CAPTURE GAMMA-RAY PRODUCTION CROSS SECTION MEASUREMENTS IN THERMAL NEUTRON CAPTURE ON MN, CU AND FE AT UMASS LOWELL RESEARCH REACTOR

MARIAN JANDEL

PHYSICS AND APPLIED PHYSICS

UMASS LOWELL

National Nuclear Security Administration

U.S. DEPARTMENT OF ENERGY | Office of Science

NSF

Learning with Purpose

Nuclear Applications and Nuclear Data Group at UML

UMASS LOWELL

MEASUREMENTS OF CAPTURE GAMMA RAYS AT UML THERMAL NEUTRON BEAM

- Measurements of capture gamma rays
  - DOE Office of Science: Mn-56 (2023-2026)
  - DOE Office of Science: Cu, Ni, Cr (2023-2027)
    - **New HPGe e-cooled detectors arrived in June 2024**
    - **Collaboration with BNL (co-PI Shuya Ota)**
  - NSF Career: Gd (2022-2027)
- NNSA: CENTAUR2.0 Texas A&M led SSAA consortium
  - Fe(n,g)
  - **Third HPGe detector purchase (2025)**
  - (2[illegible]-2029)

MOTIVATION

- A recent assessment of nuclear data libraries highlights current deficiencies and recommends materials for investigation, including Cu, Cr, Fe, Gd, Mn, and Ni [1,2].

Table 4. List of priority elements by tier to further prioritize the experimental work. These tiers should be allowed to evolve as the nuclear data libraries improve.

Experimental Priority	Elements
First	H, C, N, O, Na, Al, Si, Fe, Cu, Pb, W, U, Pu
Follow-up	He, Li, Be, B, Cl, Cr, Mn, Ni, Ge, Br, Cd, I, Cs, La
Remaining	F, Mg, P, S, Ar, K, Ca, Ti, As, Kr, Mo, Sn, Sb, Xe, Gd, Bi, Np, Np, Am

THE NEED FOR NEW DATA

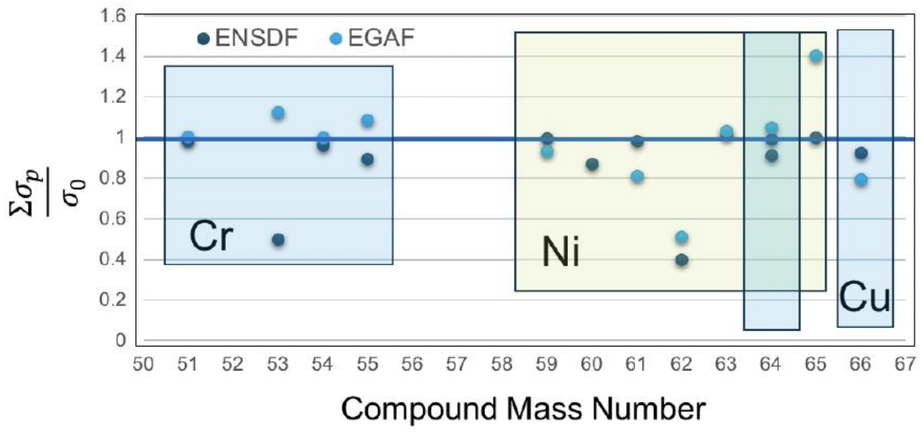


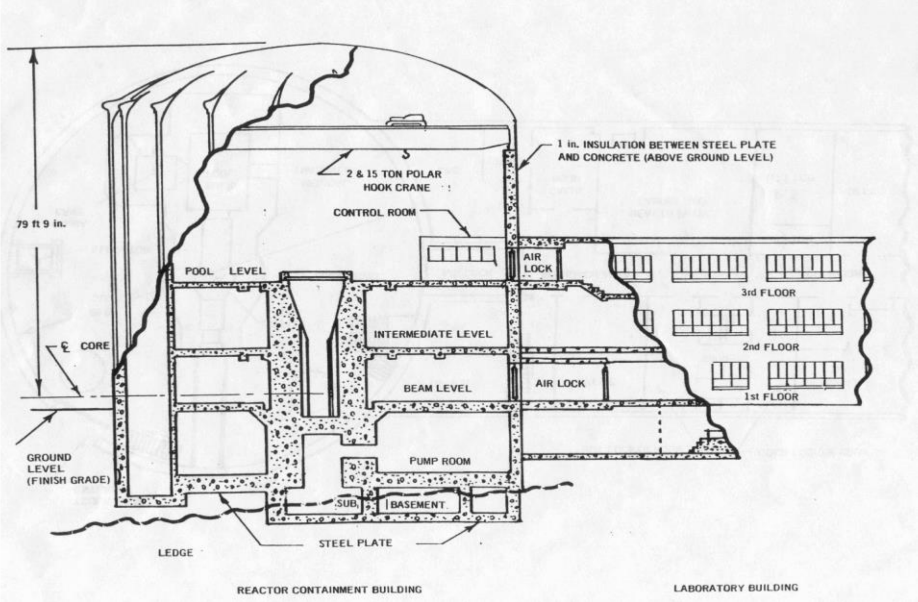
Figure 2 Ratio of the summed primary gamma-ray transition strength to the capture cross section for the Cr, Ni, and Cu isotopes. Data are plotted versus compound mass number (target +n). Data are compared for the ENSDF and EGAF libraries.

- New evaluations of **Fe** and **Cu** are required given their key role in the construction of nuclear infrastructure and reactor design, as well as nucleosynthesis via the *r*- and *s*-*processes*
- The large capture cross section of **Gd** makes it a candidate for neutron capture therapy (NCT) and neutron detectors

[1] M. Jandel, et al., Neutron capture measurements at UMass Lowell research reactor, Nuclear Physics A, Volume 1060, 2025
[2] S. McConchie et al., Assessment of Modeling and Nuclear Data Needs for Active Neutron Interrogation, ORNL TM-2021/1900, April 2021

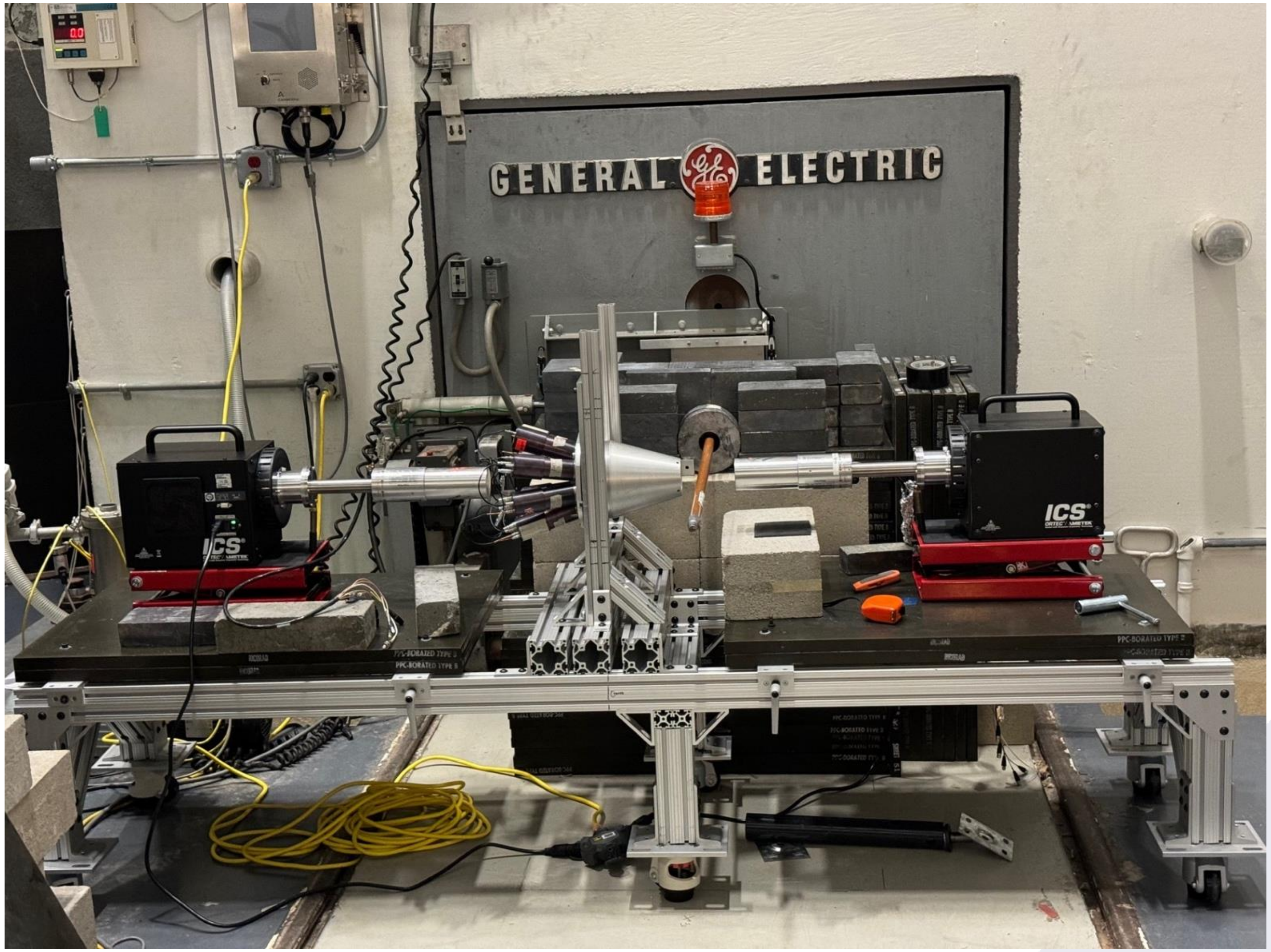
UML RESEARCH REACTOR

- Pool of 75,000 gallons of demineralized water
- Steel reinforced concrete
- Welded steel shell
- Extends 30’ below grade
- Ventilation isolation system designed and tested to be pressure tight



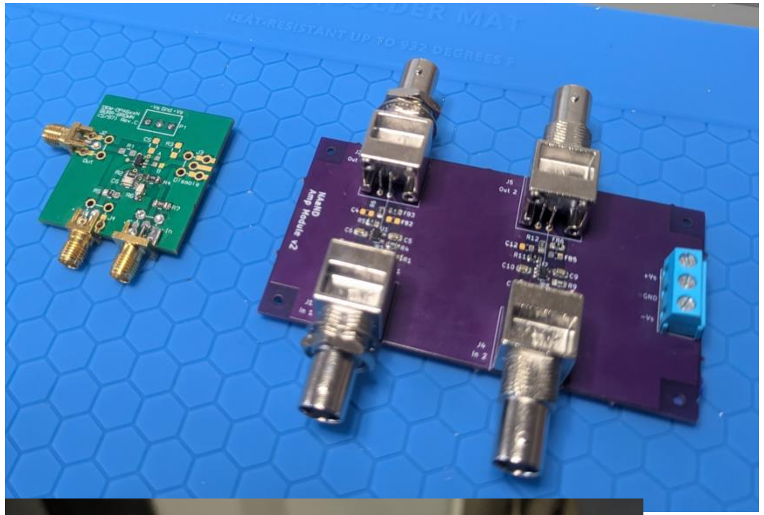
EVOLUTION OF THE EXPERIMENTAL SETUP 2024 - FAIRRAY

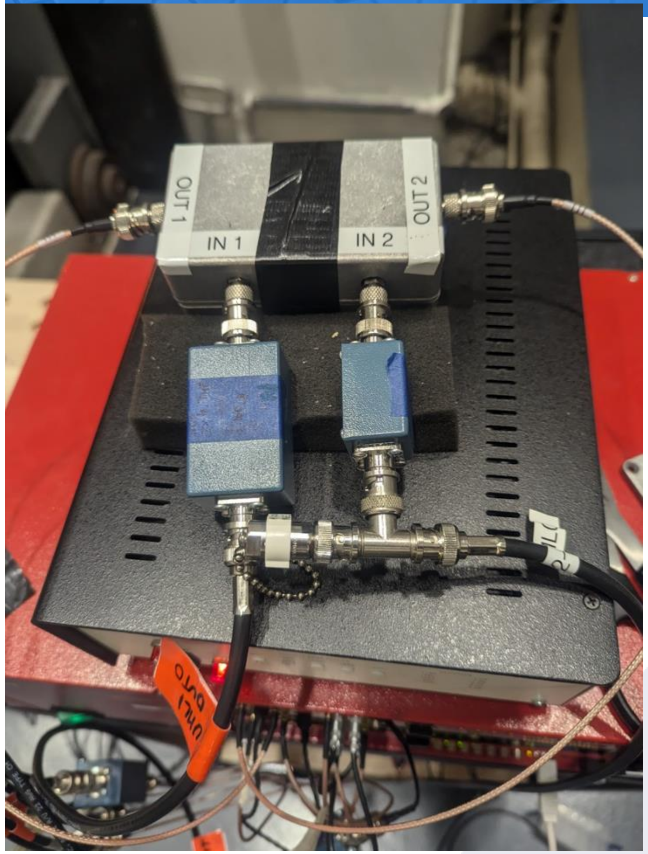
- **Dedicated detectors Ecooled acquired June 2024**
- **Transistor Reset Preamp – capable of high rates**
- **1 Compton Active Shielding**
- **In future, dedicated 100% HPGe will be added to the FAIRRAY**
- **Added Borated Silica wrapping around both HPGe**



CUSTOM ELECTRONICS FOR FAIRRAY

- Work by Graduate student – Daniel Fernandez
- Transistor Reset Preamp signals are the staircase voltage signal from -0.5V to -7.5V followed by a 5us long reset
- We developed a custom amplifier, based on Texas Instruments OPA657 low noise amp in non-inverting configuration. AC coupling forms 5us high pass filter on input.
- Good performance – no loss in resolution up to 50 kHz – recovers quickly after reset pulse (total ~10us)

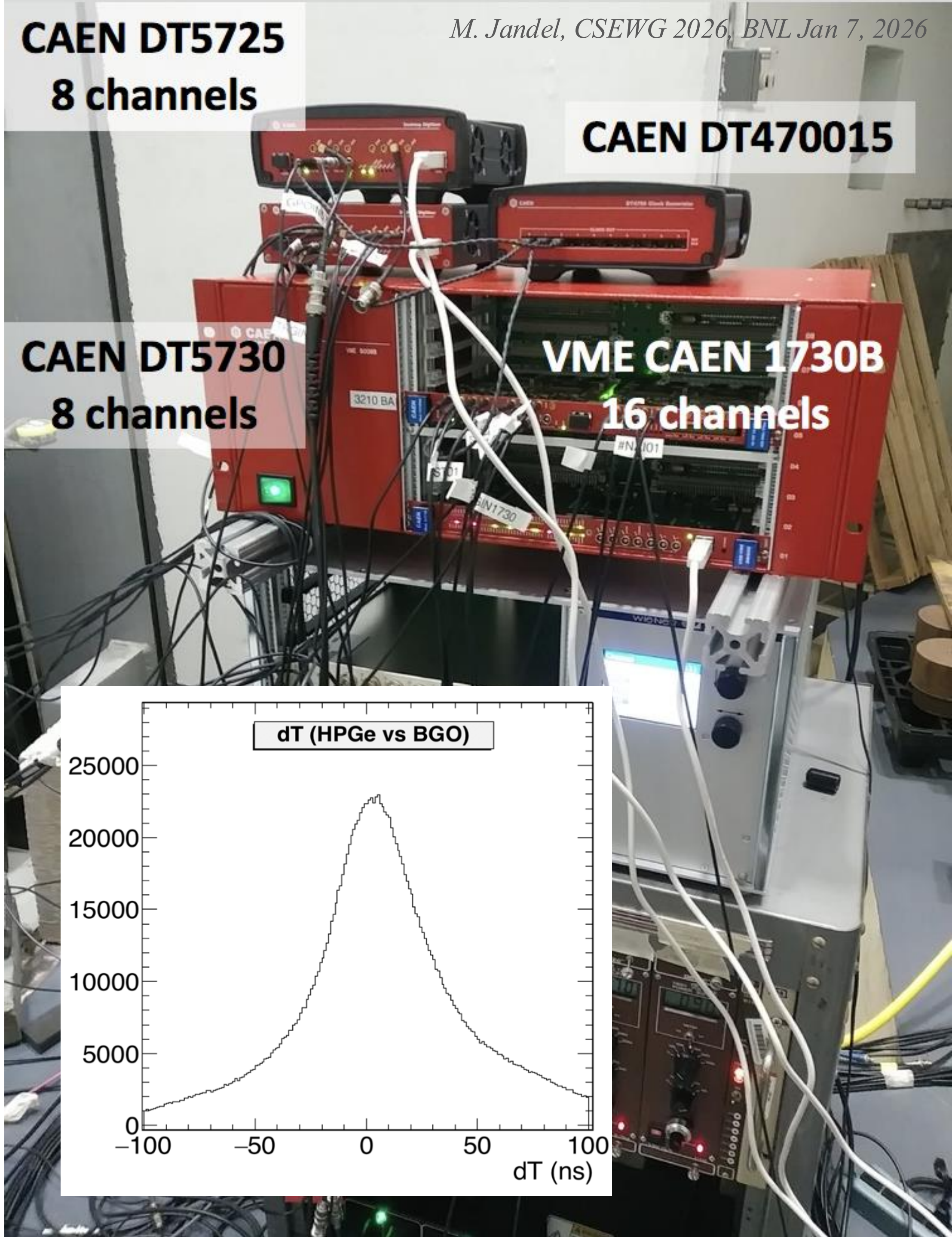




UMLDAQ – DATA ACQUISITION

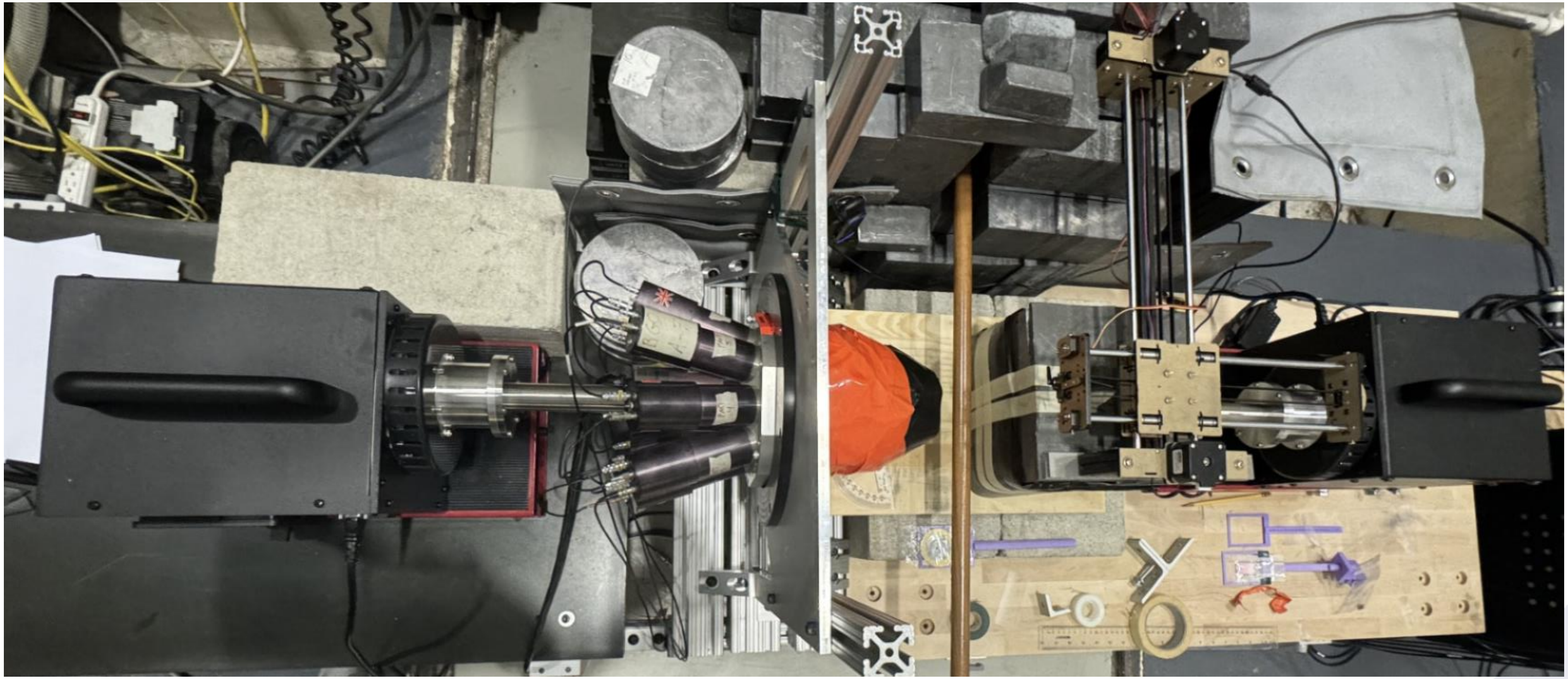
- UMLDAQ – based on CAEN hardware, software drivers and C++ libraries
- Asynchronous data acquisition using FPGA digital pulse processing
- VME based:
- 16 channel 14-bit 500-MHz CAEN V1730
- Two 8 channel x 14-bit 500-MHz CAEN V1730
- In house DAQ frontend and backend codes

- HPGe are using PHA firmware with trapezoid filter (4 channels)
- BGO/NaI are using PSD firmware using pulse integration (8 channels)



MNCL2 –FAIRARRAY 2024/25

- Sample of 1.16 g of $MnCl_2$ at 1 MW (improved shielding)
- October – accrued ~26 hours at 1MW



MNCL2 – PRELIMINARY – MAD ARRAY 2023/24

- Sample of 1.16 g of $MnCl_2$ (Sigma Aldrich)
- Accrued ~26 hours at 1MW

$$N_\gamma^{Cl} = \Phi_\nu A_{beam} t \sigma_\gamma^Z(\varepsilon_\gamma^{Cl}) N_{target}^{Cl} \epsilon_{geo} \epsilon_{PE}(\varepsilon_\gamma^{Cl})$$

$$N_\gamma^{Mn} = \Phi_\nu A_{beam} t N_{target}^{Mn} \sigma_c I_\gamma(\varepsilon_\gamma^{Mn}) \epsilon_{geo} \epsilon_{PE}(\varepsilon_\gamma^{Mn})$$

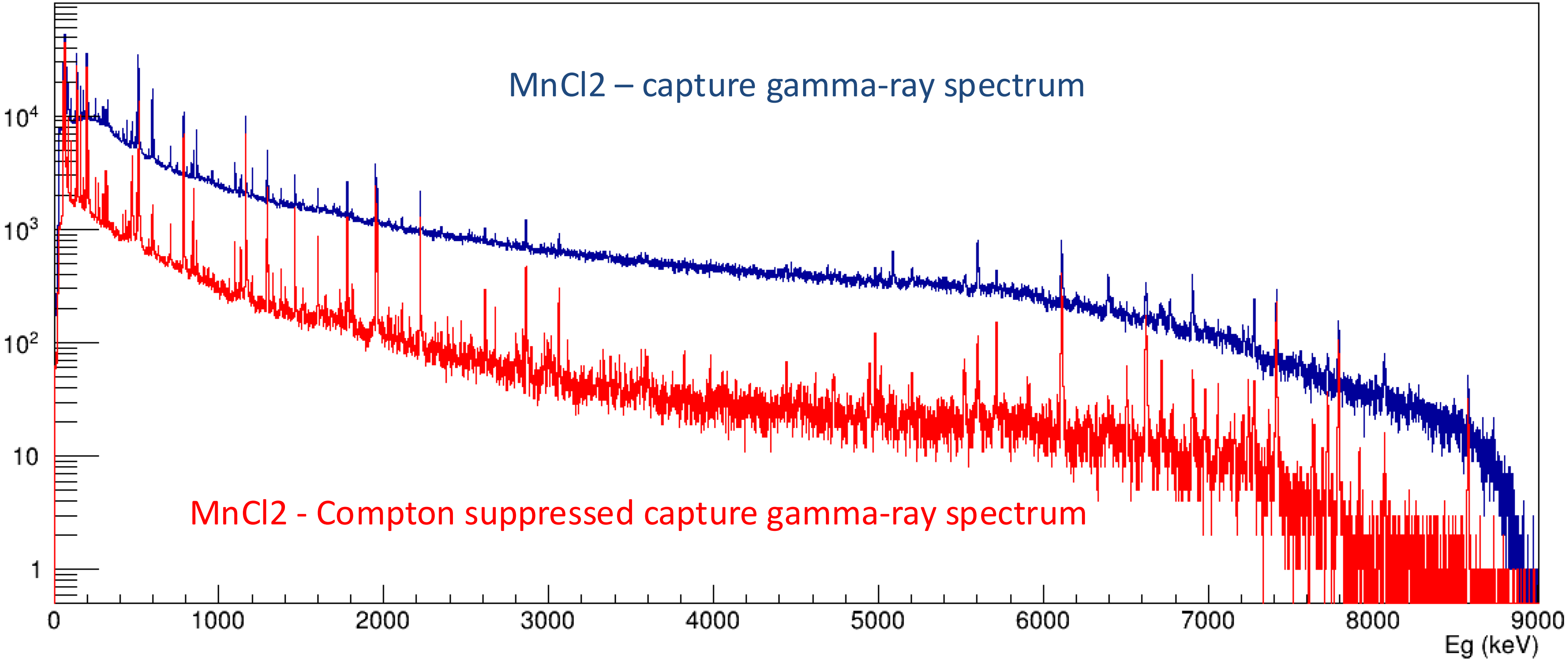
$$I_\gamma(\varepsilon_\gamma^{Mn}) = 2 \frac{N_\gamma^{Mn}}{N_\gamma^{Cl}} \frac{\sigma_\gamma^Z(\varepsilon_\gamma^{Cl})}{\sigma_c} \frac{\epsilon_{PE}(\varepsilon_\gamma^{Cl})}{\epsilon_{PE}(\varepsilon_\gamma^{Mn})}$$

- N_γ: photopeak area
- ϵ_{PE}: photoelectric efficiency
- σ_γ^Z: γ-ray production cross section of ^{35}Cl
- σ_c: thermal capture cross section of ^{55}Mn

PhD thesis of Alex Howe (in progress)

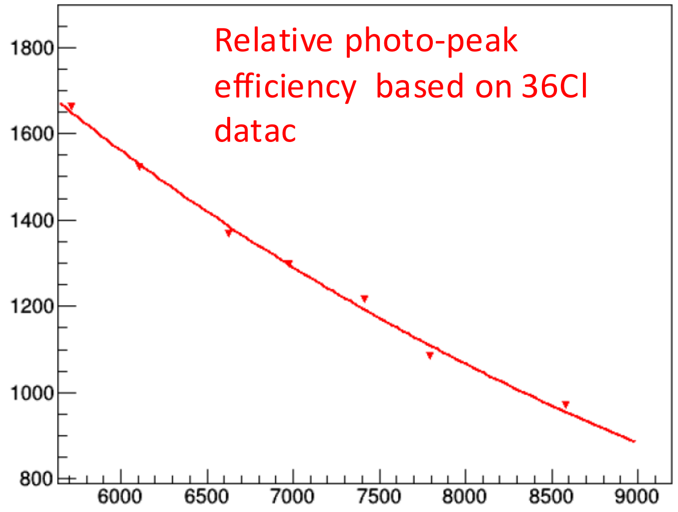
MNCL2 –PRELIMINARY – FAIRRAY 2024

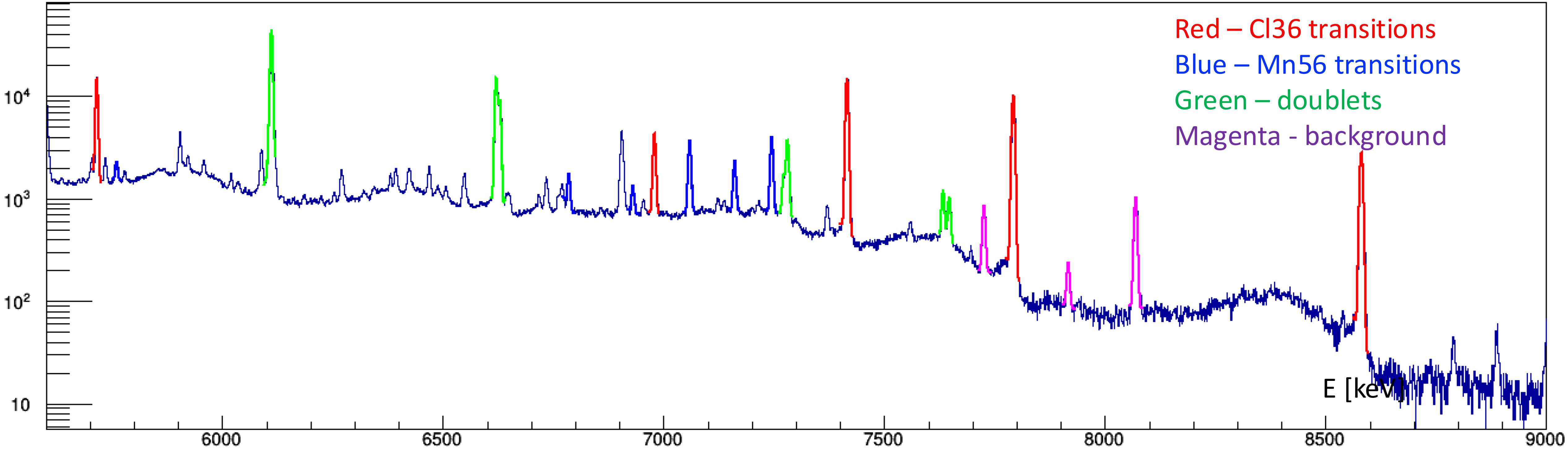
- Sample of 1.16 g of $MnCl_2$
- Sigma Aldrich



MNCL2 B& MN – FAIRARRAY 2024

- Sample of 1.16 g of $MnCl_2$
- Running at 1 MW (21 hours shown)
- Data needs subtraction of blank sample background !
- PRELIMMINARY analysis



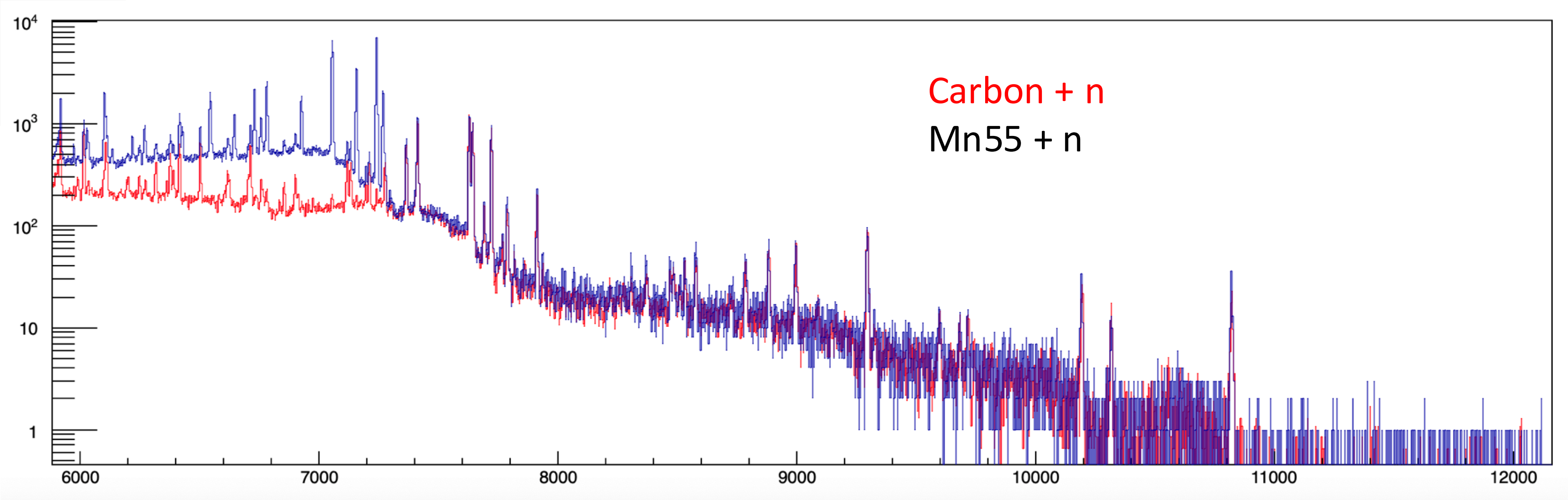


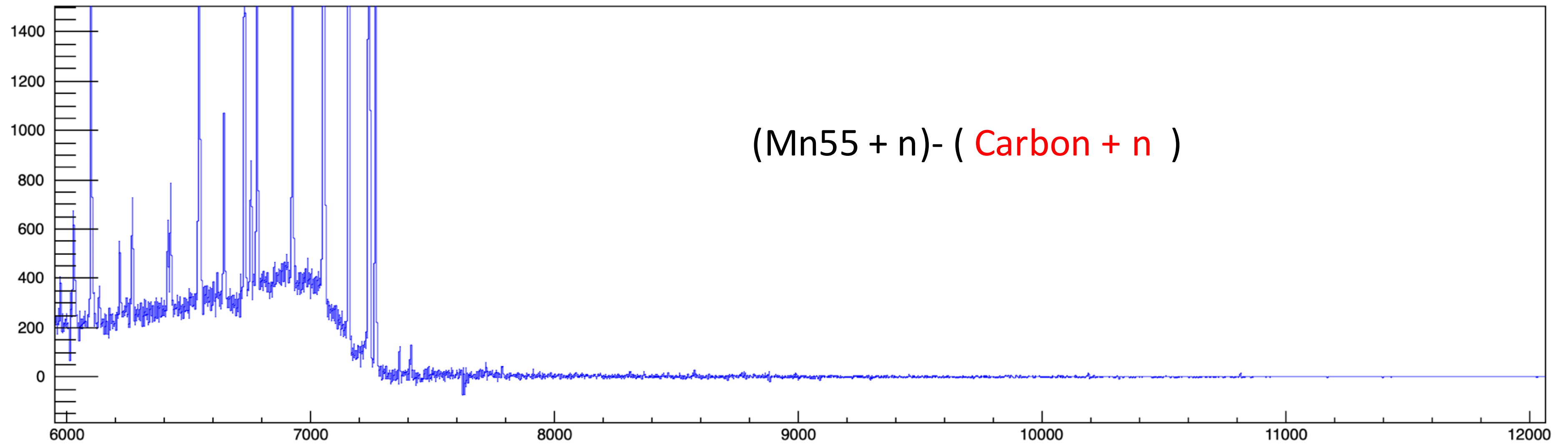
DATA ANALYSIS

- Key factors in the analysis
- Energy calibration and gain matching
- Detection efficiency for full-energy peaks
  - Ideally extends over full dynamic range: 20 keV – 10 MeV
  - Several parametrizations are considered
- Continuum background subtraction
  - Identifying background components
  - Ambient + scattering
- Peak fitting
- Final normalization

DATA ANALYSIS - SCATTERING BACKGROUND

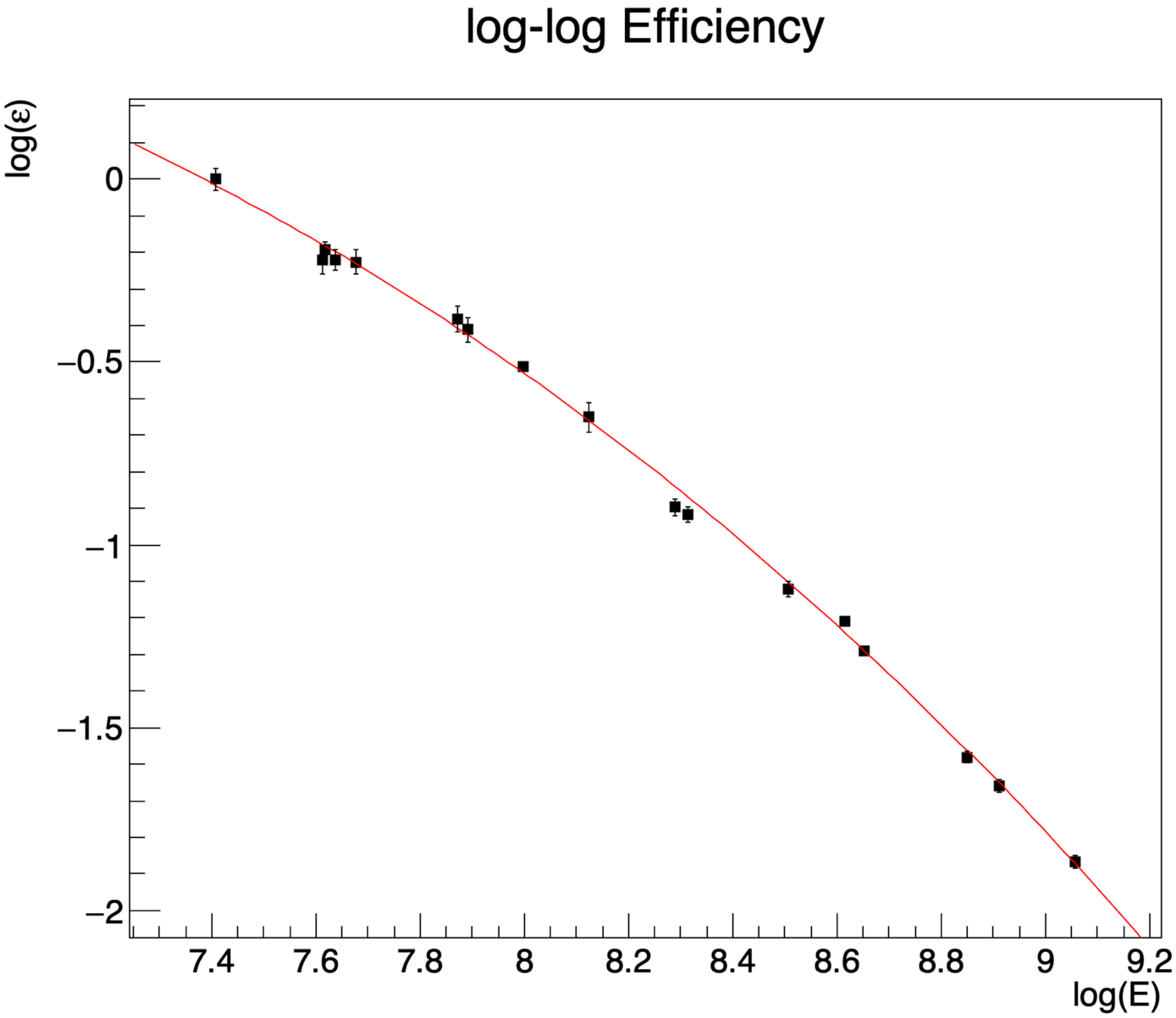
- Continuum background subtraction
  - Ambient + scattering
- We take data on C+n (graphite)





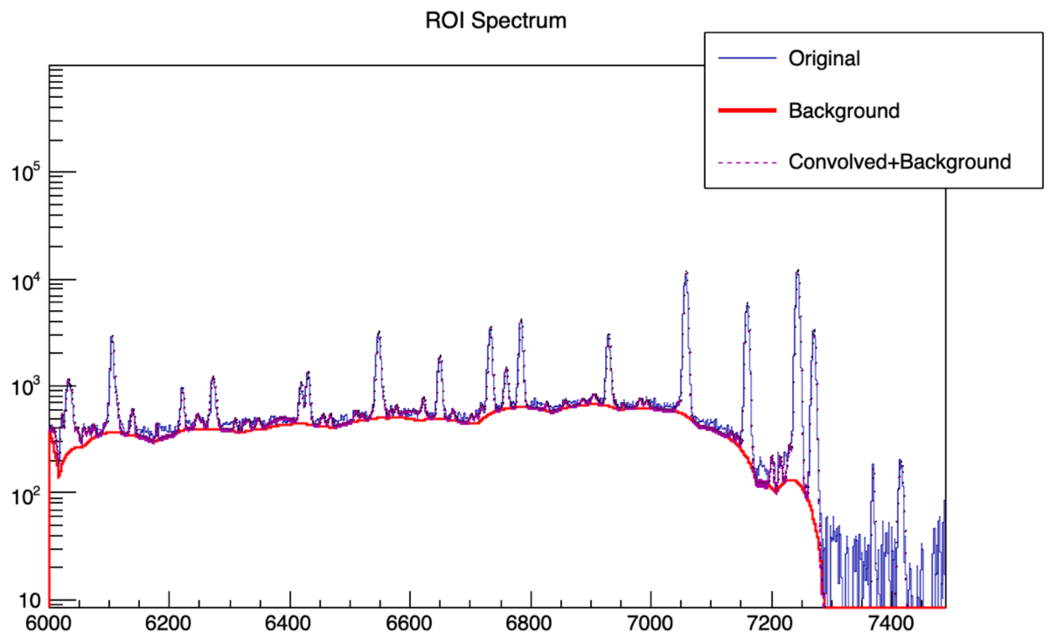
DETECTION EFFICIENCY

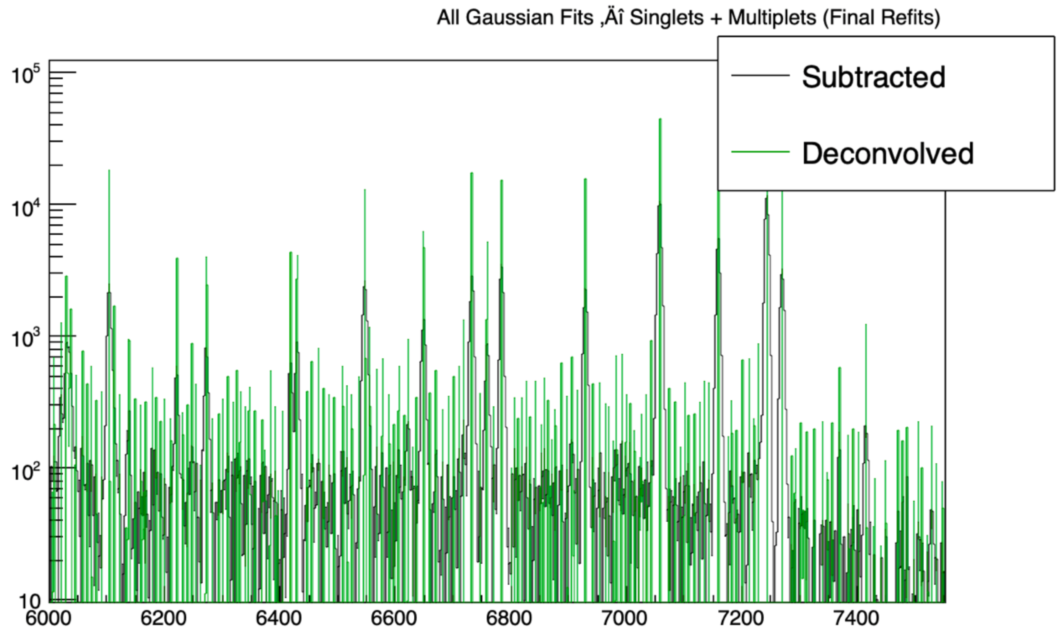
- Eu152 & Cl(n,g)
- Detection efficiency for fully energy peaks
  - Ideally extends over full dynamic range: 20 keV – 10 MeV
  - Several parametrizations are considered
- 3rd order polynomial in log-log
- Only high energy shown



DATA ANALYSIS

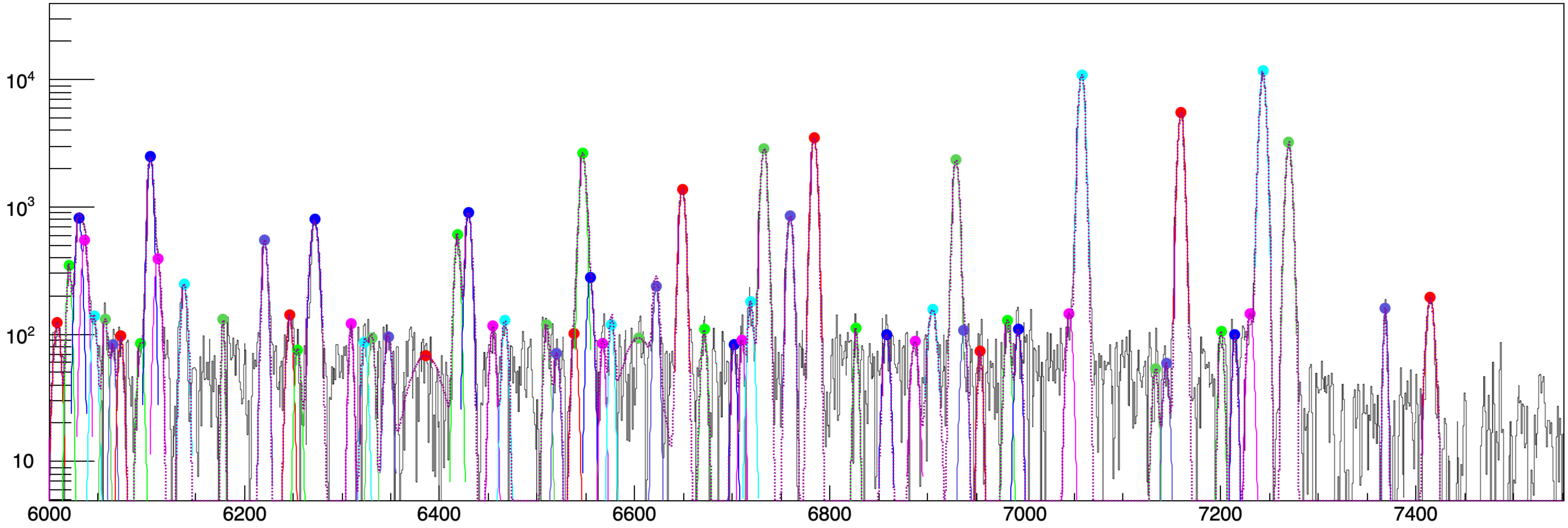
- Peak fitting
- Using ROOT-TSpectrum methods
  - Gaussian deconvolution to identify peaks
  - Multiplets fitting – regression
  - Monte-Carlo improvements to the fit parameters
- Final normalization





DATA ANALYSIS - PEAK FITTING

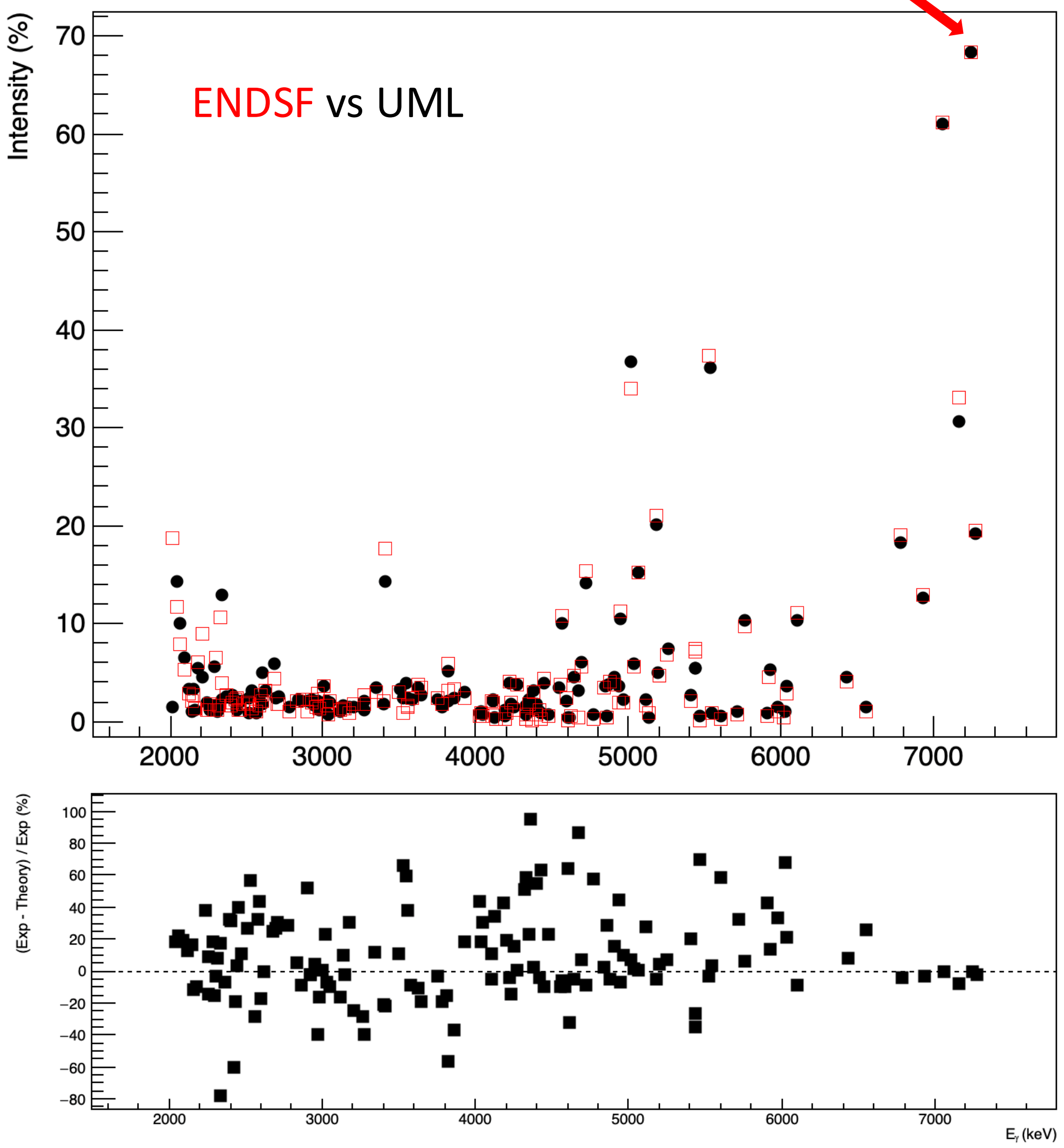
- Using TSpectrum methods
  - Gaussian deconvolution to identify peaks
  - Multiplets fitting – regression
  - Monte-Carlo improvements to the fit parameters



DATA ANALYSIS – MN55+N (ENDSF VS UML)

- Final normalization
  - Normalized to ENDSF at 7243 keV
- This is preliminary
- We will obtain Mn55(n,g) intensities relative to Cl(n,g)

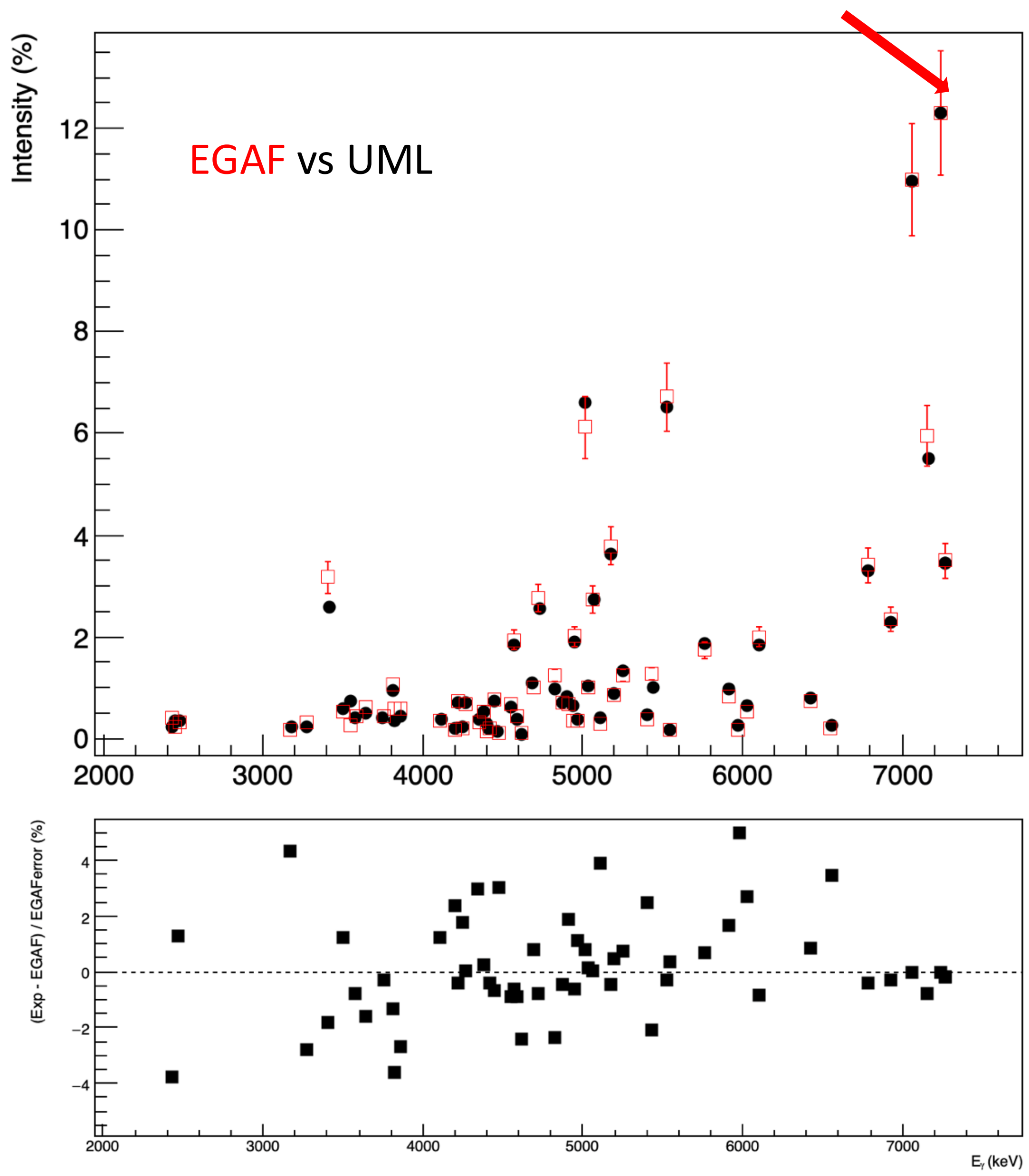
Normalized Gamma-ray Intensities



DATA ANALYSIS – MN55+N (EGAF VS UML)

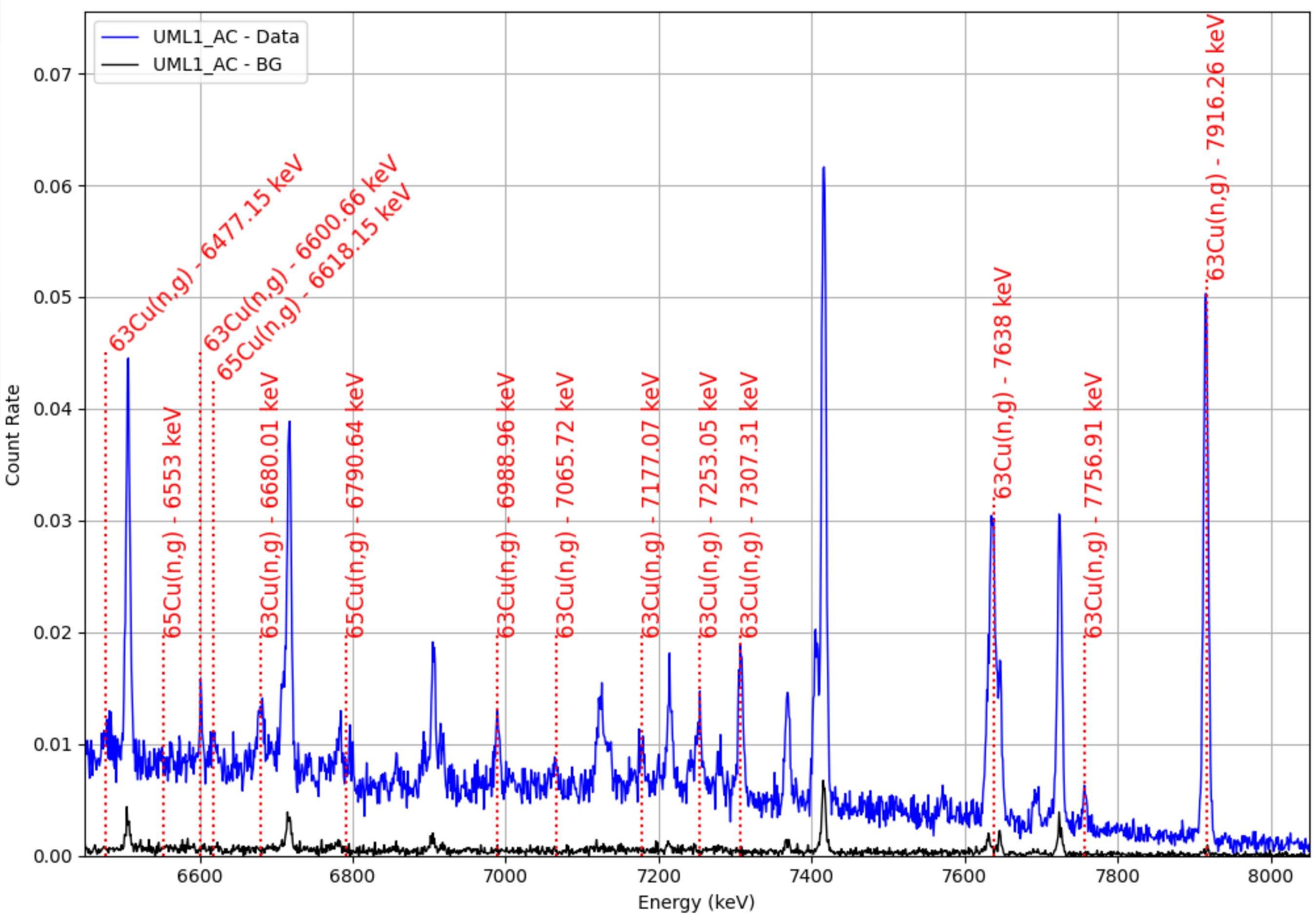
- Final normalization
  - Normalized to EGAF at 7243 keV
- This is preliminary
- EGAF claims 10% errors for strong primaries and larger for secondary
- Here we have used 10% for all
- Our errors are significantly smaller
- We will obtain Mn55(n,g) intensities relative to Cl(n,g)

Intensity per 100 captures



CU(N,G) – MORE MEASUREMENTS IN 2026 PLANNED

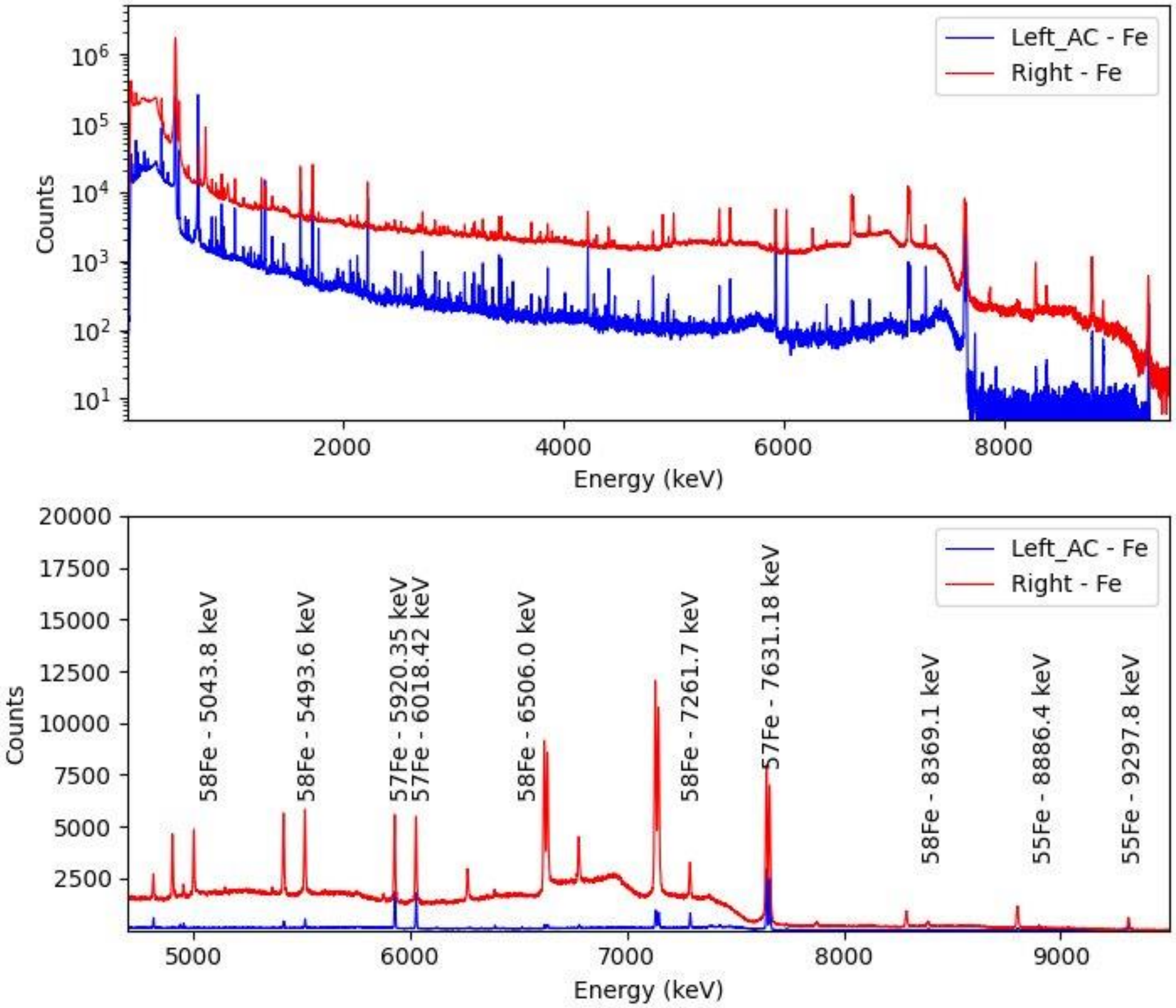
- Sample of 1g of natural Copper - ~20 hours
- Analysis by Daniel Fernandez – grad student of UML



Capture Gamma-ray spectra:
- Blank background data
- Copper

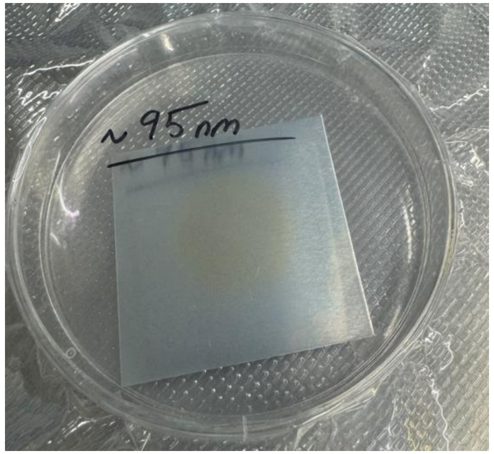
FE(N,G) - FUTURE MEASUREMENTS FOR CENTAUR2.0 IN 2026-27

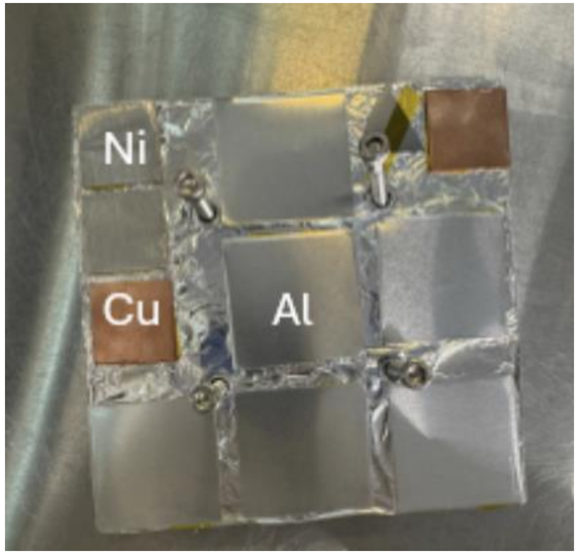
- Daniel Fernandez is currently working on designing the neutron capture experiment on Fe isotopes at Umass Lowell Research Reactor.
- Preliminary data taken in May (shown in the Figure on the left)
- Long measurement planned in 2026
- First measurements on 57Fe in 2026



THIN FILMS DEPOSITION – LOCAL UML CAPABILITY

- UML's Core Research Facilities
  - Collaboration with J. Moreau – head of The **Nanofabrication Lab** - E-Beam Evaporator (CHA)
- We can evaporate up to 150 nm thick uniform Gd films
- Superior uniformity and thickness control
- Important for cross section analysis and reference measurements
  - Gd/Ni, Gd/Cu etc





CU+GD(N,G)

- We deposited 150 nm of Gd on 1mm thick Copper backing

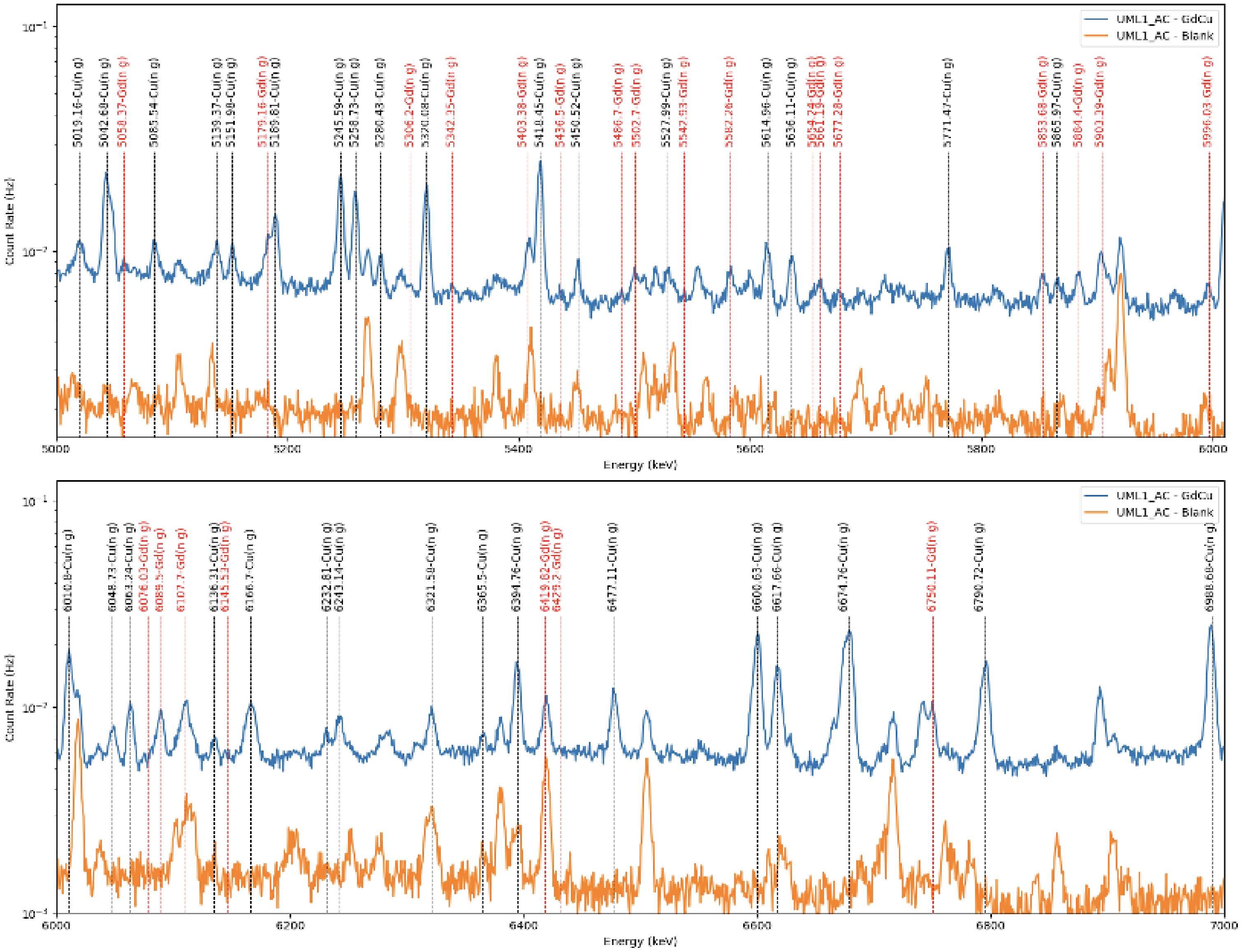
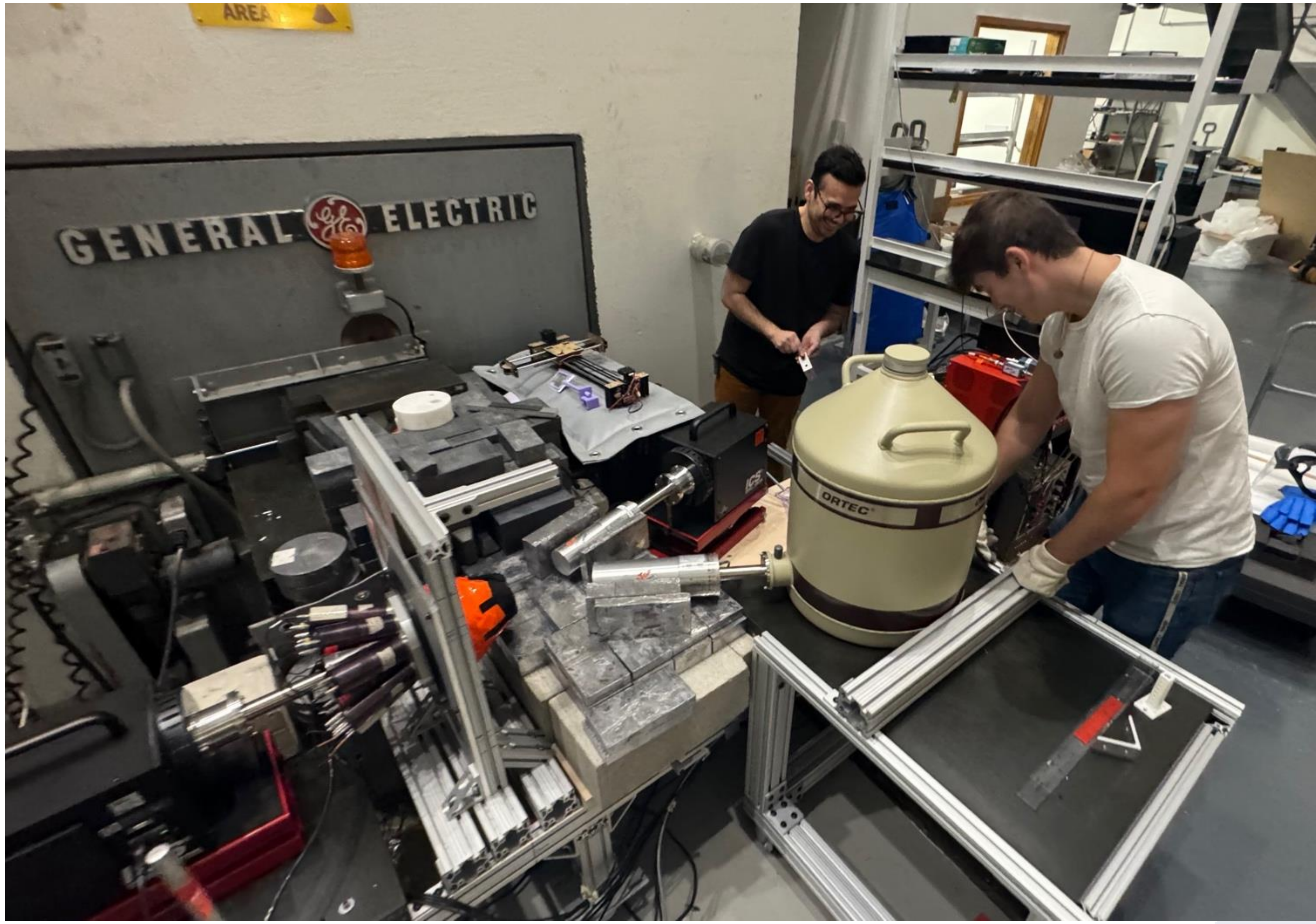


Figure 9 – Gamma spectra between 5-9 MeV with annotated photopeaks correspondi
Gd (red) and Cu (black) neutron-capture

NEW SETUP IN 2026

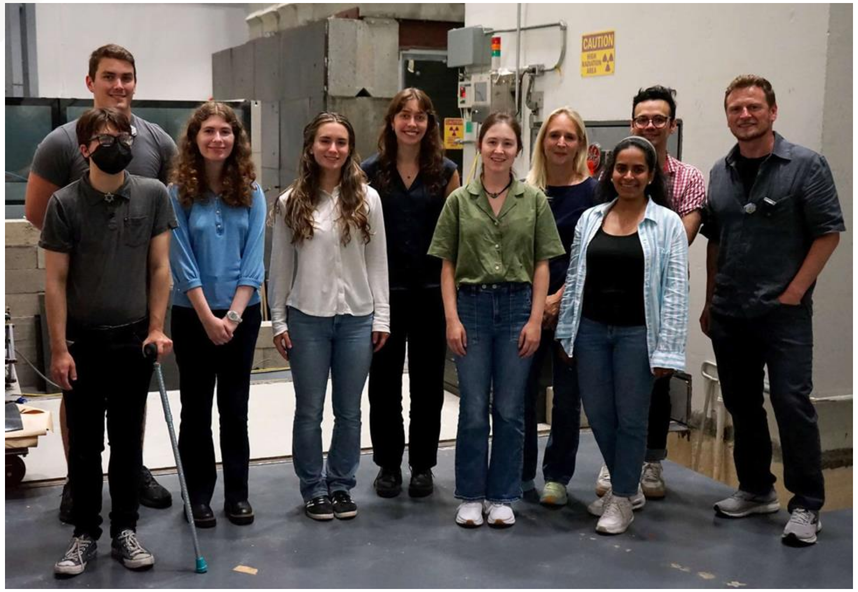
- Adding 65% BNL HPGe detector
- 1 more HPGe + ICS should arrive in March 2026
- Move to MESYTEC (+CAEN) DAQ



ACKNOWLEDGEMENTS

Nuclear Applications and nuclear data group at UML

- UML Reactor Staff: Leo Bobek, Tom Regan, Kseno Konomi, Tim Rogers
- UML Undergrads: Michael McGlynn (now in UK), Michael Wooldridge, Tabor Morin
- UML Grad students: Alex Howe (RA), Daniel Fernandez, Aaron Fishbein
- Stan Valenta, Milan Krticka (Charles University, Czech Republic) – DICEBOX, data analysis
- UML Nuclear Structure Group: P. Bender, P. Chowdhury, K. Lister
- E. Ricard-McCutchan, A. Sonzogni, S. Ota, Brookhaven National Lab.



Work is supported by:
- U.S. Department of Energy Funding for Accelerated, Inclusive Research (FAIR) under Award No. DE-SC0024373.
- U.S. Department of Energy, Office of Science/Nuclear Data under Award No. DE-SC0022907.
- National Science Foundation Grant No. 2144226
- DOE National Nuclear Security Administration under Award Number DE-NA0004150

U.S. DEPARTMENT OF ENERGY | Office of Science

National Nuclear Security Administration

NSF

UMASS LOWELL