Ultrafast Radiation Hard Gallium Oxide 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 Aug 15, 2023
DoE NP PI Meeting

Program Overview

Program Goal: <u>Radiation Hard</u> Scintillators for Crystal Calorimetry

Gallium Oxide (β-Ga_2O_3) Scintillators

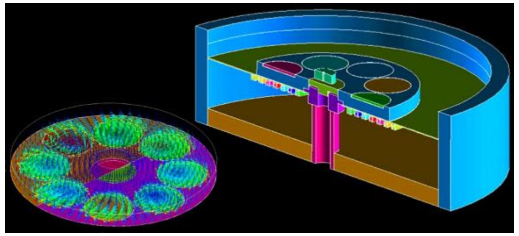
- **01** Non-Hygroscopic
- **02** High-density
- **03** Robust

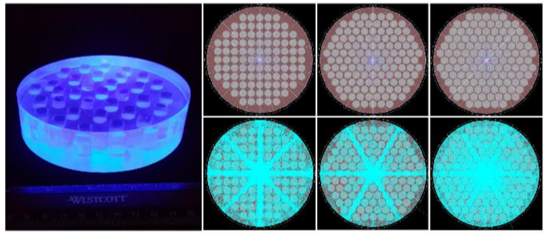
On CapeSym

- Founded 1992
- Employees: 14
- 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

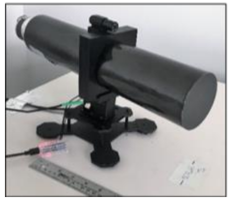
GEANT4 Scintillation Modelling

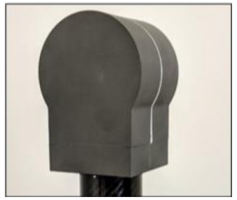


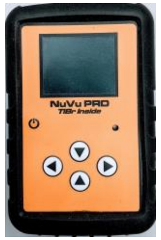


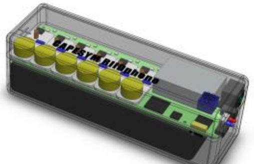
Scintillator Crystal Growth

Radiation Detection Instruments Development

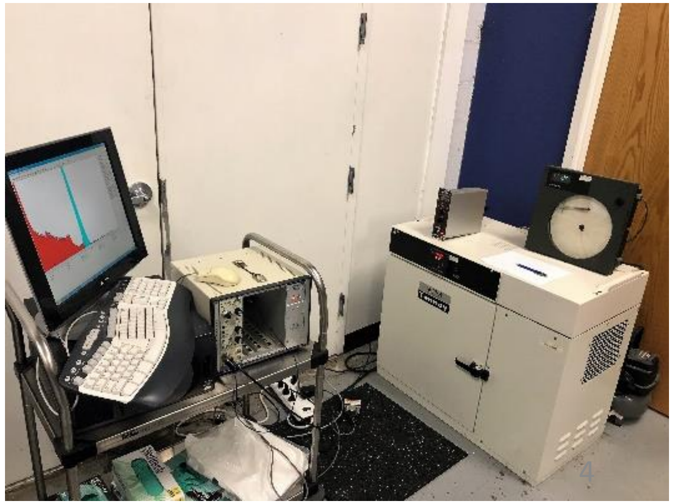


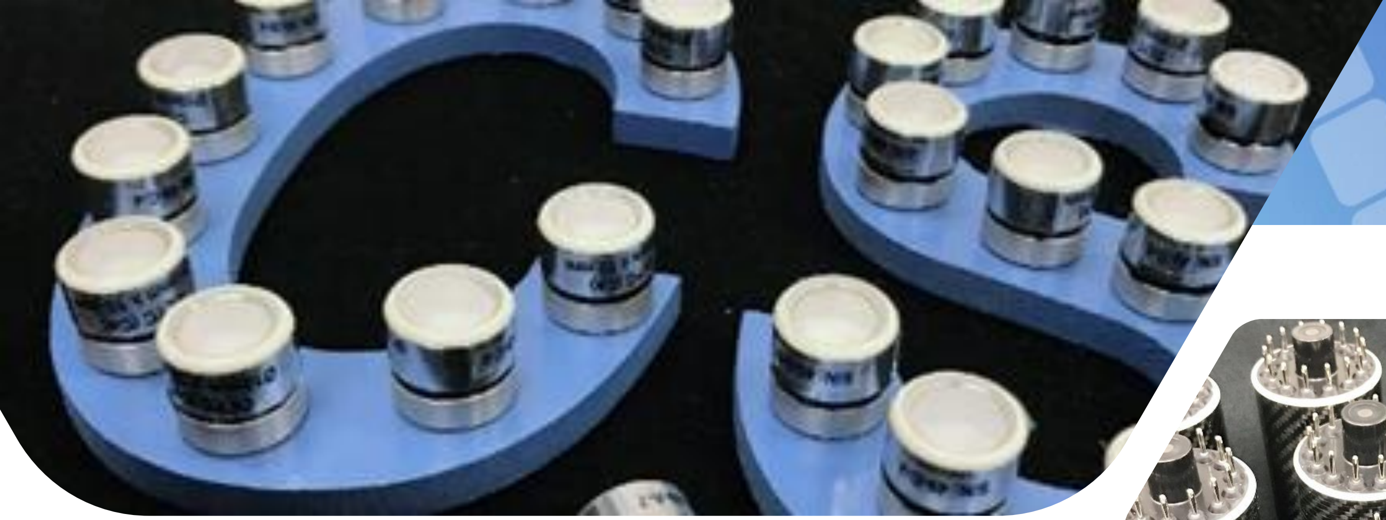






Radiation Detection Characterization





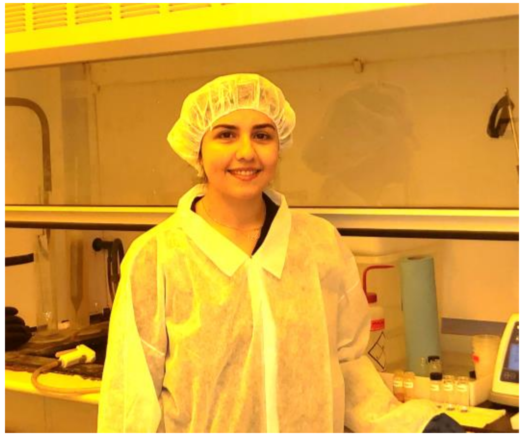
CapeSym Manufacturing Capabilities

- Today: ~250 medium 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

CapeSym Team

Shariar Motakef (PM)
Detector Development

Hao Mei (Scientist)
Crystal Growth and Device Characterization



Reyhaneh Toufanian (Scientist)
Device Fabrication and Characterization

Piotr Becla (Principal Scientist)
Device Characterization

Krys Becla
Equipment Design & Fab

Amlan Datta (PI)
Crystal Growth and Detector Fabrication

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:

01 Extremely Radiation Hard

02 Fast Decay Time (~2ns)

03 High Light Yield (>20 times $PbWO_4$)

04 Low-Cost Crystal Growth Technique: Float Zone!

Program Overview

Phase II Objectives:

Develop radiation hard scintillators for crystal calorimetry:

- Enhance the scintillation and radiation hardness properties of the β-Ga_2O_3 crystals using purification, doping, and annealing.

- Develop a reproducible crystal growth technique for growing large diameter β-Ga_2O_3 scintillator crystals.

β-Ga_2O_3: Advantages & Promise

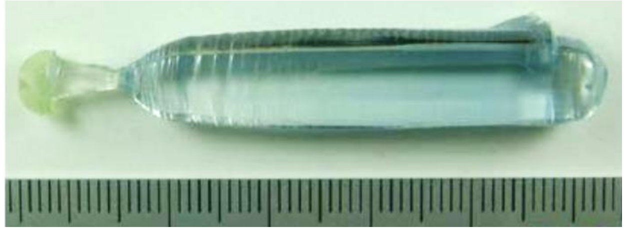
Why β-Ga_2O_3 Scintillator:

1. Extremely radiation hard, demonstrated up to 160MRad (γ).
    - We tested up to 2MRad (About 8 days of beamtime at ^{60}Co irradiator): need more beam time
2. Good scintillation properties: High Light Yield (15k Ph/MeV, highest reported)
    - We measured a highest value of ~6500 Ph/MeV: room for improvement
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 options.
7. R&D investment for high power substrates (beyond SiC and GaN)



Phase II Approach

Establishment of Float Zone Growth Capability

Impurity Reduction;
Feed rods Preparation;
Growth recipe development.

Optimization of the Crystal Growth Process

Doping/Co-doping of β-Ga_2O_3;

Growth of large volume crystals.

Material and Detector Characterization

Radiation hardness tests;

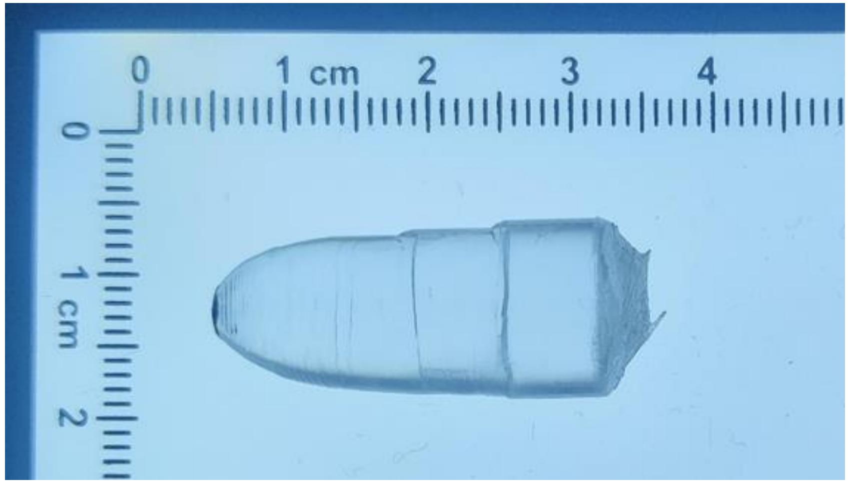
Development of complete detector modules.

1. Establishment of FZ Growth Capability at CapeSym

Ultrahigh Temperature Crystal Growth facility
At CapeSym

Advantages of FZ:

- No containment issues
- Process materials with melting temperature up to 3000^{o}C
- Relatively quick turn-around time
- Low capital cost and short learning curve

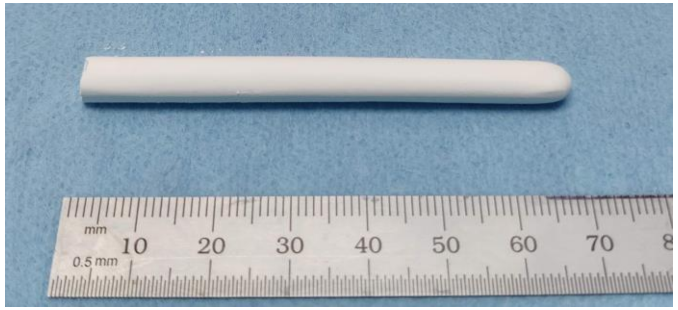


First β-Ga_2O_3 CapeSym Crystal May 2023

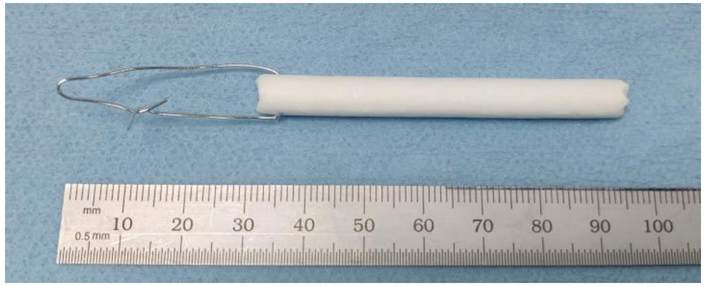
2. Optimization of the Crystal Growth Process

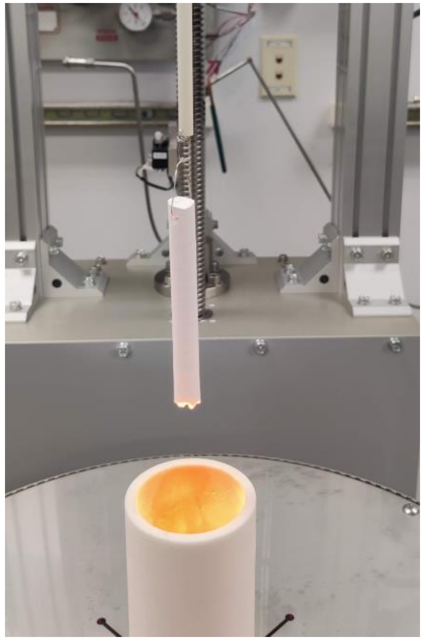
Feed Rods Optimization

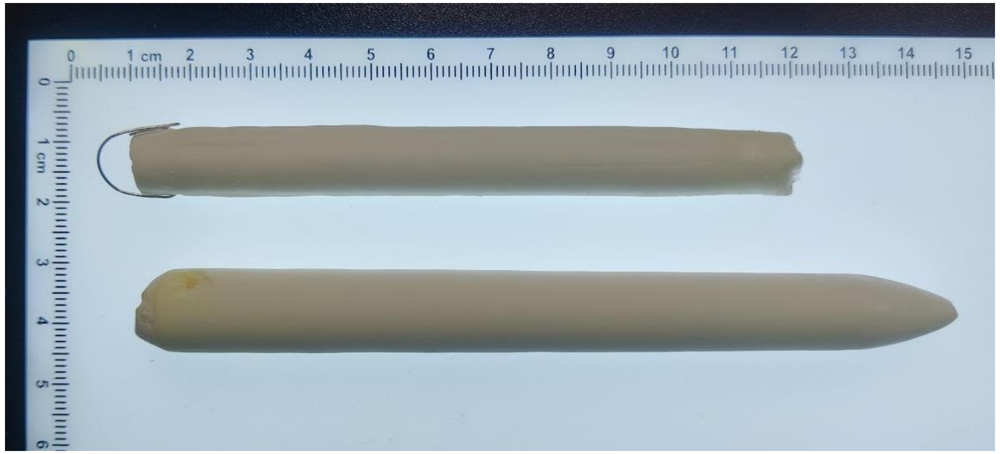
Feed Rod Pressing



Feed Rod Annealing

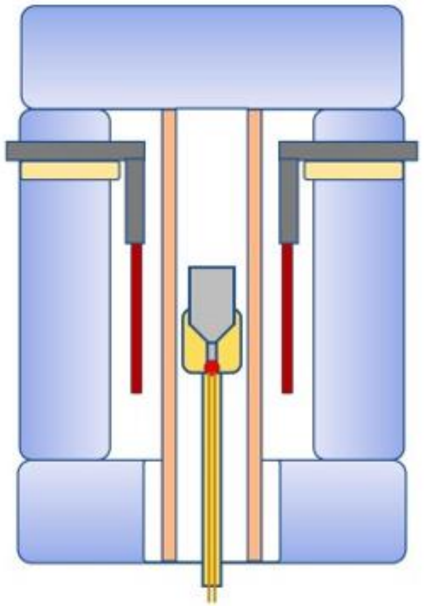




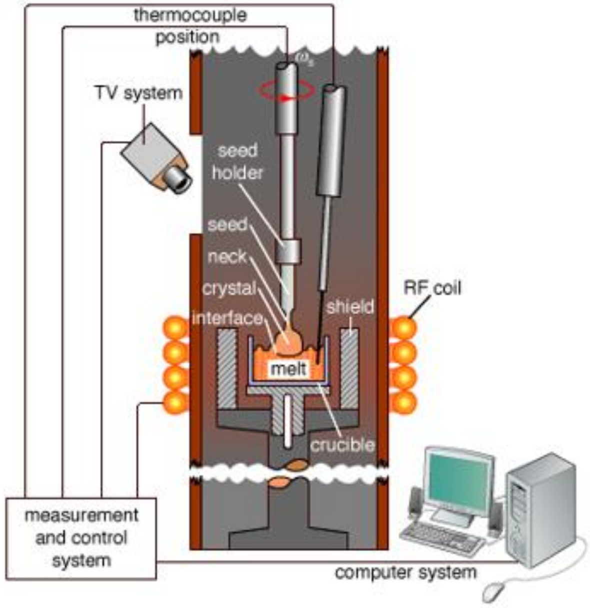


2. Optimization of the Crystal Growth Process

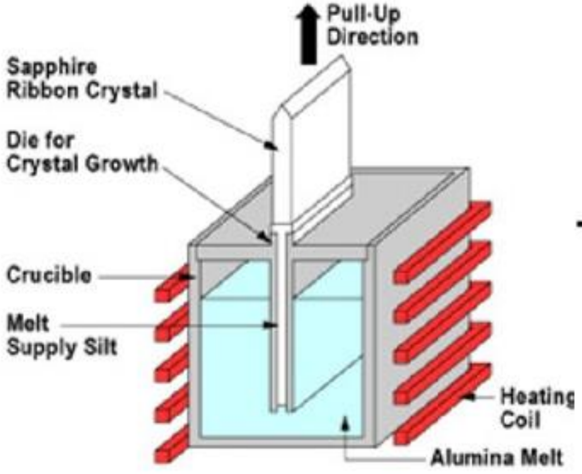
Crystal Growth using Float Zone technique



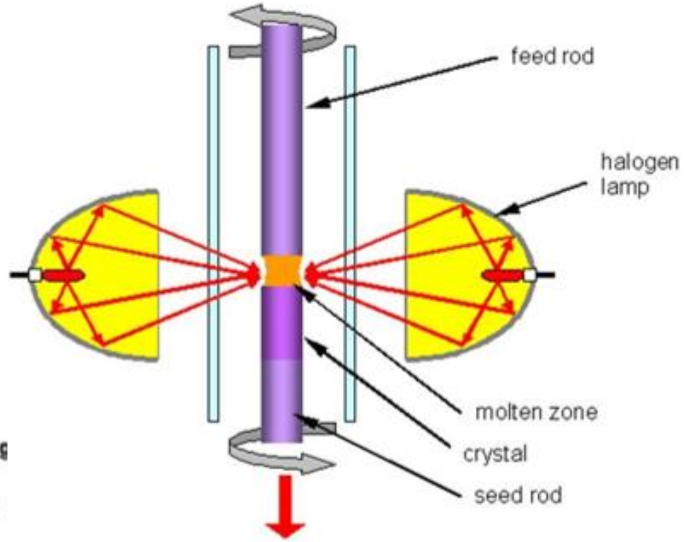
Vertical Bridgman



Czochralski



EFG



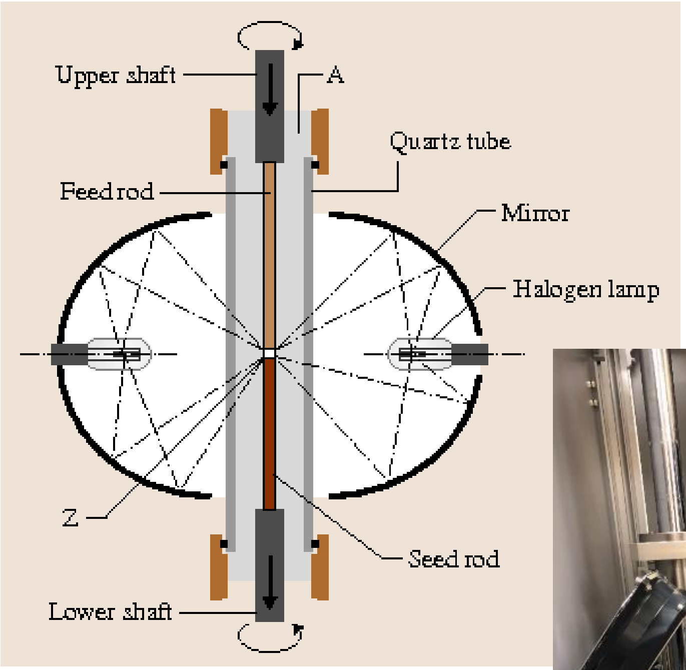
Float Zone

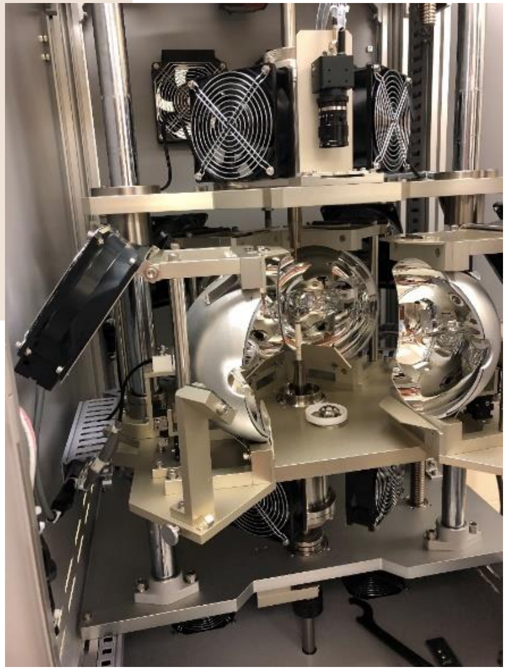
- **Fast setup and turnaround time -** so it allows testing of doping and co-doping methodically and rapidly.
- **No crucible interaction –** Lesser defects.

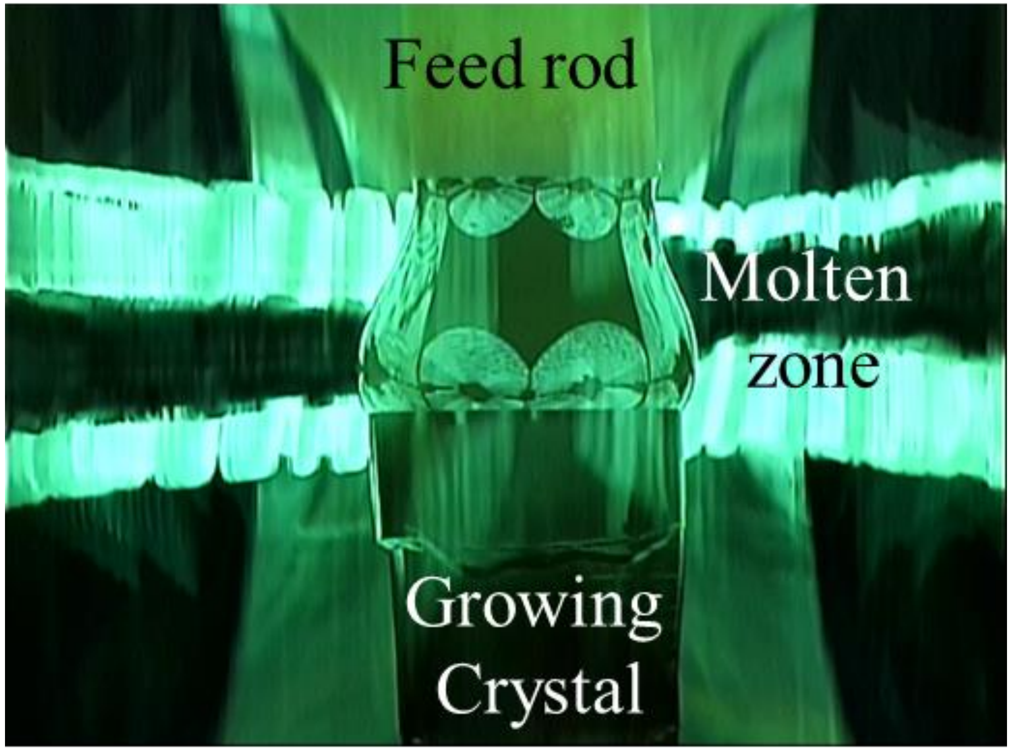
- **Low cost -** Doesn't need iridium crucible
  - 2-inch crucible ~ $75k
  - Needs repair after few growth ~ $25k

2. Optimization of the Crystal Growth Process

Crystal Growth using Float Zone technique





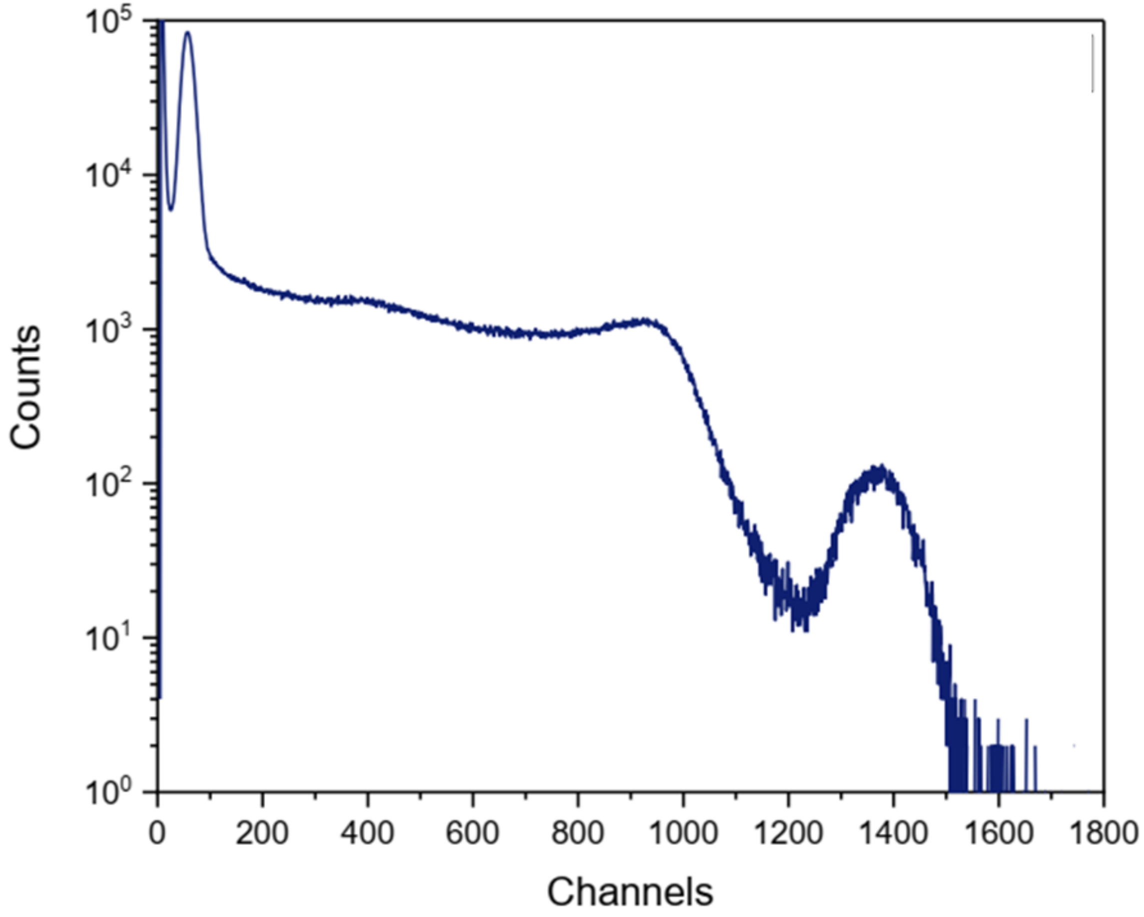


In situ photograph of a growing β-Ga_2O_3 crystal in the FZ furnace at ~1900°C.

3. β-Ga_2O_3 Crystal Characterization

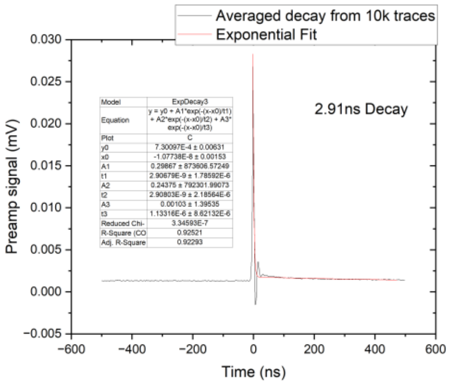
Optimized high-purity transparent β-Ga_2O_3 crystal grown after parameter optimization.

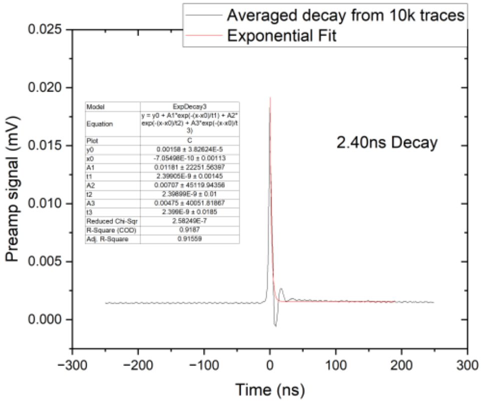
6.3% Energy Resolution at 662keV

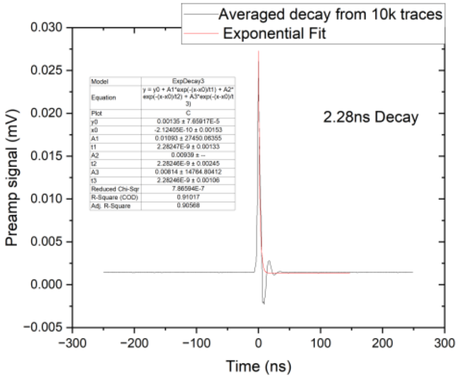


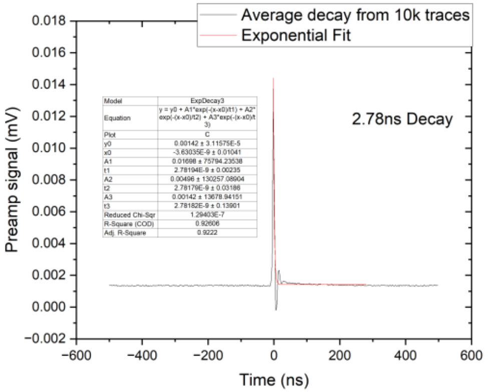
^{137}Cs Gamma spectra yielding a light yield of 6446 ±716 Ph/MeV.

3. β-Ga_2O_3 Crystal Characterization



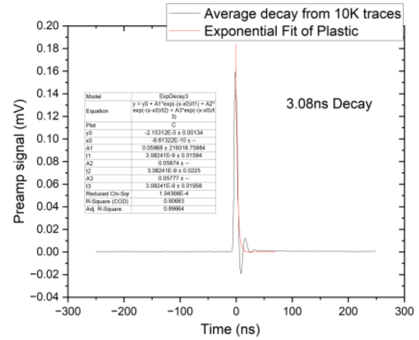


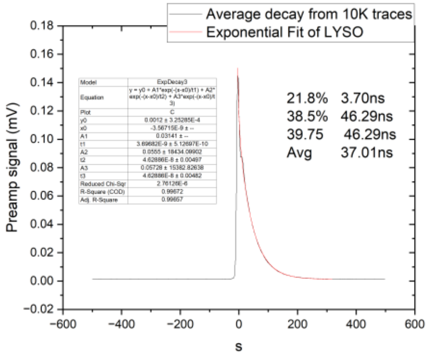


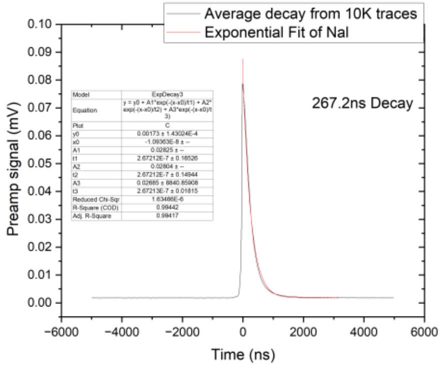


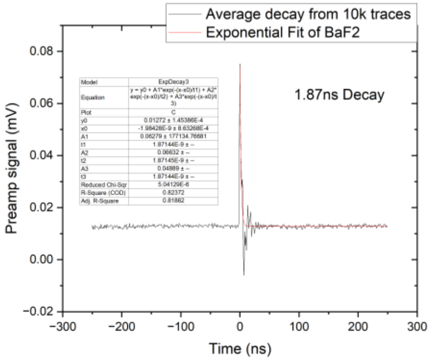
Decay curves for β-Ga_2O_3 Detectors: ~2ns Decay

Decay curves for 4 different types of standard scintillators obtained from calibrated set up





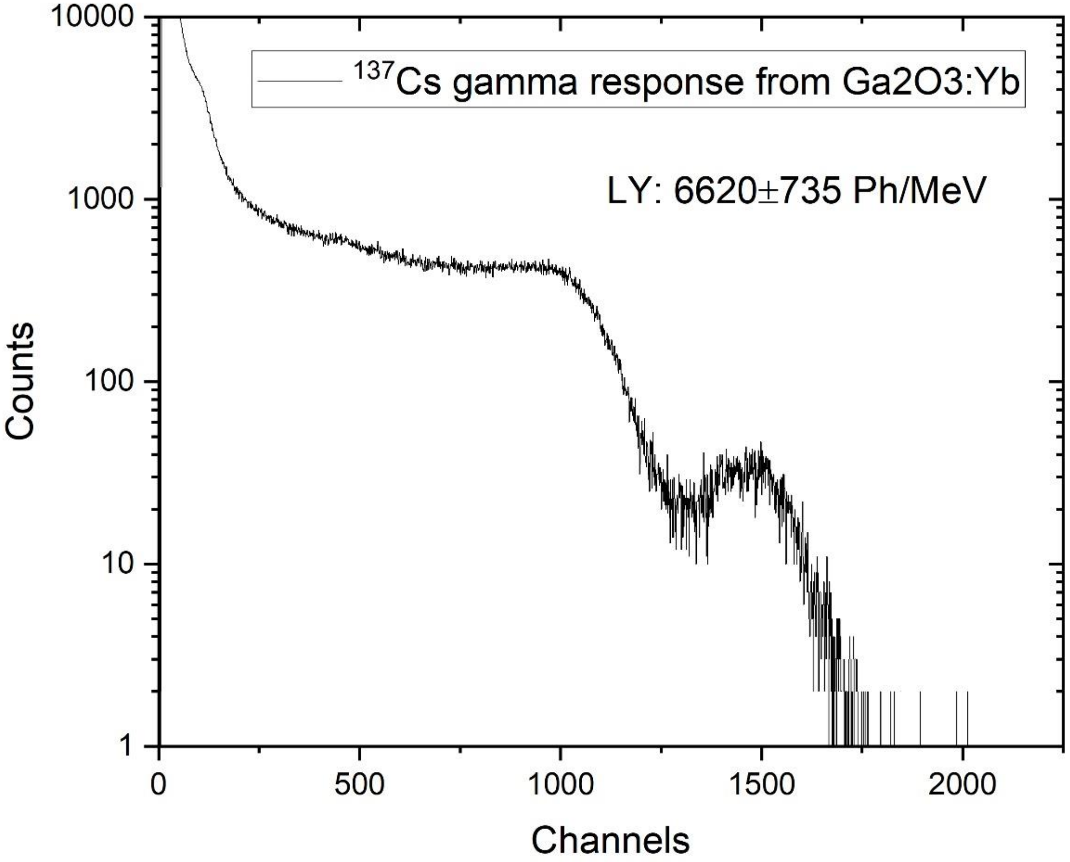




Name	Measured Value (ns)	Literature Value (ns)
Plastic Scintillator	3.08	0.7-3.3[5]
LYSO	37.01	40[6]
NaI	267.21	250[7]
BaF2	1.87	0.88[8]

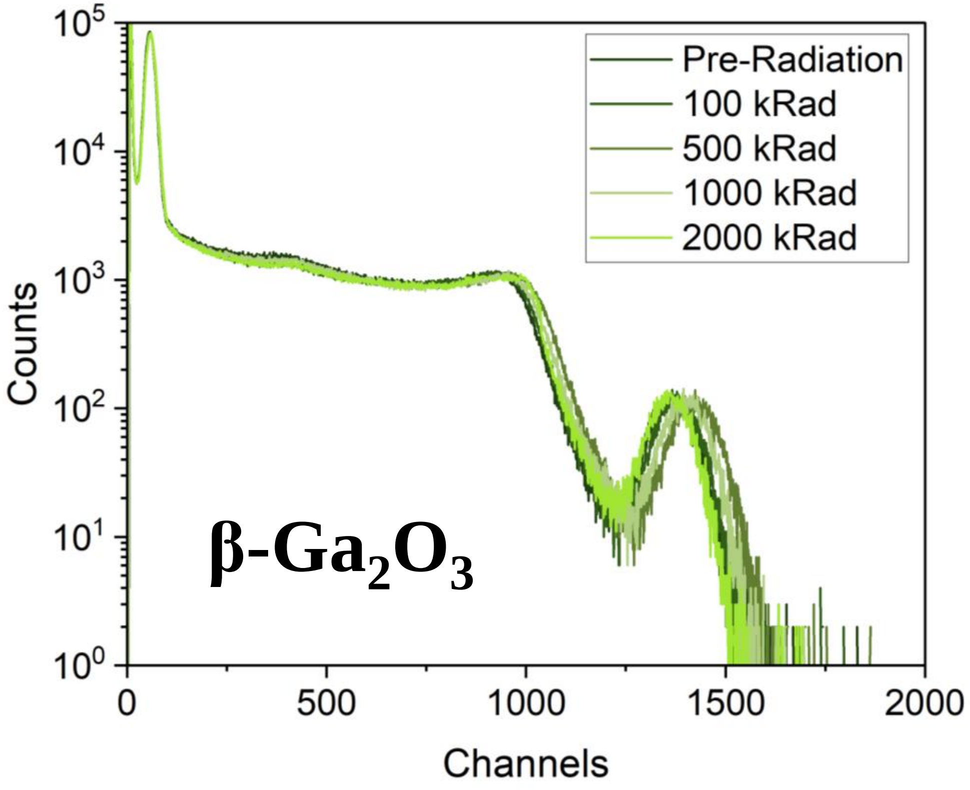
4. Doped β-Ga_2O_3 Crystal Growth

Yb^{3+} (left) and Nd^{3+} (right) doped β-Ga_2O_3 crystals growth using OFZ technique.



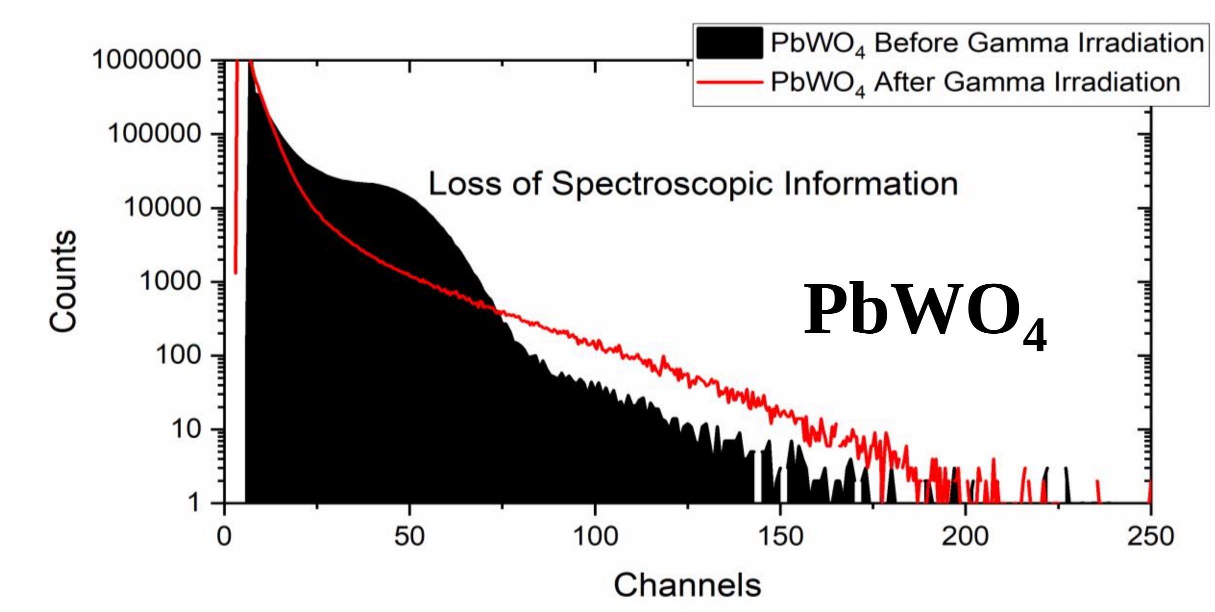
^{137}Cs Gamma spectra from β-Ga_2O_3:Yb scintillator yielding a light yield of 6620 ±735 Ph/MeV.

5. Radiation Hardness



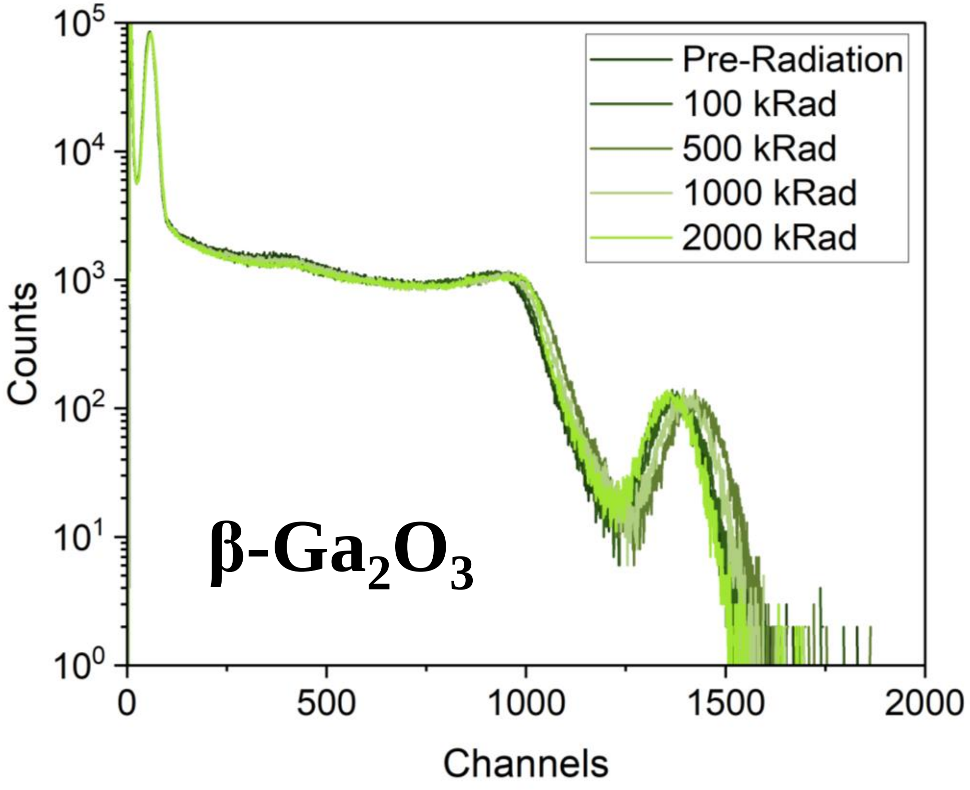
^{137}Cs Gamma spectra from β-Ga_2O_3 measured during 2MRad ^{60}Co irradiation

Both Detectors are of SAME size



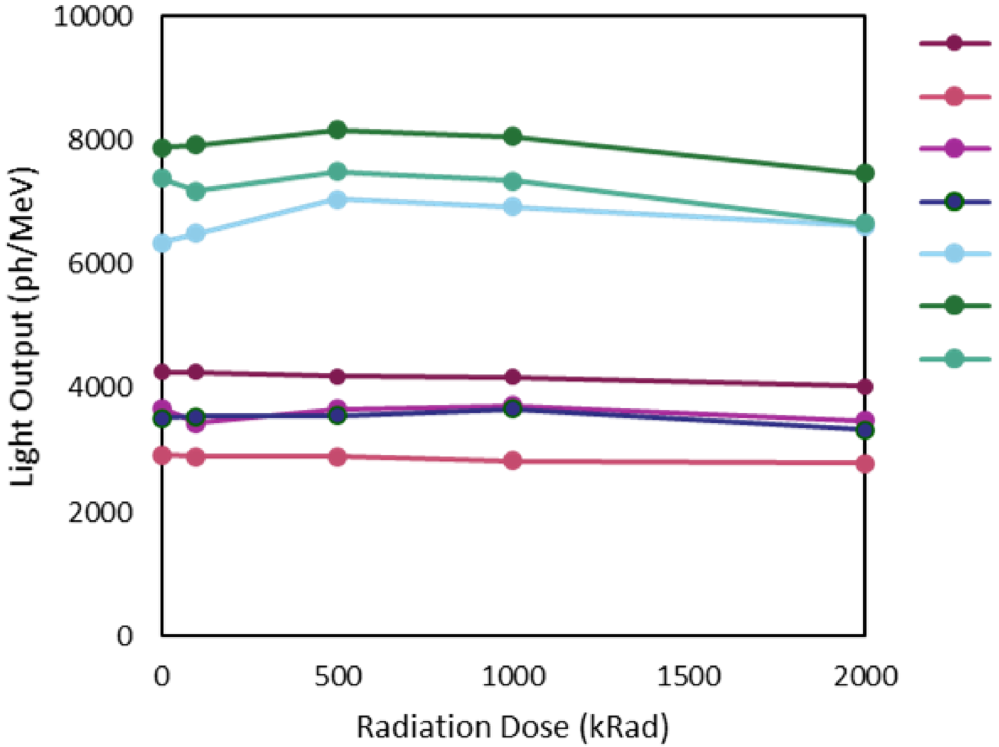
^{137}Cs Gamma spectra from $PbWO_4$ measured during 2MRad ^{60}Co irradiation

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 26 β-Ga_2O_3 detectors



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

Future Tasks

Phase II Future Tasks

- Further optimization of the crystal growth process
- Scale up of the β-Ga_2O_3 crystals – other growth techniques
- Material and Detector Characterization – Single photon timing measurements
- Radiation hardness measurements using gamma, neutrons and protons – need help
- Development of detector modules complete with digital signal processing electronics

Thank you

Questions: datta@capesym.com