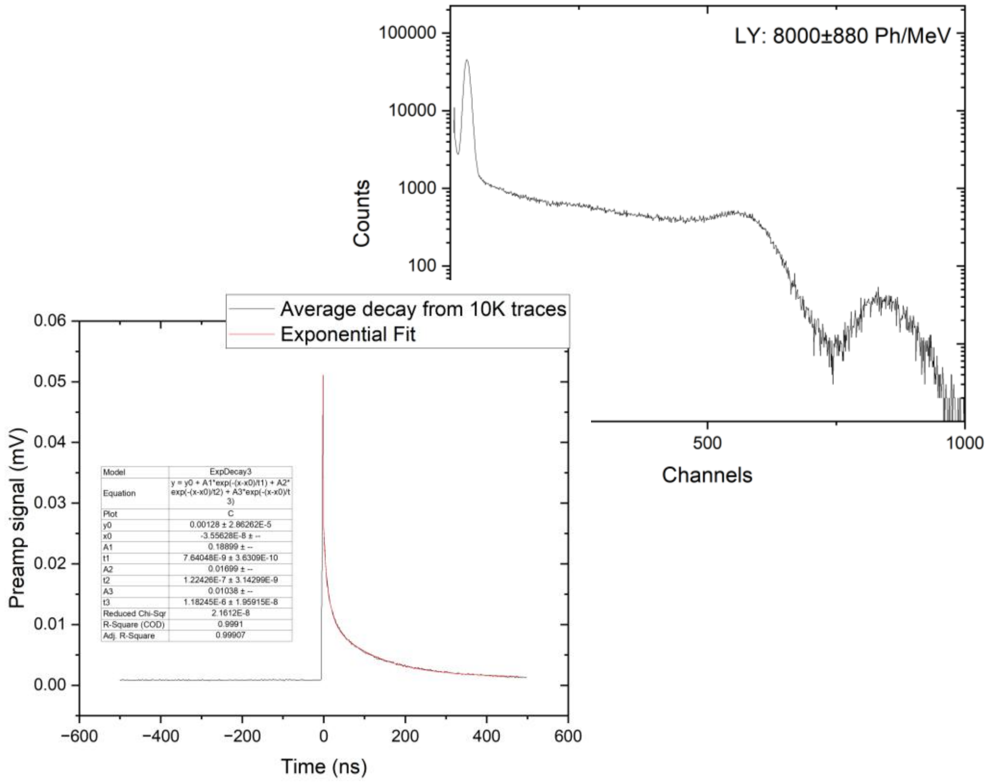
Significant Capital Investment : Currently looking for funding to set this up and optimize growth

Compact β-Ga_2O_3 Modules

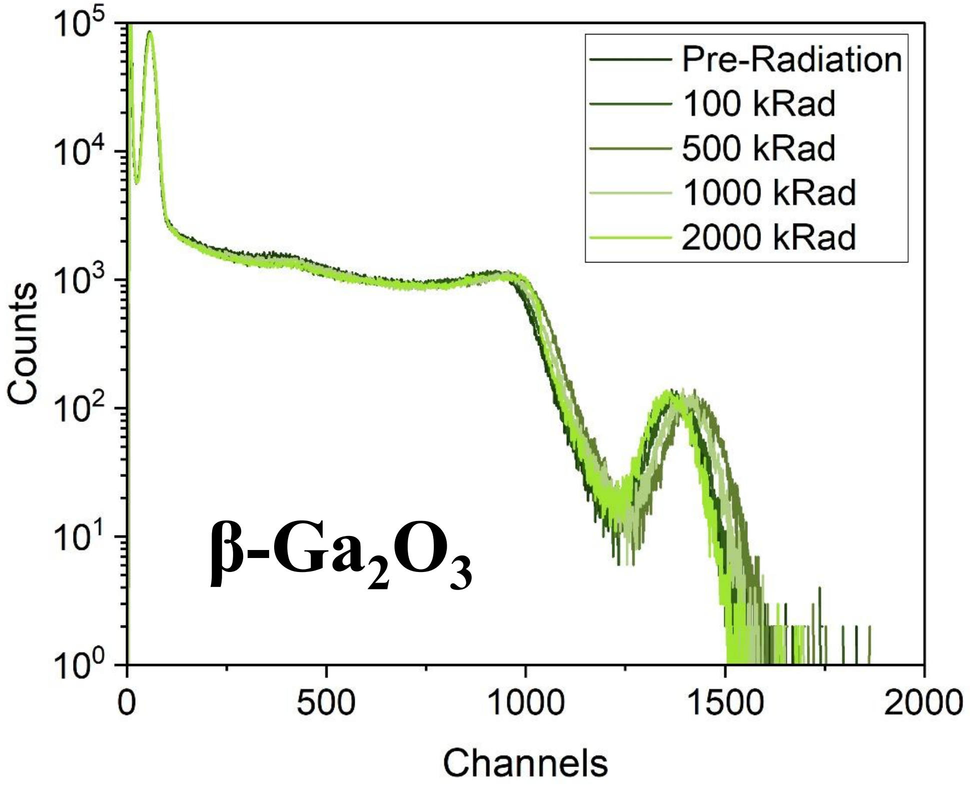
Compact β-Ga_2O_3 Detector Modules

Complete Commercial Modules

β-Ga_2O_3 Detector Module Performance Similar to the large PMTs

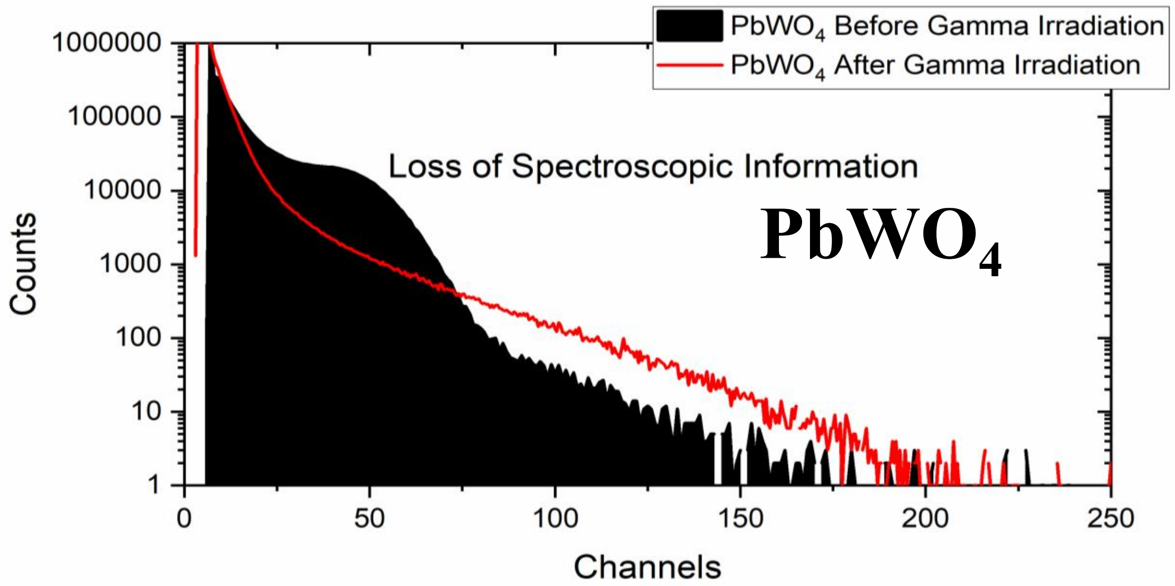


5. Radiation Hardness



^{137}Cs Gamma spectra from β-Ga_2O_3 measured during 2MRad (20kGy) ^{60}Co Gamma irradiation

Both Detectors are of SAME size

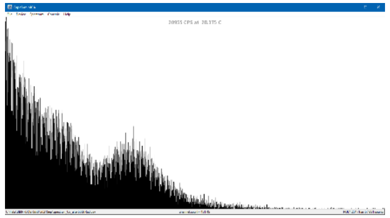


^{137}Cs Gamma spectra from $PbWO_4$ measured during 2MRad ^{60}Co irradiation

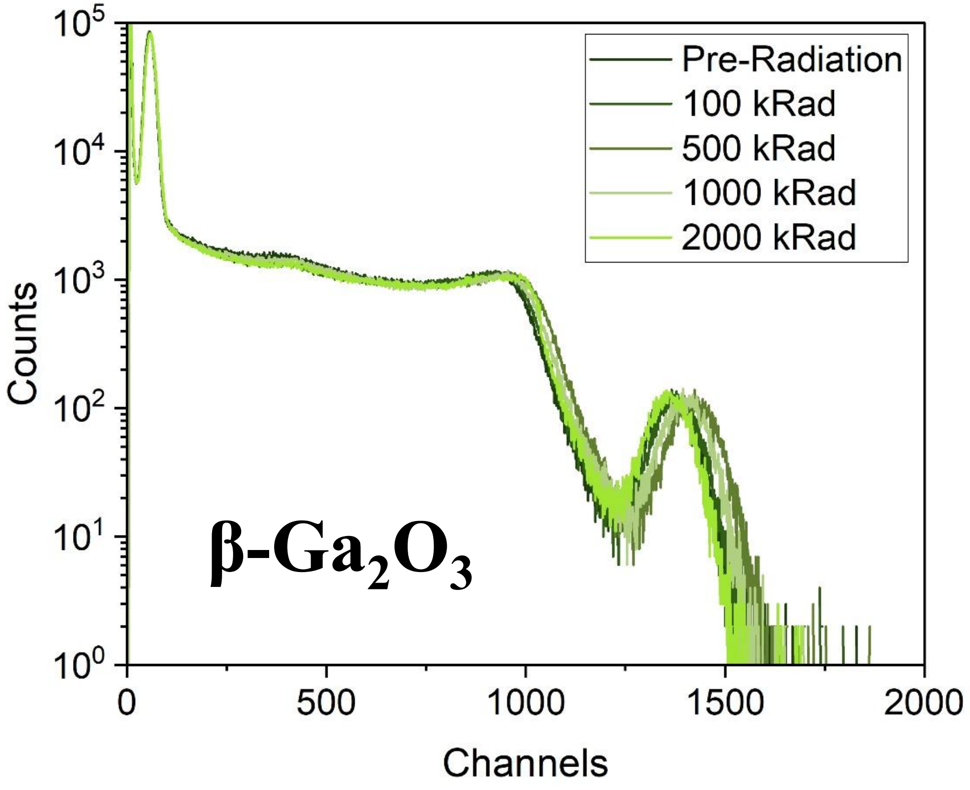
CLYC Scintillator

Before

After 0.5MRad

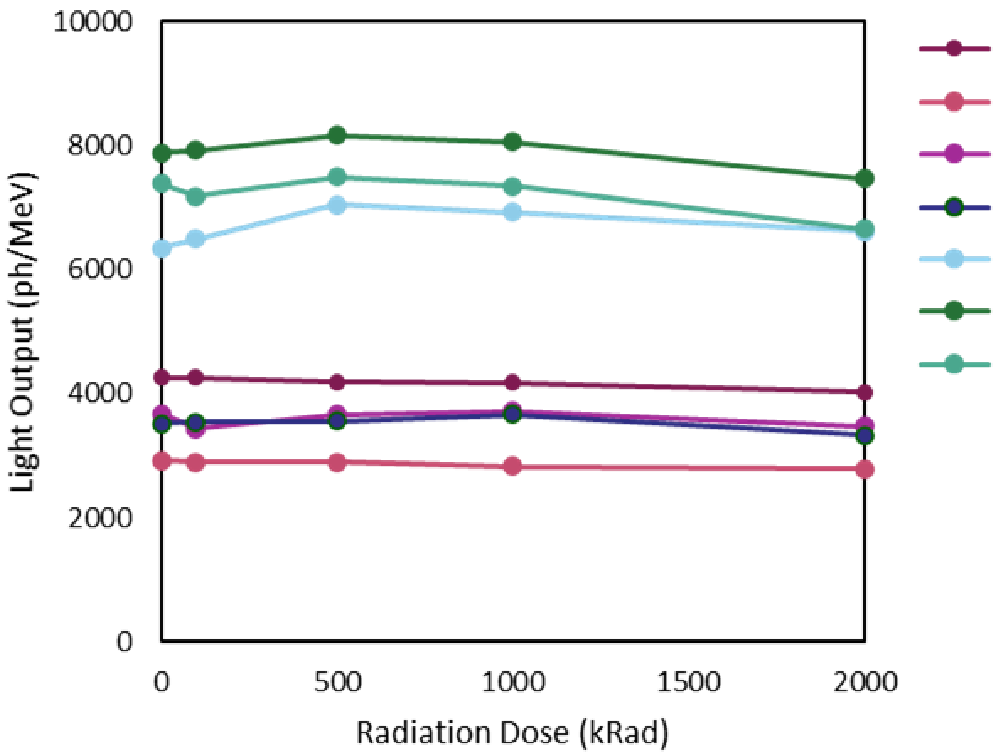


5. Radiation Hardness



^{137}Cs Gamma spectra from β-Ga_2O_3 measured during 2MRad ^{60}Co irradiation

Not just for One device, measured for β-Ga_2O_3 26 detectors



^{137}Cs Gamma spectra from multiple β-Ga_2O_3 detectors measured during 2MRad ^{60}Co irradiation

Conclusions

Phase II Achievements and Conclusion

1. Demonstration of β-Ga_2O_3 inorganic scintillators with:
   - High light yield (~8000 photons/MeV),
   - Good spectroscopic response (7% energy resolution at 662 keV), and
   - Ultrafast decay times (~2 ns)
2. Spectroscopic β-Ga_2O_3 scintillators grown in just one day, commercially viable.
3. Radiation hardness demonstrated using gamma irradiation.
4. Commercial detector modules complete with digital signal processing electronics.

More Details in the Publication

Gallium oxide semiconductor-based large volume ultrafast radiation hard spectroscopic scintillators
A. Datta, H. Mei, A. Lebedinsky, P. Shiv. Halasyamani, S. Motakef, Journal of Applied Physics, 14 August 2024; 136 (6): 064503.

https://doi.org/10.1063/5.0219987

Conclusions

Phase II Achievements and Conclusion
Commercial Pull

Detector under evaluation in four industries:

- **Dosimetry Applications** – A dosimeter company purchased our Ga_2O_3 sensors and is evaluating for further acquisition.
- **Defense Applications** – Detectors are being evaluated at a defense company for field applications
- **Scientific Instruments** – Detectors are being evaluated for scientific instruments like electron microscopy.
- **Medical Imaging** – Detectors are being tested for imaging like Ultrafast PET with Universities like Delft University (Results to be presented at IEEE NSS MIC 2025 at Yokohama, Japan)
- **Substrate Industry** – Sold substrates to electronics customers, waiting for more orders (limited by size).

Acknowledgements

This work was made possible by the support of the DOE Office of Science **Nuclear Physics (NP) program** under award DE-SC0023561.

We extend our sincere thanks to our collaborators:

- **University of Houston**
- **Ohio State University**

Thank You for Your Attention!

datta@capesym.com