Radiation Hardened Opto-Atomic Magnetometer (RHOM)

Progress Update

DOE Funding Opportunity: DE-FOA-0001770
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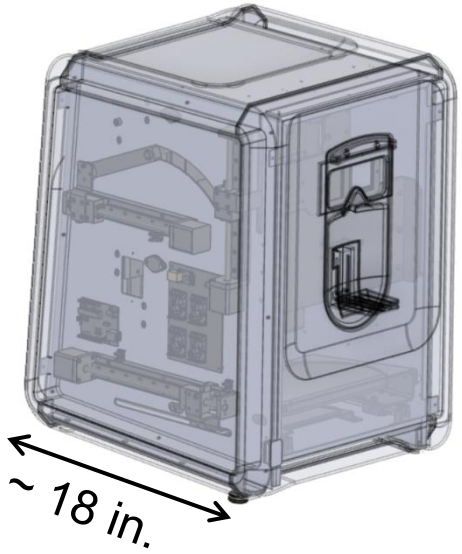
Subcontractor: Argonne National Laboratory (w/ Dr. Jerry Nolen, Jeongseog Song, Amy Renné, and Ravi Gampa)

Company Overview

Hedgefog Research (HFR) is a young (6 y.o.), fast growing company; its team has expertise in the fields of optical metrology/sensing, atomic/molecular spectroscopy, atom-based sensors, mass spectrometry, and electrical/mechanical engineering.

- **Optical system design** and **metrology/sensor development**
- ISO 13485:2016 certified
- Full-cycle product development



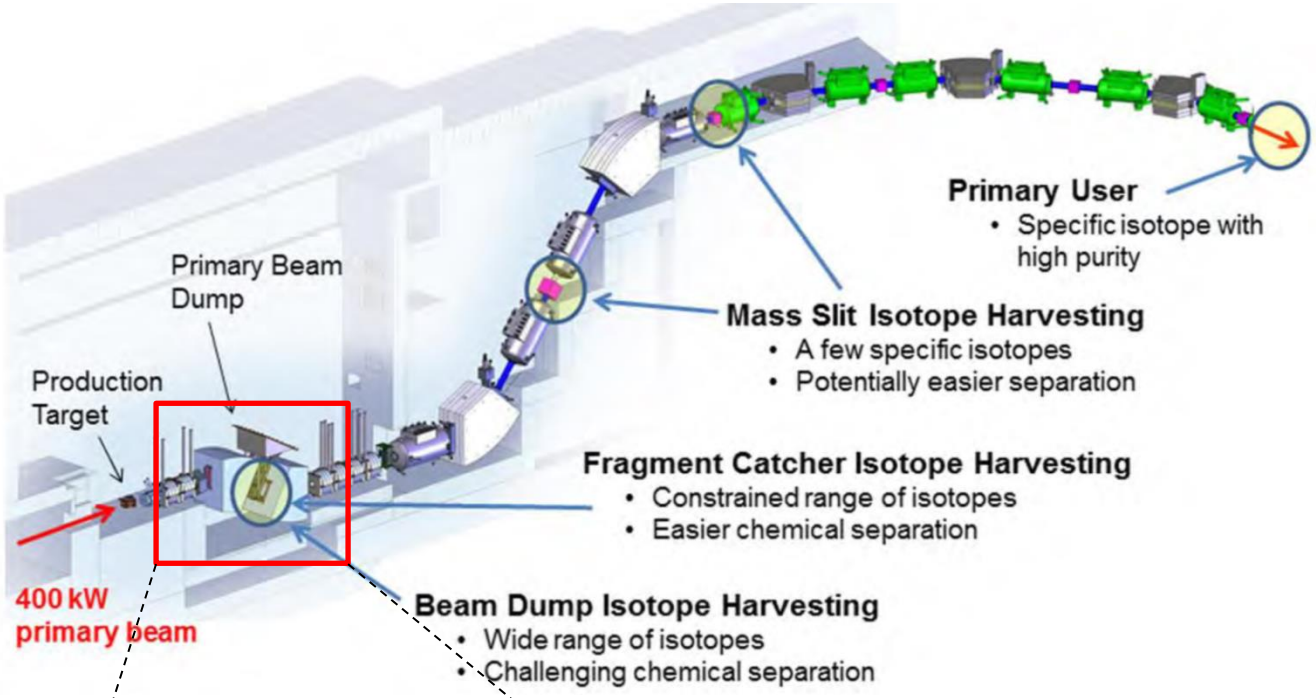
Automated Vision Tester *being developed for USAF*

- All-in-one vision tester for Air Force pilots
- SBIR Phase I started in 2016
- Currently in Phase IIB / Phase III

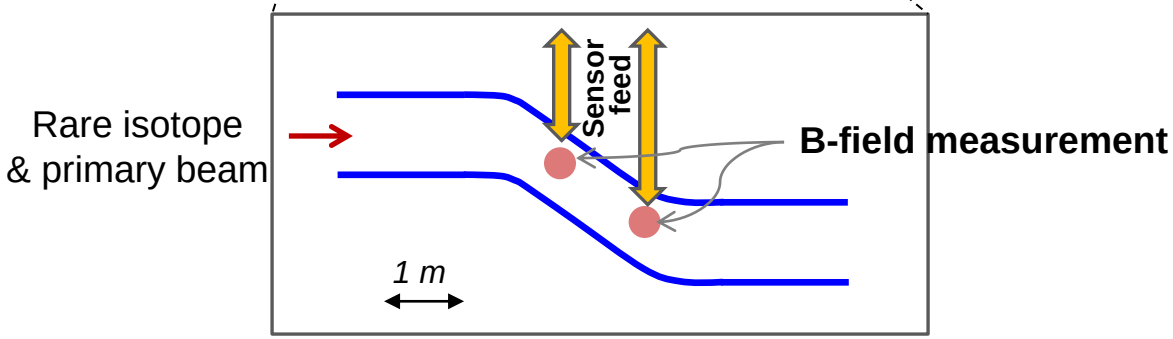
DOE Needs

- Magnetic-field sensing in high-radiation environments (gamma ray and **neutron**, **0.1 ~ 10 MGy/yr**), replacing NMR probes
- Target operation lifetime **> 1 year**
- Field range: **0.2 ~ 5 T**
- Precision ($\Delta B/B$) better than 10^{-4}, **10^{-5} desired**
- Field gradient (in one direction): 10^{-4} cm^{-1}
- Rep. rate: higher than 1 min^{-1}, **1 Hz desired**

Isotope Harvesting at FRIB



**** FRIB: Opening New Frontiers in Nuclear Science***
August 2012



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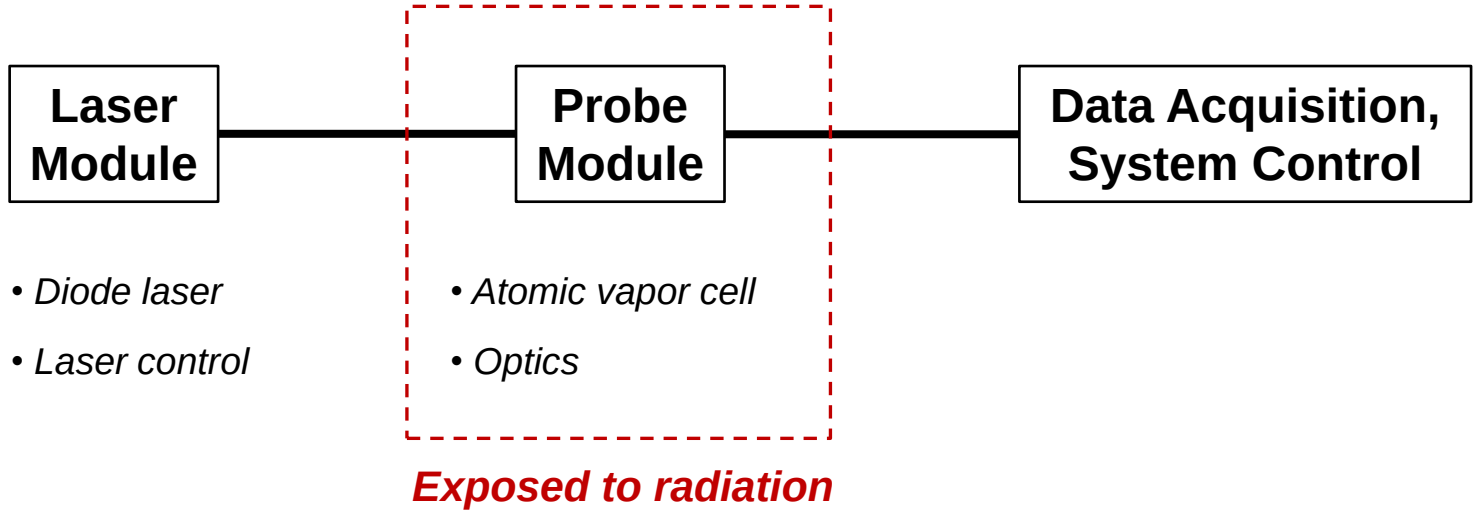
Radiation Hardened Opto-Atomic Magnetometer

- Contains **minimal number of radiation-hard components** exposed to radiation (glass cell, metallic mirror, optical fiber, mechanical housing)
- RHOM accuracy guaranteed by quantum mechanics; **no need for device calibration**
- Sensitivity better than **10^{-5} T**
- Relative precision **($\Delta B/B$) better than 10^{-5} at 1 T**
- **>1 Hz** sampling rate



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RHOM Phase II Accomplishments

- Developed a new probe module design
- Devised and tested a new optical scheme for precise measurement of magnetic fields
- Developed data acquisition and signal processing software, which, combined together, will provide a fully automated real-time magnetic-field sensing.
- Built, tested, and evaluated a full-scale RHOM prototype that provides a real-time measurement of a local magnetic field
- Performed a radiation hardness test of the RHOM optical fiber in a neutron-rich radiation environment with the help of the ANL team.

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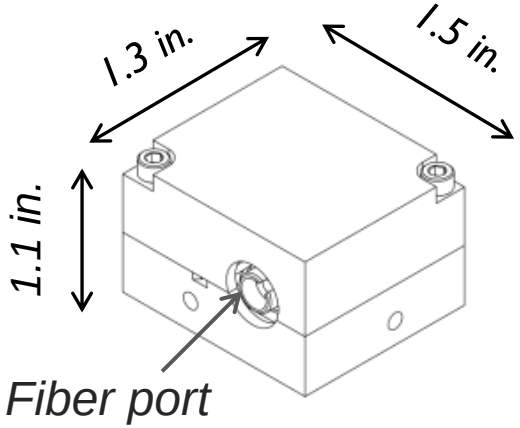
Phase II Probe Prototype and Test Setup

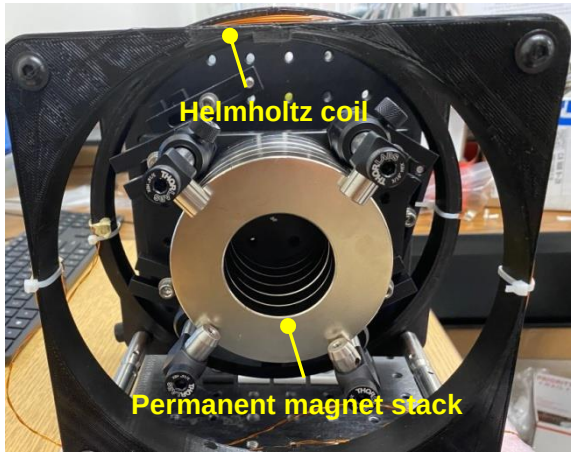


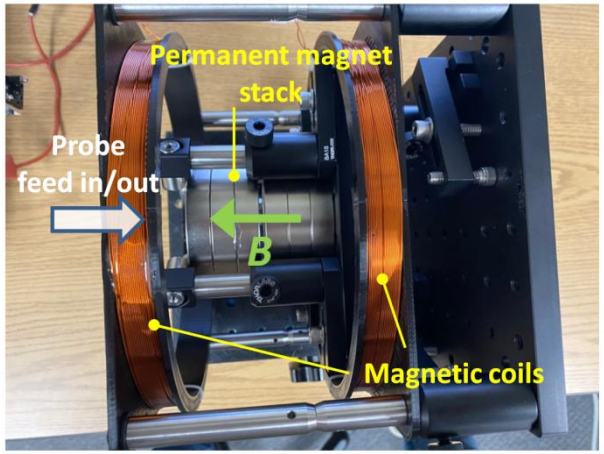
RHOM Probe

** non-magnetic construction*

Test Setup

Axial view





Side view

Magnet / Coil assembly (generating ~ 0.2845 ± 20×10^{-4} T)

Ring magnets *Helmholtz coil*

- Test field is significantly more inhomogeneous spatially than the field at FRIB

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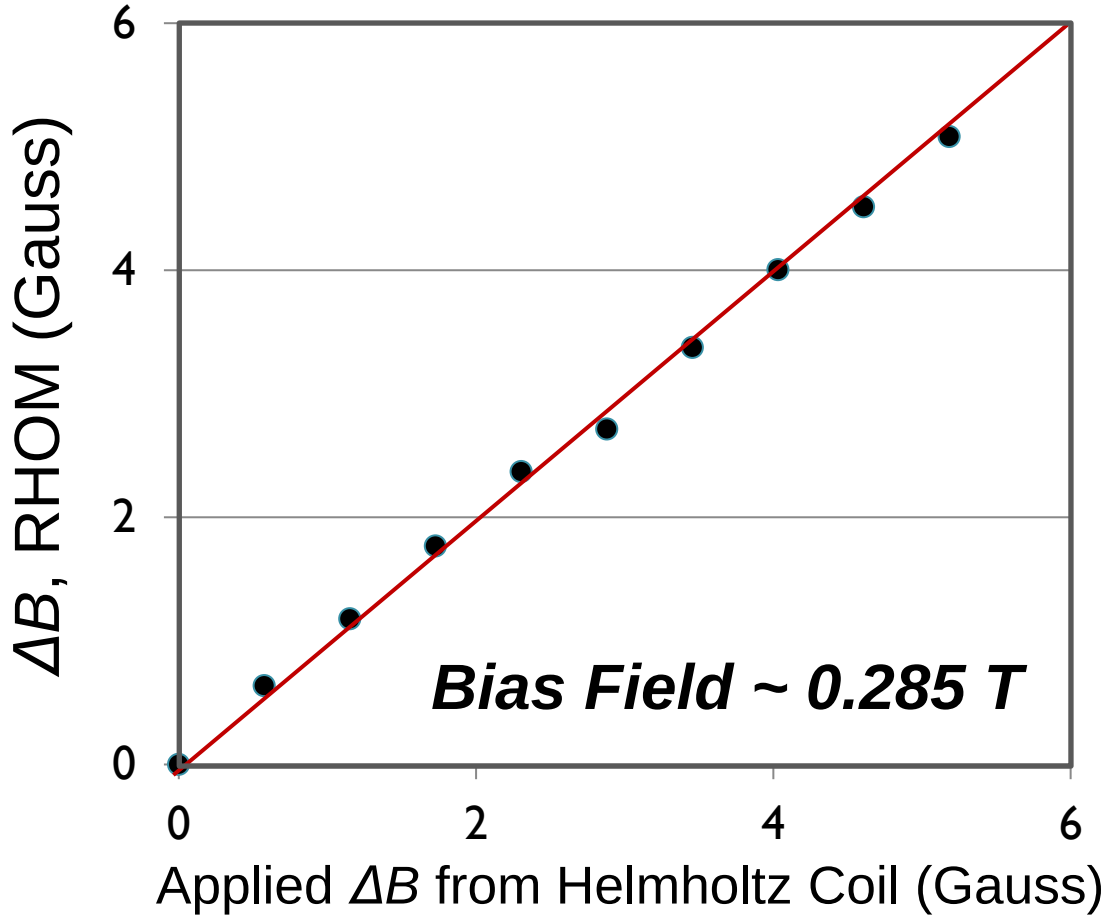
Magnetic Field Measurement



Calibration-free determination of magnetic field

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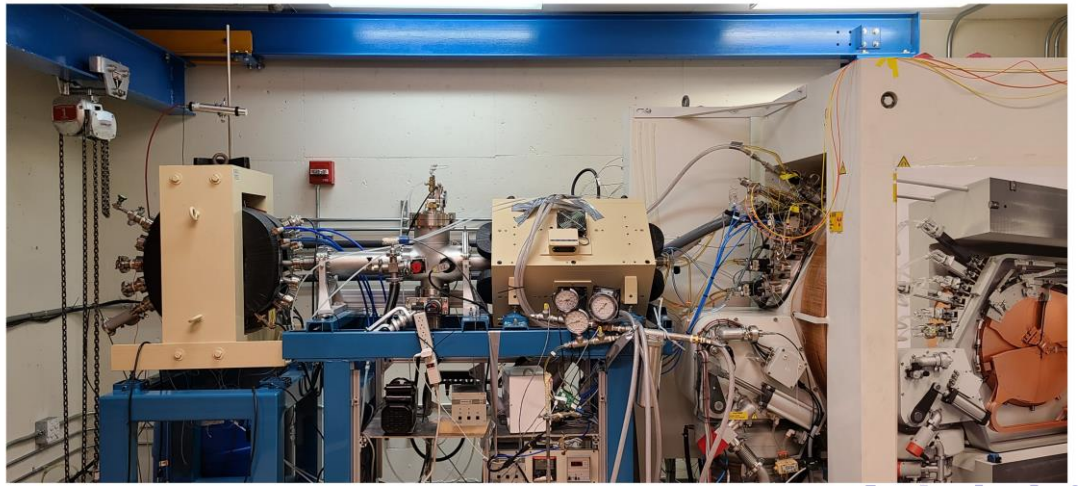
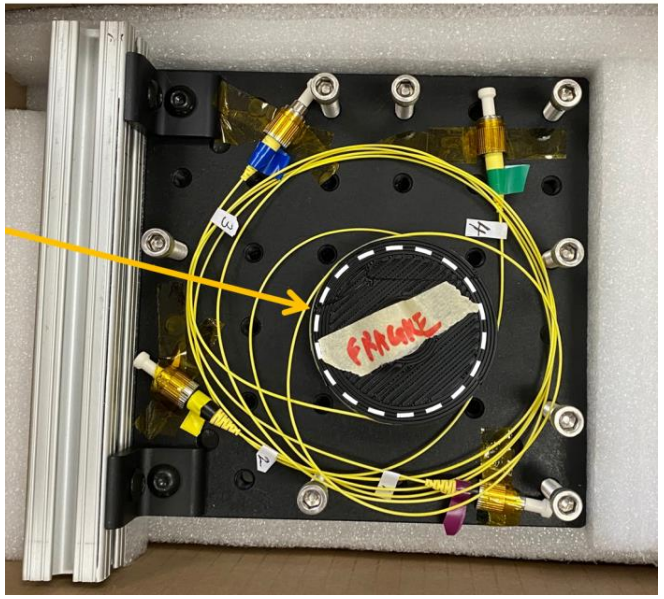
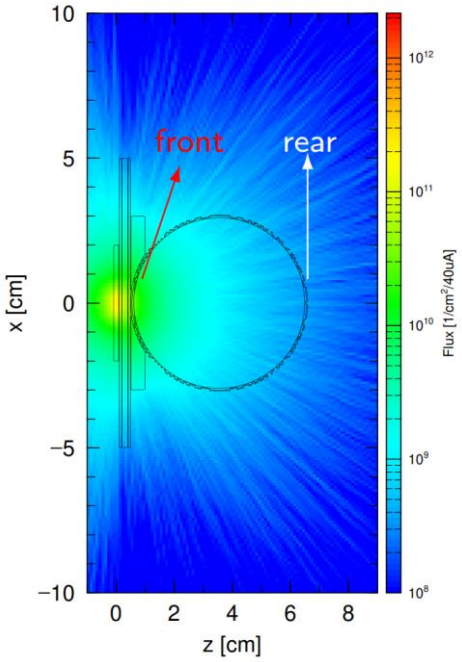
RHOM Phase II Radiation Hardness Test

- Radiation testing was conducted with the aid of Argonne National Lab
- ANL Point of Contact: Dr. Jerry Nolen
- Testing performed at the Medical Cyclotron at the University of Wisconsin, Madison
- Two fibers tested
  - Thorlabs single mode
  - Polymicro radiation hardened multimode
- Neutron dose equivalent to six days at FRIB







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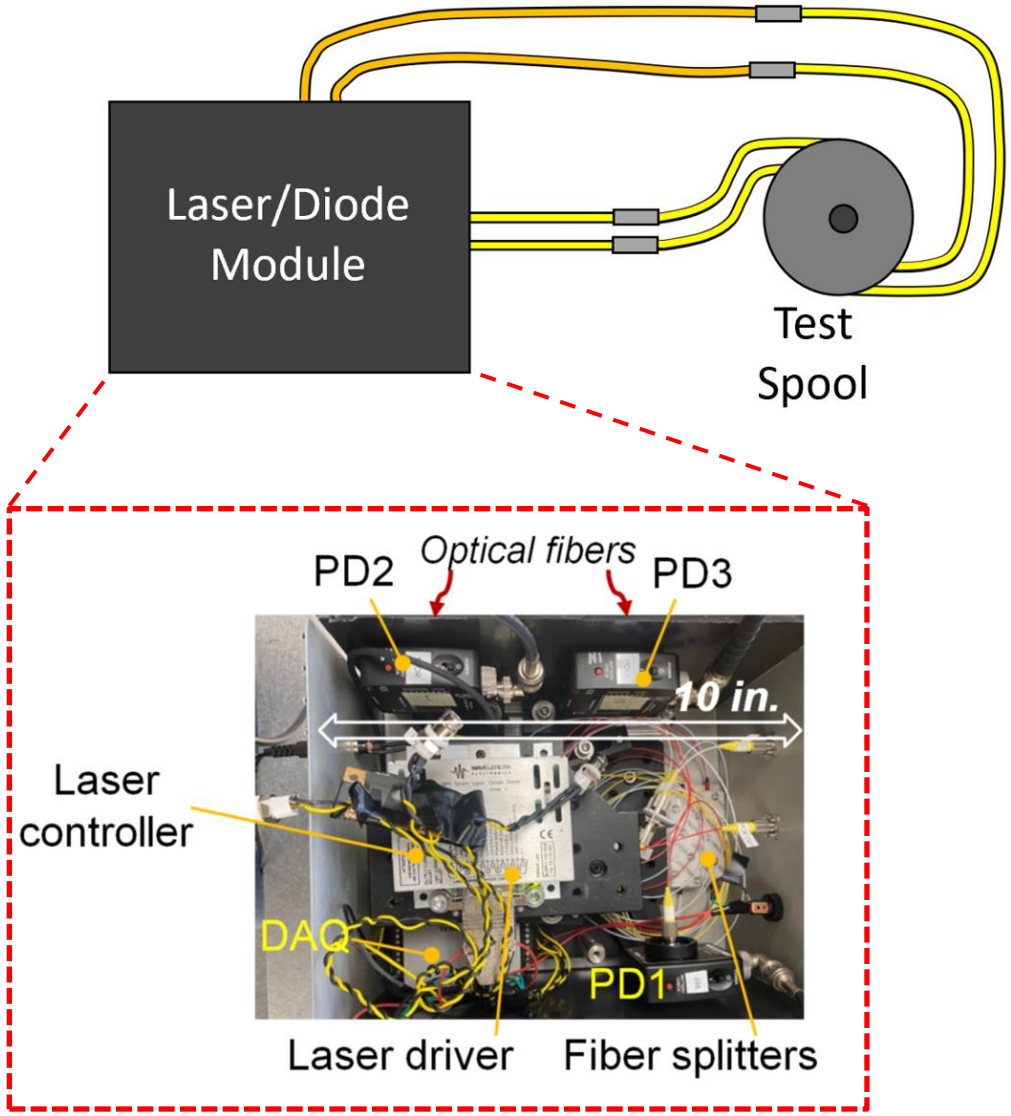
RHOM Phase II Radiation Hardness Test

- HFR designed a radiation test module
  - Laser diode and controller
  - Photodiodes
  - DAQ
- Laser light from the Laser/Diode Module was coupled into the test spool
- Real-time monitoring of fiber transmission during the radiation test



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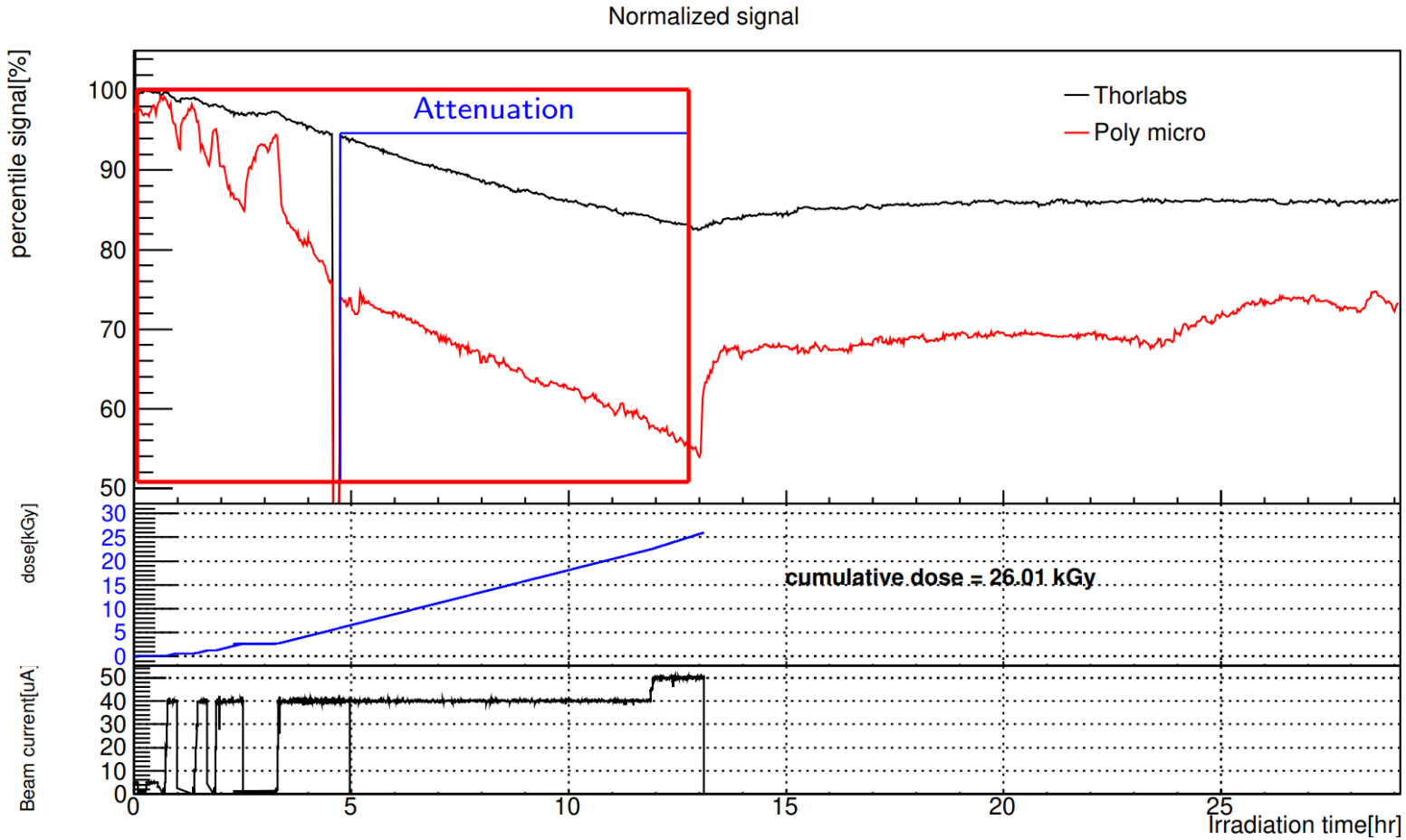
RHOM Phase II Radiation Hardness Test

- Single mode fiber displayed less radiation induced attenuation than was seen for the multi-mode
- Smaller core cross-section may account for the better performance
- For the single mode fiber estimated lifetime at FRIB is 240 days
- Decide whether to proceed with multi-mode or single mode fiber



RHOM Phase IIa Development Plans

Goals

- Continue to optimize both the optics and probe modules
- Develop DAQ/Control software for automated field determination
- Radiation testing of the entire probe module
- Development of a packaged beta prototype for RHOM

Current Work

- Optimizing probe layout and design
- Finalizing down-selection of laser system
- Developing the algorithm for the RHOM software

		Year 1												Year 2											
Task	Task Description	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1	Design Beta-prototype RHOM System																								
2	Down-select System Components for Beta-prototype RHOM																								
3	Assemble Beta-prototype RHOM Probe and Laser System																								
4	Test Beta-prototype RHOM in Laboratory Settings																								
5	Develop Fully Automated Beta-prototype RHOM Software																								
6	Perform Radiation-Hardness Test																								
7	Assess Performance of Beta-prototype RHOM																								
8	Enhance RHOM Performance on End User Feedback																								
9	Deliver Beta-prototype RHOM to DOE End User																								
10	Plan for Commercialization																								
11	Manage Program																								
	Milestones												①								②				③

Milestone 1. Completion of initial assembly and testing of beta-prototype.
Milestone 2. Radiation testing of RHOM probe.
Milestone 3. Delivery of beta-prototype RHOM to DOE end user.

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