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

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U.S. DEPARTMENT OF ENERGY | Office of Science
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Learning with Purpose

Nuclear Applications and Nuclear Data Group at UML

UMASS LOWELL

MOTIVATIONS: ^{55}MN(N,G) DISCREPANCIES

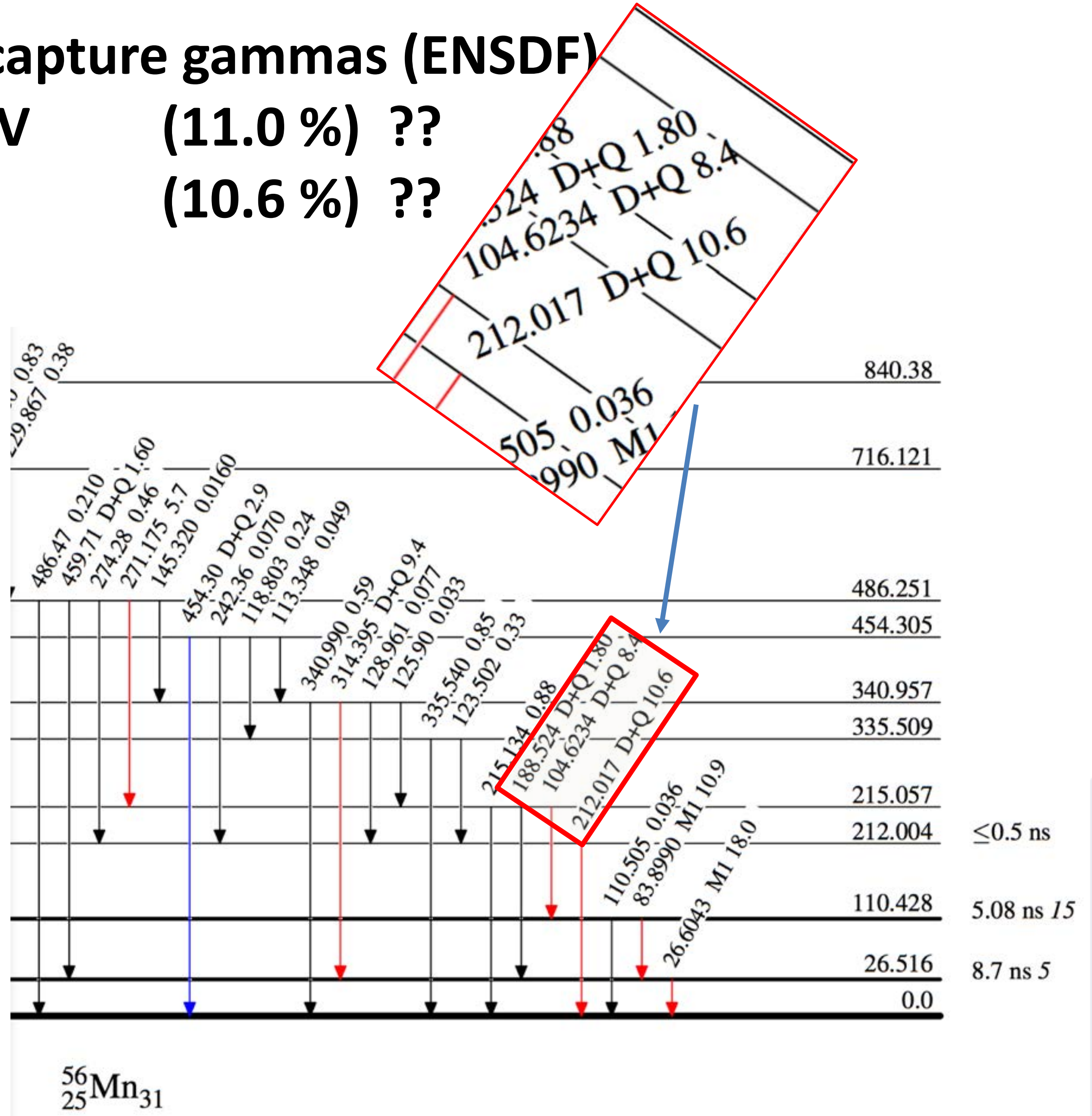
In collaboration with Brookhaven National Laboratory

Mn-56 capture gammas (ENSDF)

7058 keV (11.0 %) ??

212 keV (10.6 %) ??

- Data is typically older obtained with single HPGe shielded detector
- Pileup/deadtime correction and normalization procedures can be complicated
- Gaps and discrepancies found in data
- Improve ENDF to ENSDF correspondence



- Supported by U.S. Department of Energy, Office of Science/Nuclear Data under Award No. DE-SC0022907.

MOTIVATIONS: CR, NI AND CU DISCREPANCIES

The work is carried out in collaboration with Brookhaven National Laboratory and supported by the US DOE, Office of Science, under the Funding for Accelerated, Inclusive Research (FAIR) under Award No. DE-SC0024373

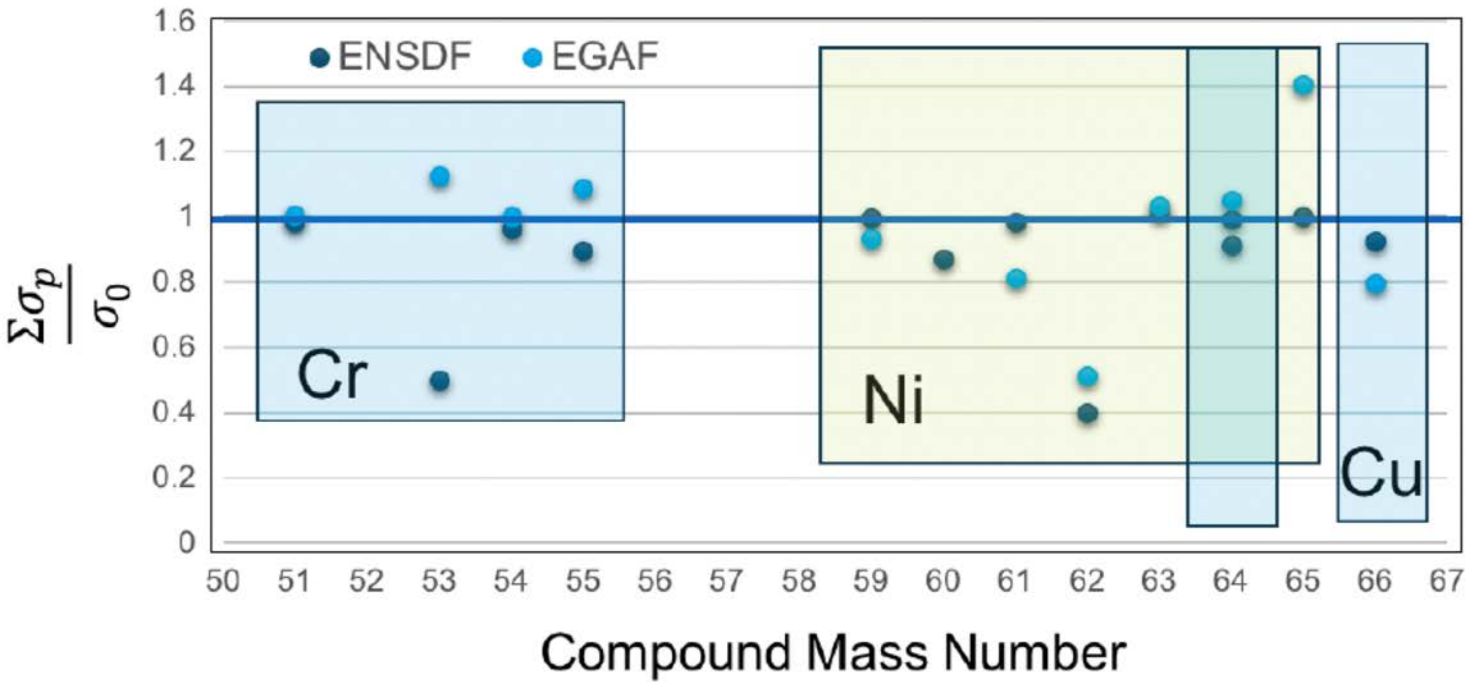
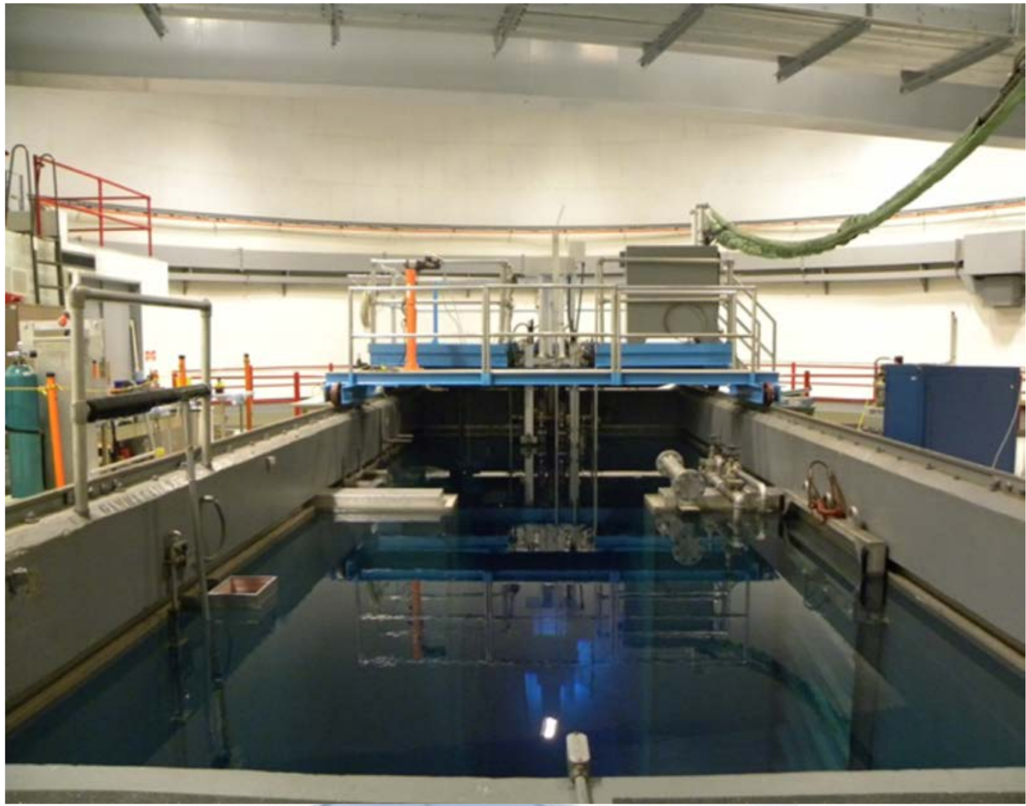
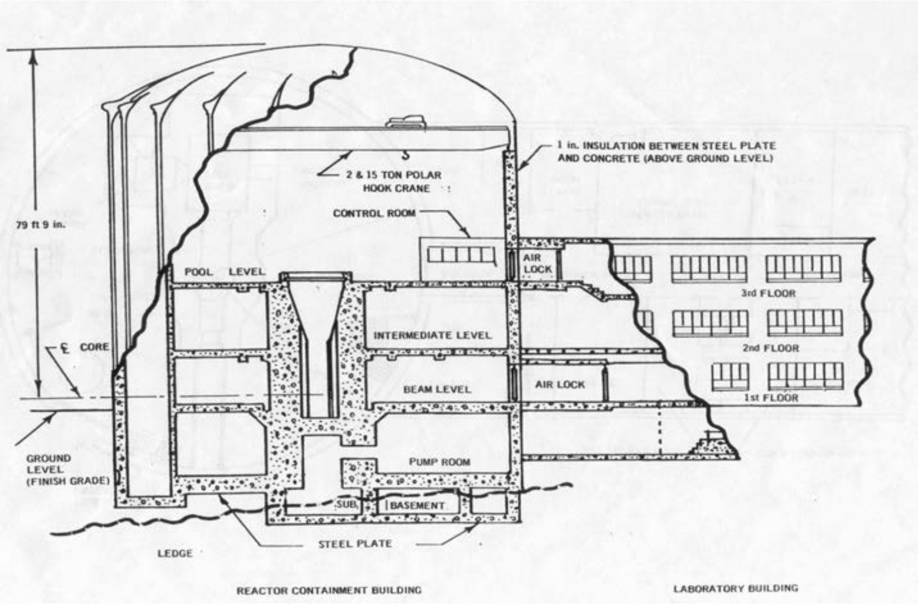


Figure 2 Ratio of the summed primary gamma-ray transition strength to the capture cross section for the Cr, Ni, and Cu isotopes. Data are plotted versus compound mass number (target +n). Data are compared for the ENSDF and EGAF libraries.

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





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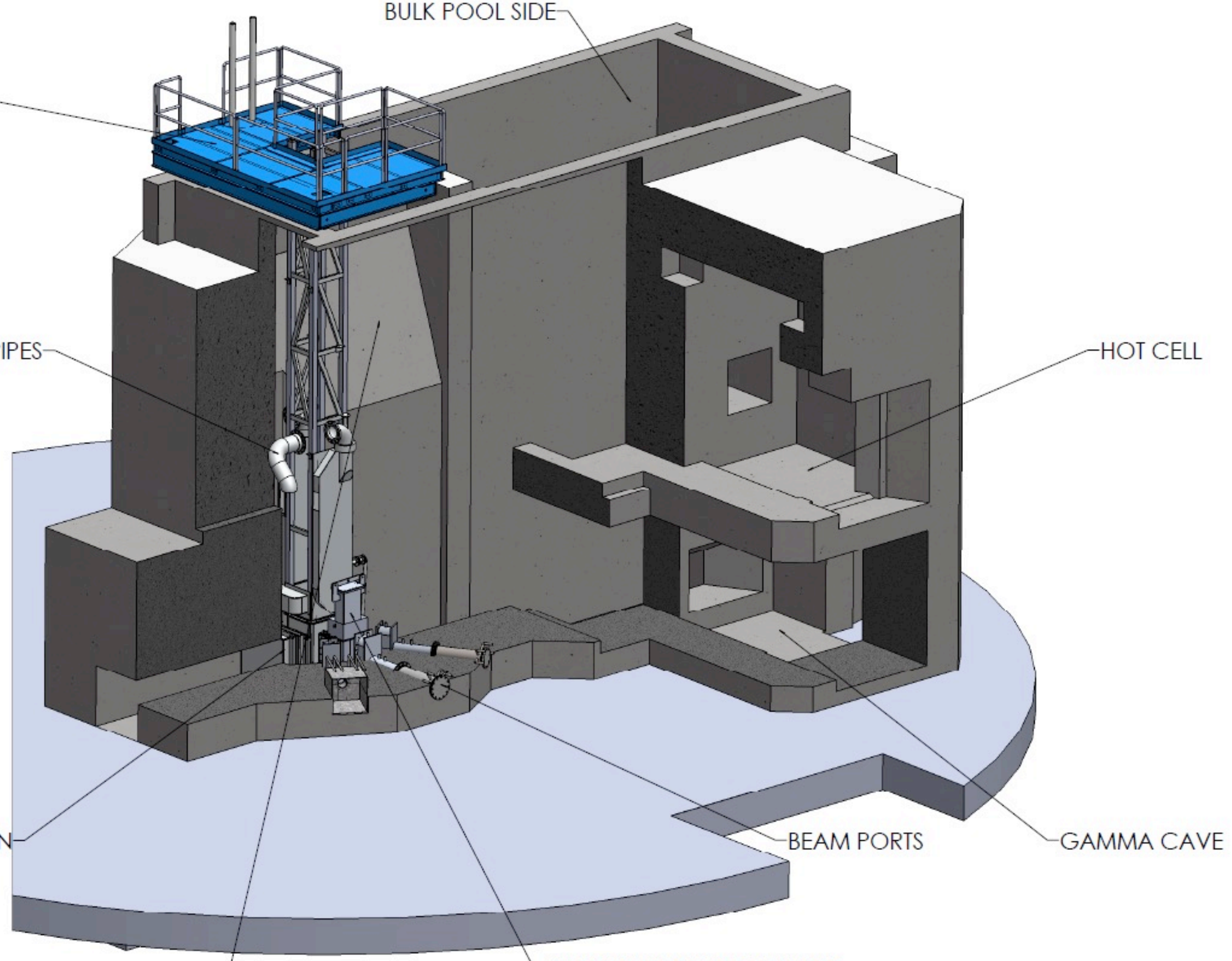
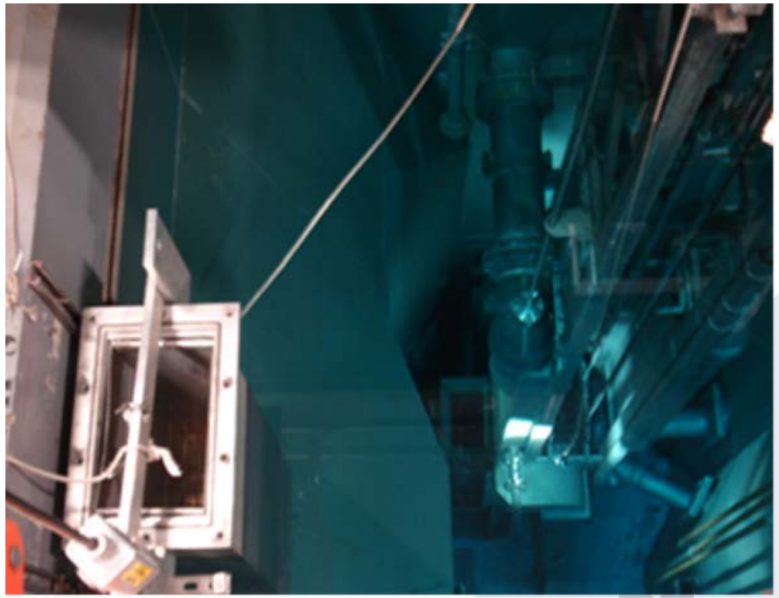


UMLRR NEUTRON FACILITIES

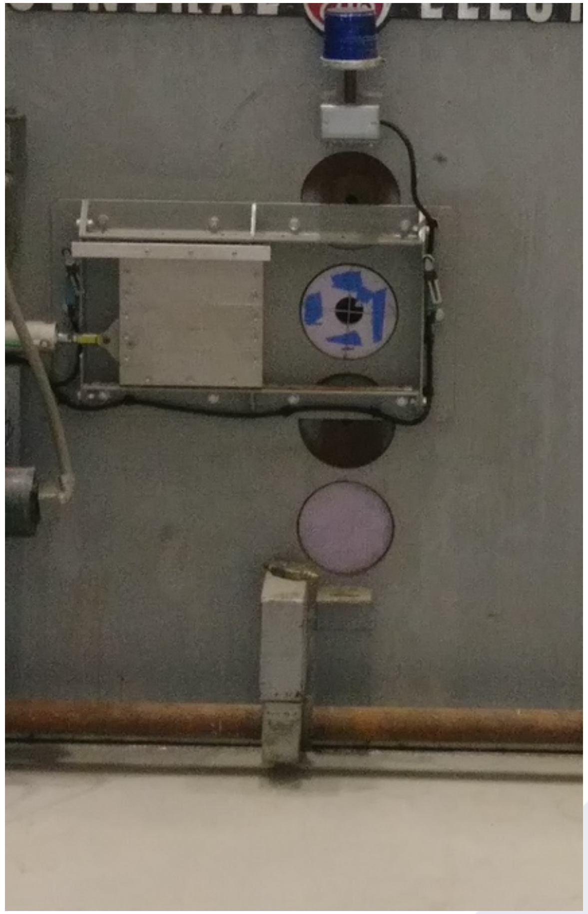
- Fast Neutron Port
  - Shielded bunker, interlock, continuous monitoring.
  - 6-inch diameter beam – can be collimated
  - External access to switch samples (mobile tray/station – can be automated)
  - Total: **~1 x 10^{12} n/cm^2/s**
- In core Irradiations
  - Maximum neutron flux in the core front:
  - **1.3 x 10^{13} n/cm^2/s** thermal , **8.2 x 10^{12} n/cm^2/s** fast
  - Maximum neutron flux available in the core center:
  - **2.5 x 10^{13} n/cm^2/s** thermal , **1.6 x 10^{13} n/cm^2/s** fast
- Pneumatic System
  - A timer system permits automatic return of samples for irradiations from 2 seconds to 20 minutes.
  - Maximum neutron flux: **~5.3x 10^{12} n/cm^2/s** thermal **~2.5 x 10^{12} n/cm^2/s** (fast)
- Fast Neutron Irradiatior
  - 1 MeV equivalent flux: **~10^{11} n/cm^2/s**
  - Supports samples as large as 30cm x 30cm x 15cm
  - Greater than 4000:1 fast-to-thermal flux ratio
- https://www.uml.edu/research/radlab/



UMLRR FACILITIES – THERMAL COLUMN

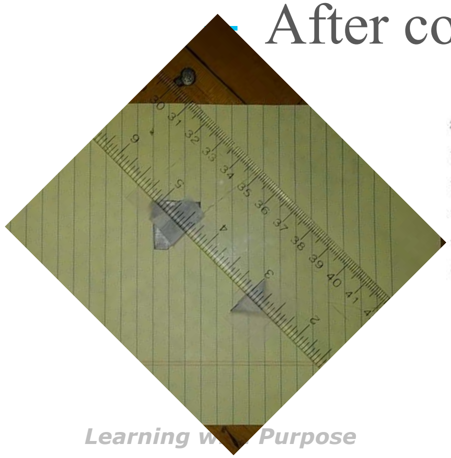
- **Graphite column adjacent to the reactor core**
- **Pneumatic shutter**
- **6-inch diameter beam – can be collimated**
- **Total thermal flux: ~6-7 x 10^6 n/cm^2/s**
- **Easy access, low gamma contamination, parallel beam**

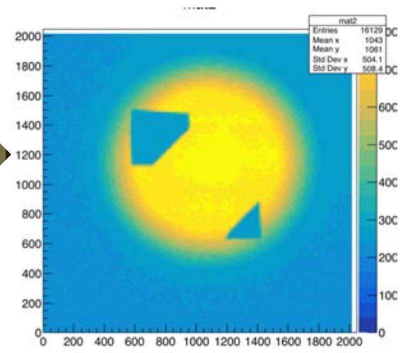
- **https://www.uml.edu/research/radlab/**

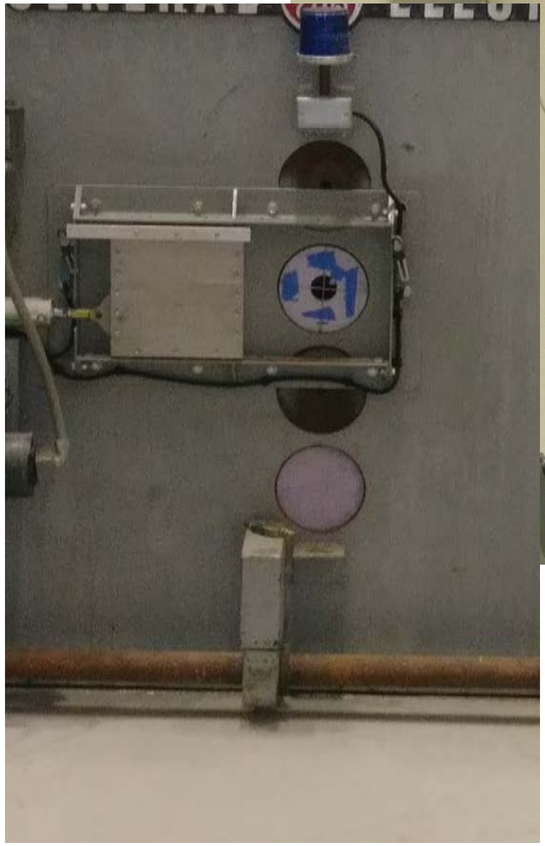


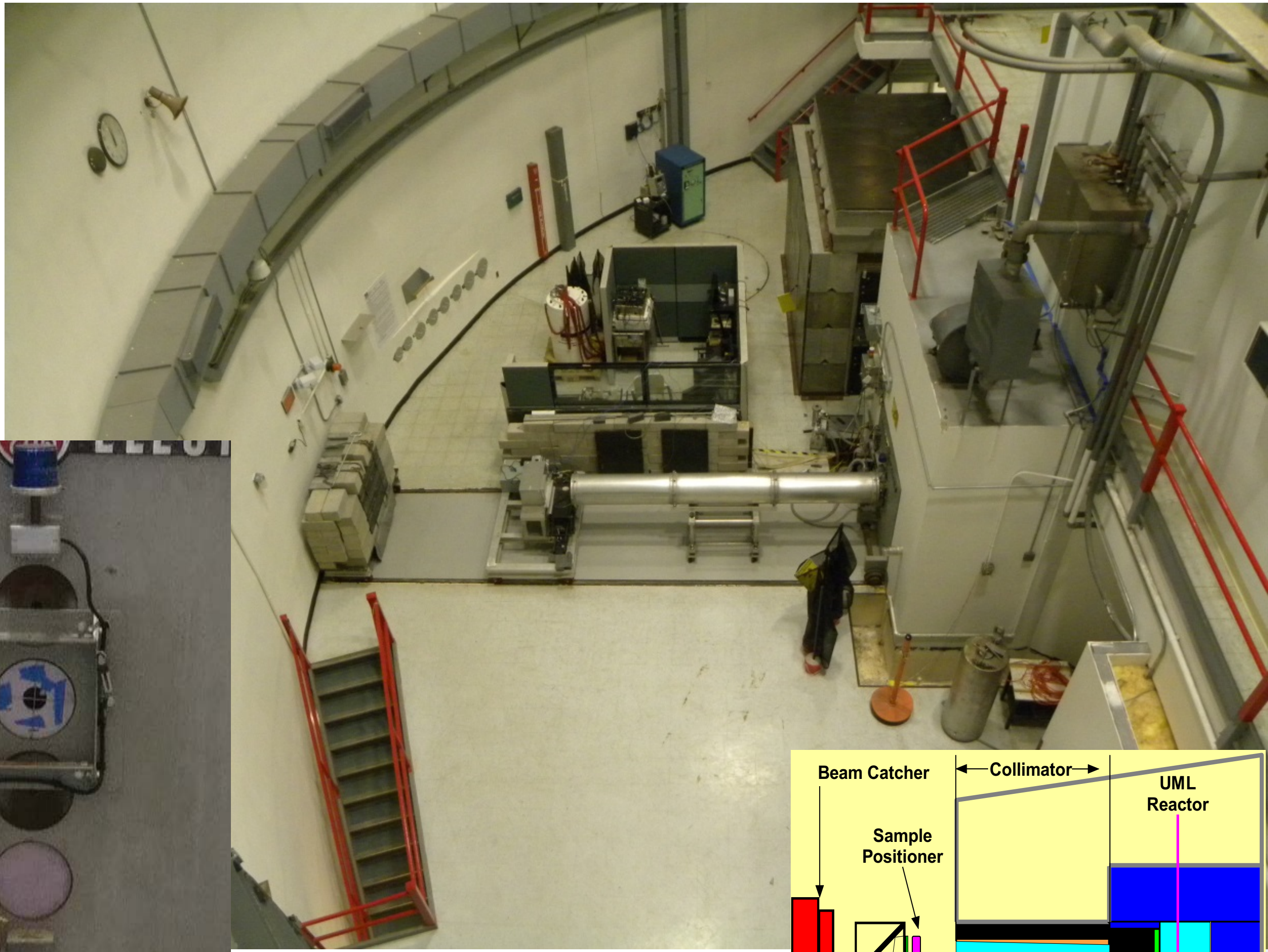
UMLRR FACILITIES OVERVIEW: THERMAL BEAM PORT

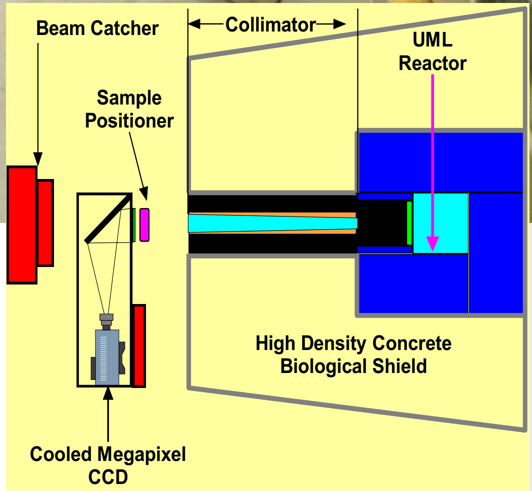
- Shown configured for neutron radiography
- Fluxes originally of ~$5x10^5$ $n/cm^2/s$
- In-pool graphite pile
- Pneumatic shutter
- Beam images:
  - After collimations





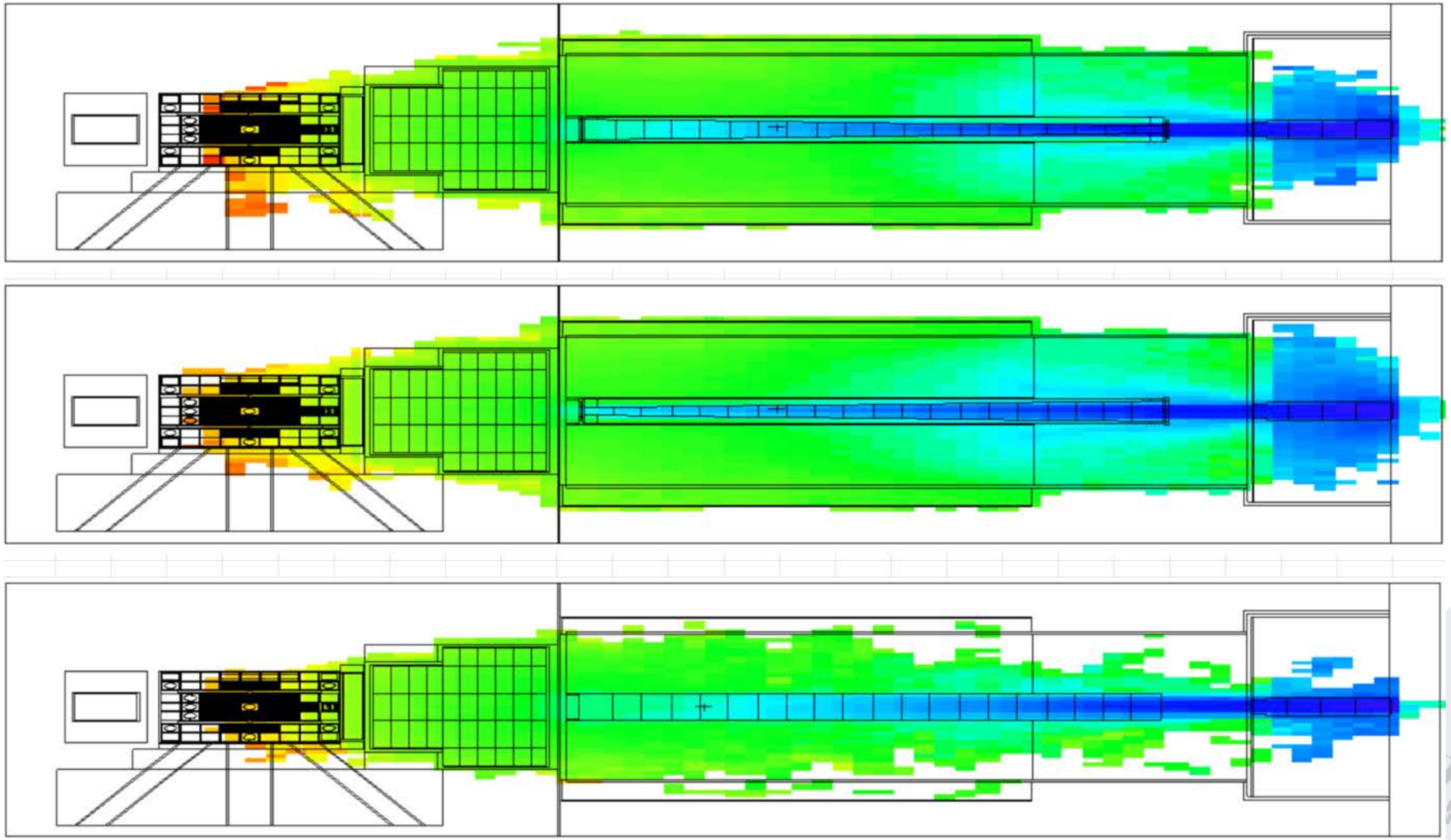






NEW NEUTRON COLLIMATION

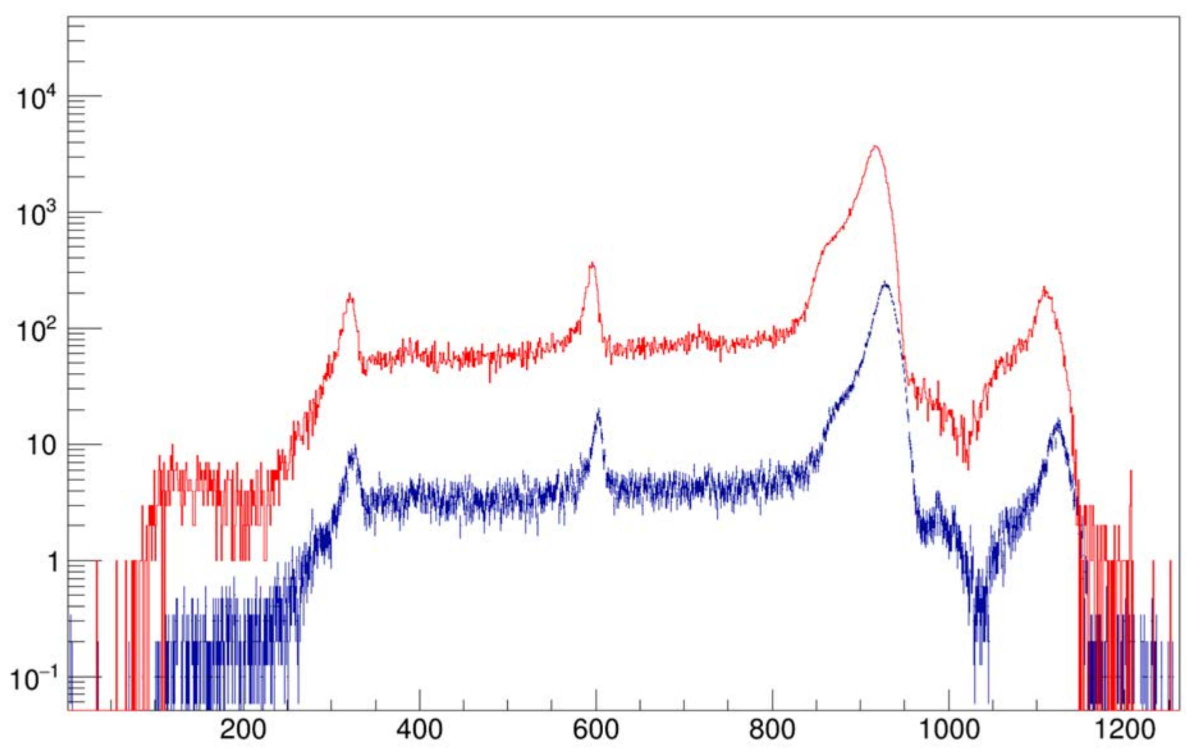
- MCNP6 (Konomi) and Geant4 (Jandel) simulations of the full thermal column assembly were designed and guided the setup
- Internal collimator
  - Standard conf.
  - Flipped
  - Removed

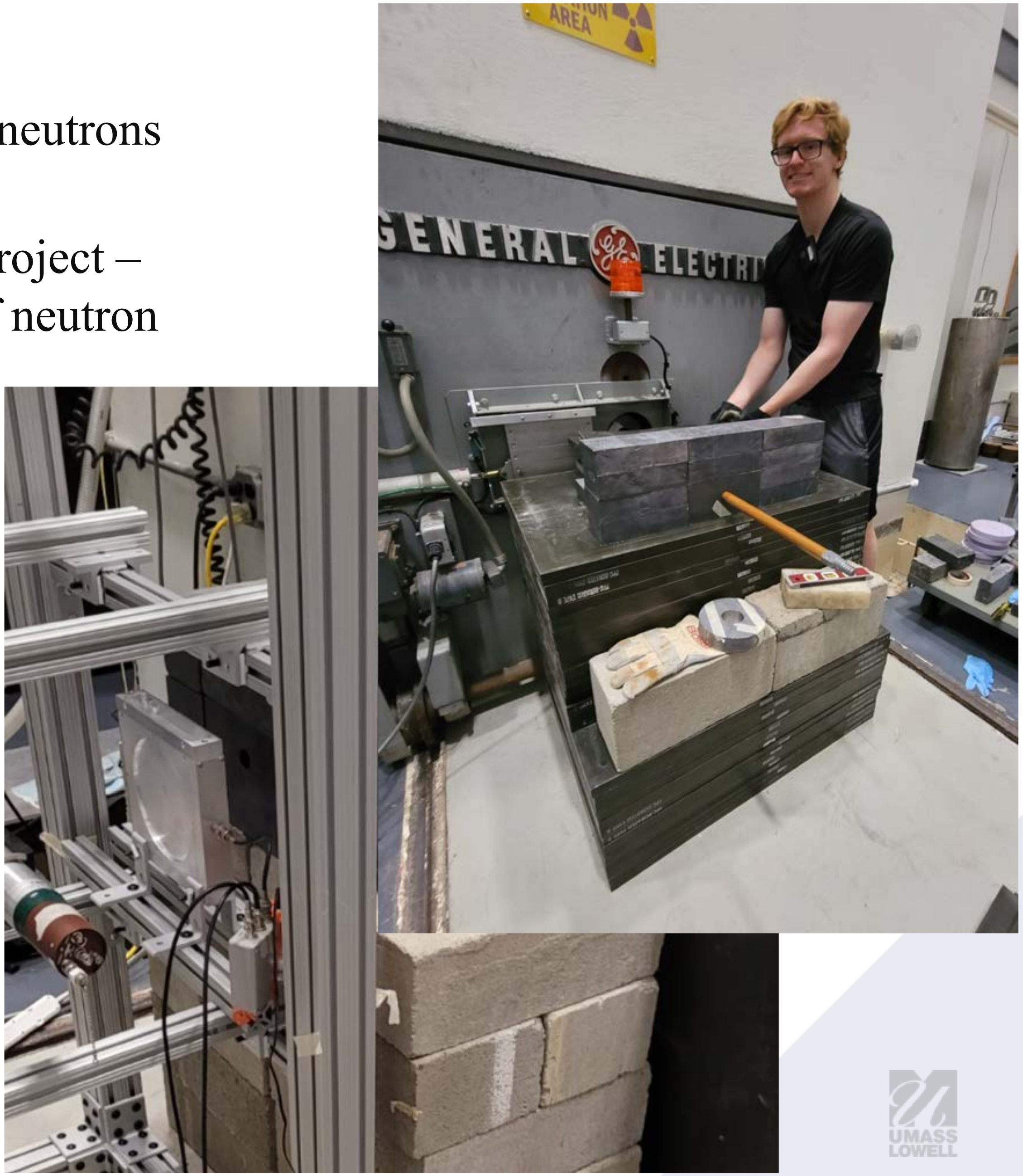


MCNP6 neutron flux simulations by Ksenofon Konomi, UML

NEUTRON BEAM

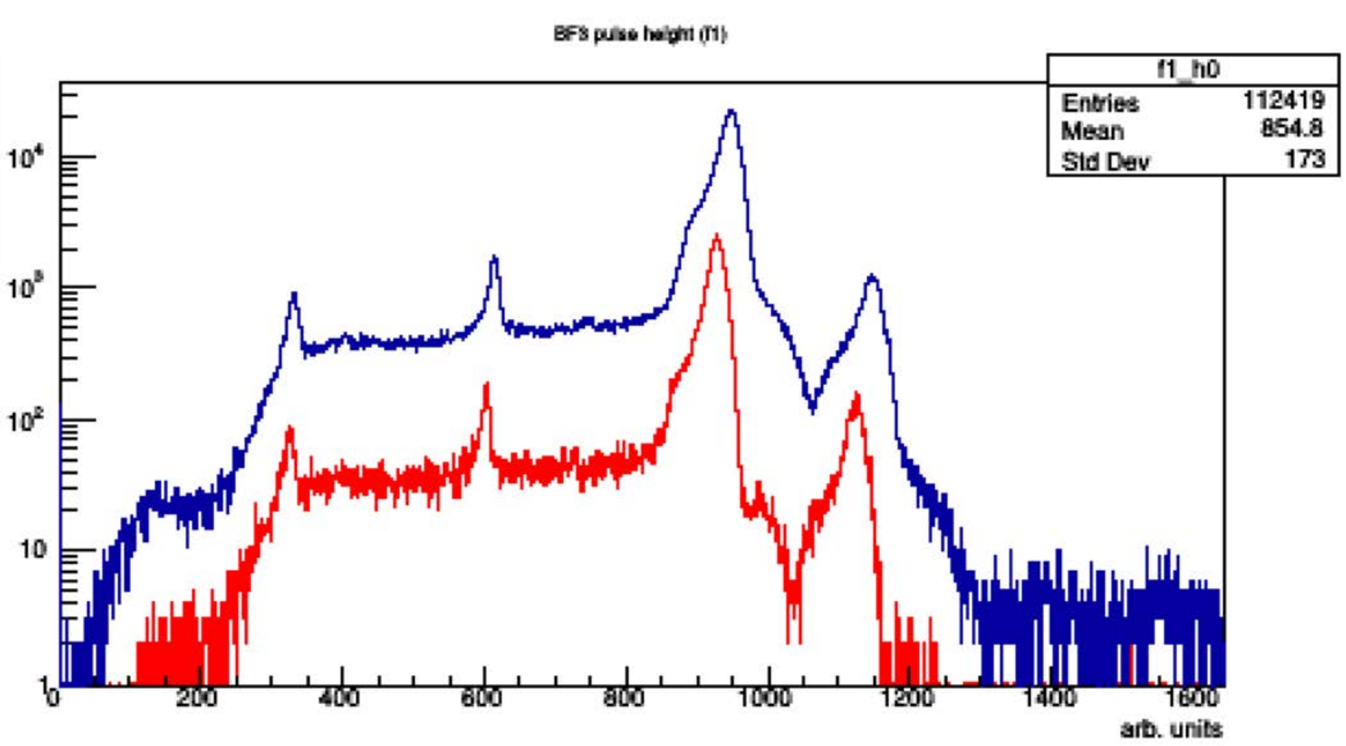
- We redesigned the collimation, and were able to gain 18x neutrons compared to original configuration
- M. Wooldridge will measure the neutron flux (Capstone Project – Spring 2024) with Cd slit and actuator to get the profile of neutron beam





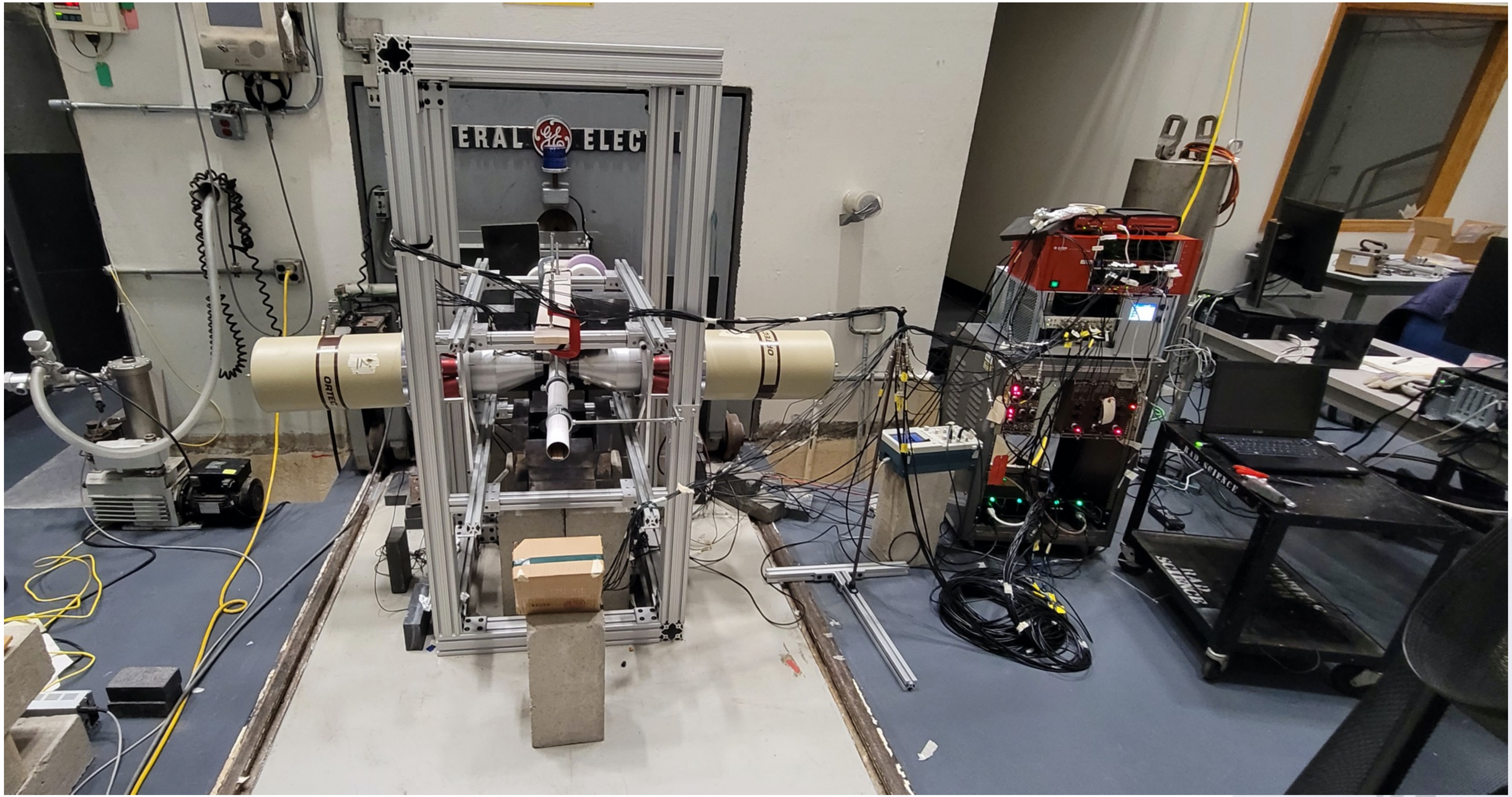
NEUTRON BEAM – ACTUAL MEASUREMENTS – JUNE 2023

- (June 2023) We have confirmed enhancement of neutron intensity by a factor of **18** when collimator is removed: 6 x 10^6 n/s/cm^2 using BF3 thermal neutron monitor with UML built preamp (R. Krueger capstone project)
- We started design of new external and in door collimation
- Currently, neutron flux ~**7 x 10^6 n/s/cm^2**



EVOLUTION OF THE EXPERIMENTAL SETUP MIXED ARRAY OF DETECTORS – (MAD)

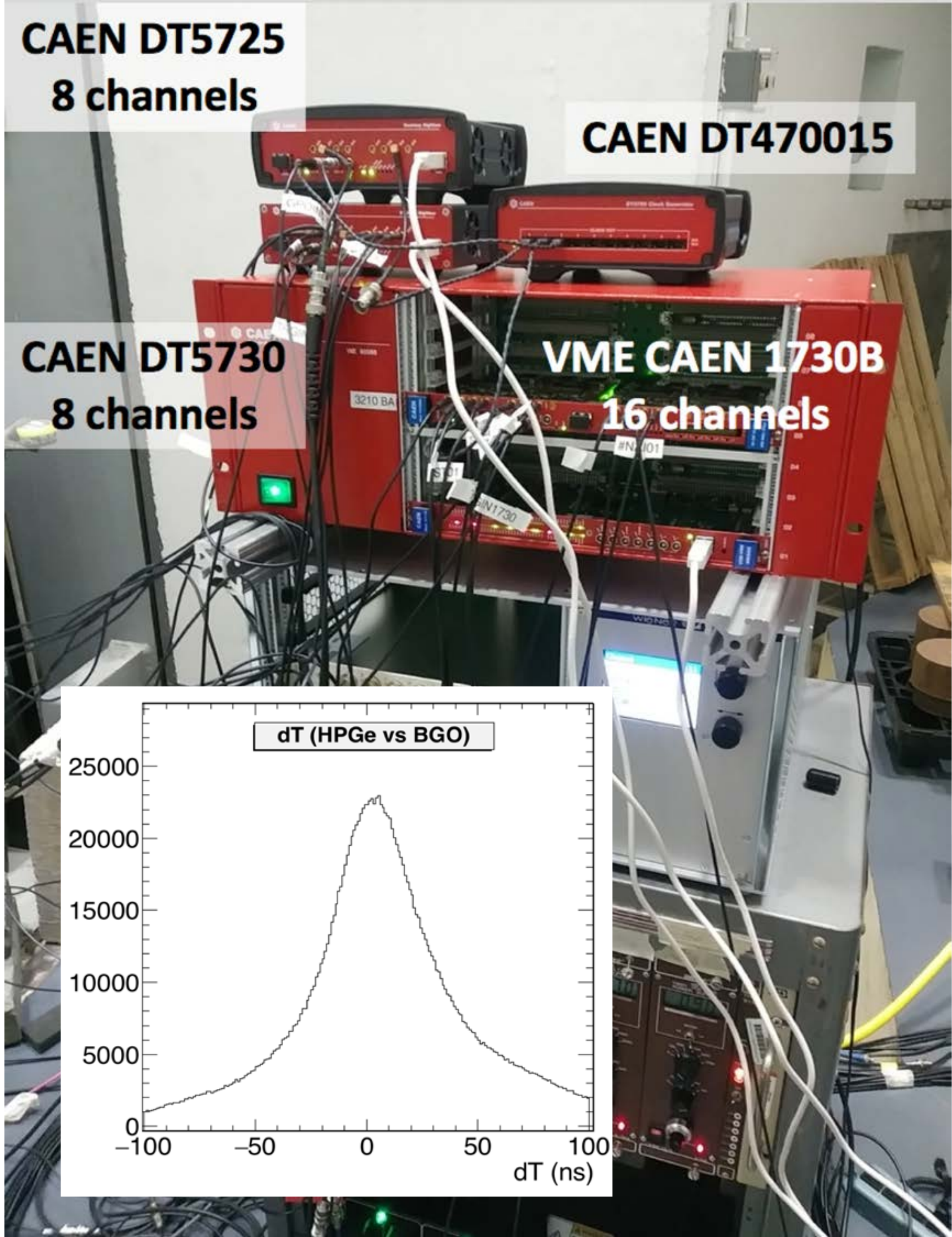
- **2020-2023**
- **2 x HPGe (30%) w Compton Active Shielding (LN2)**
- **Digital DAQ**
- **DPP-PHA/PSD**



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)
- BF3 is also on PHA firmware (1 channel)



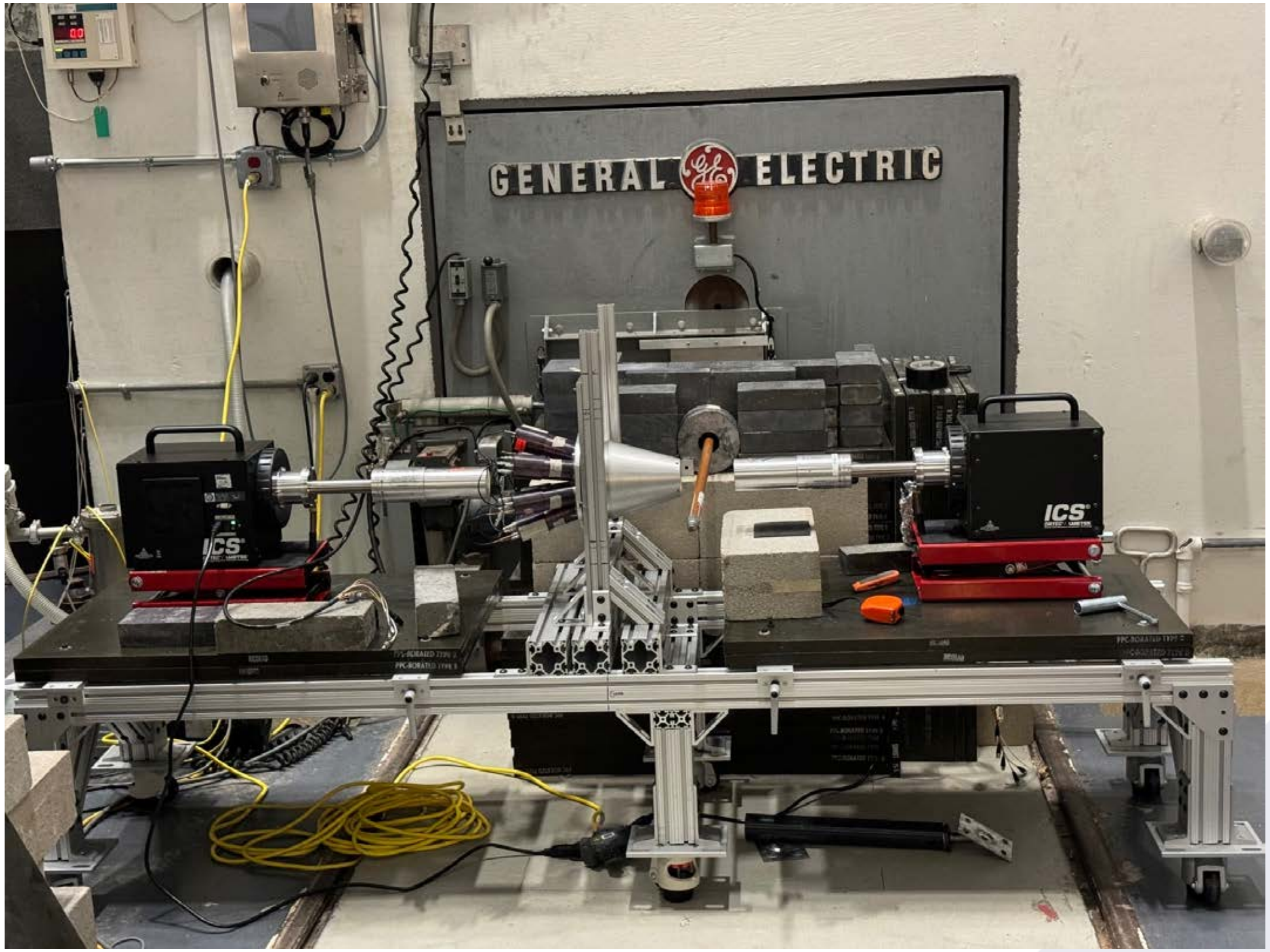
EVOLUTION OF THE EXPERIMENTAL SETUP

- **2023**
- **2 x HPGe (30%) w Compton Active Shielding (LN2)**
- **2 x HPGe (30%) – Ecooled (BNL)**

- **BNL detectors – p-type small dynamic range and not capable of high rates**

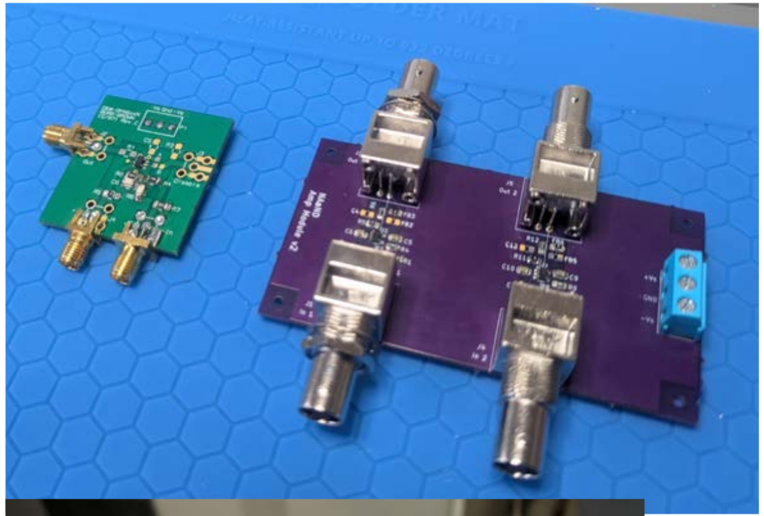
EVOLUTION OF THE EXPERIMENTAL SETUP 2024 - FAIRRAY

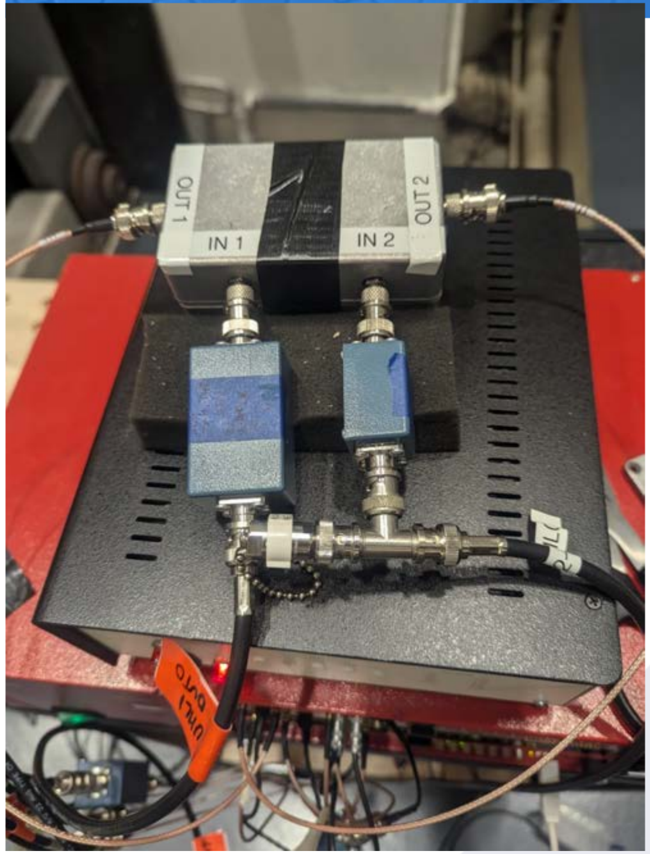
- Dedicated detectors Ecooled acquired June 2024
- Transistor Reset Preamp – capable of high rates
- 1 Compton Active Shielding
- In future, dedicated 100% HPGe will be added to the FAIRRAY
- Added Borated Silica wrapping around both HPGe



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)





MNCL2 – PRELIMINARY – MAD ARRAY 2023/24

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

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

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

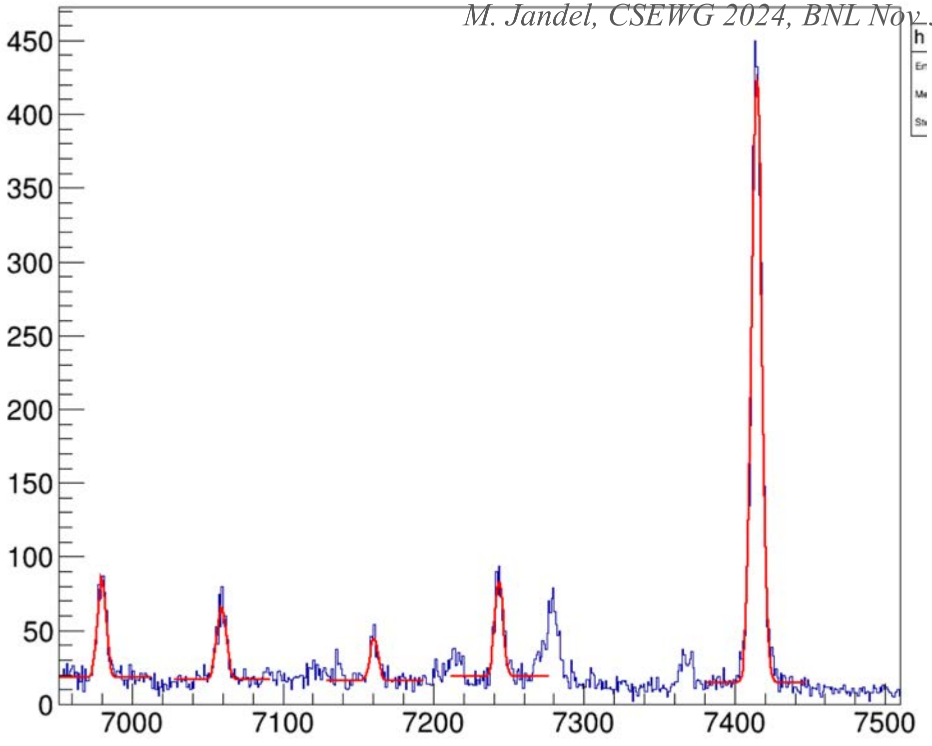
$$I_\gamma\left(\varepsilon_\gamma^{Mn}\right) = 2 \frac{N_\gamma^{Mn}}{N_\gamma^{Cl}} \frac{\sigma_\gamma^Z(\varepsilon_\gamma^{Cl})}{\sigma_c} \frac{\epsilon_{PE}(\varepsilon_\gamma^{Cl})}{\epsilon_{PE}(\varepsilon_\gamma^{Mn})}$$

- 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 – MAD ARRAY 2023/24

- ~24 hours at 120 kW



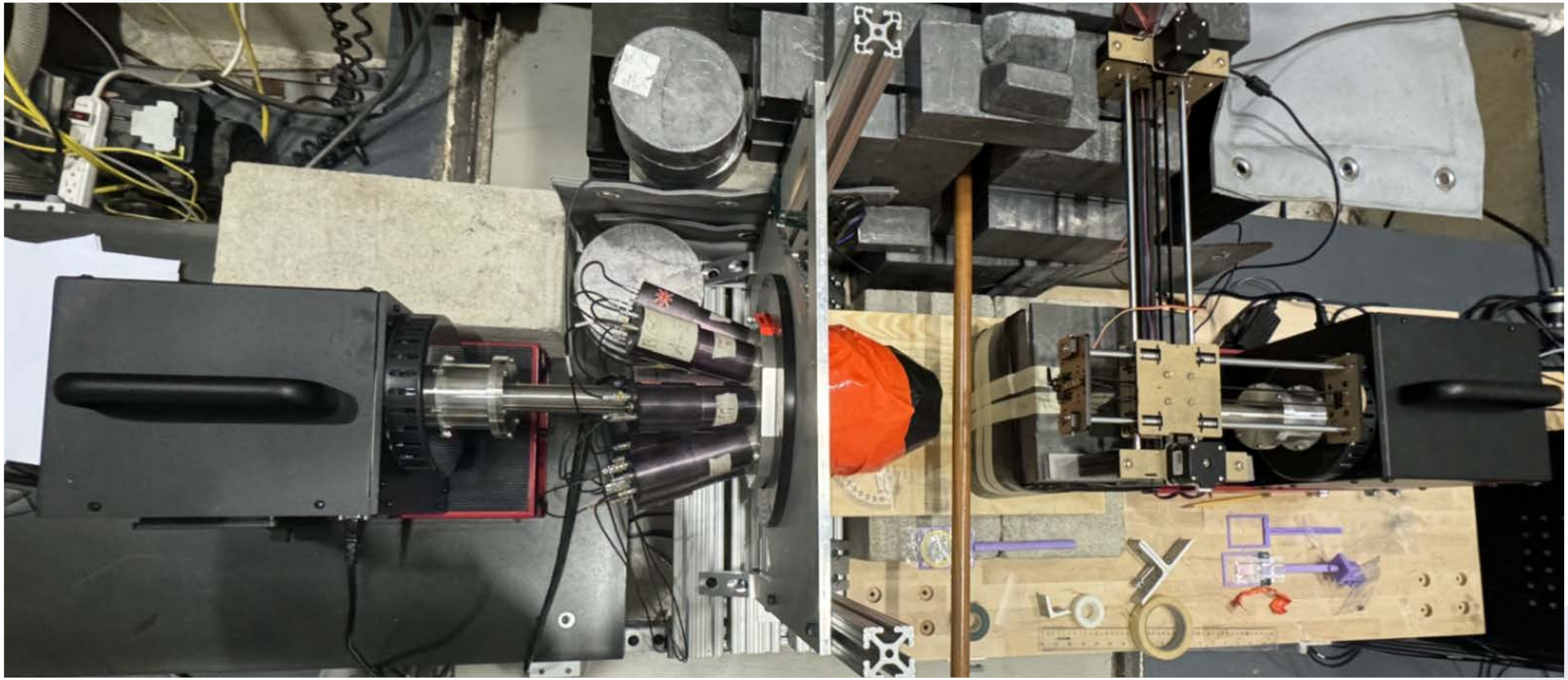
E_γ (keV)	I_γ (ENSDF)	I_γ (EGAF)	I_γ (Left HPGe)	I_γ (Right HPGe)
5181	3.79	3.10	3.37 ± 0.76**	3.03 ± 0.65
6784.9	3.42	2.84	2.78 ± 0.65**	2.95 ± 0.66**
6930.1	2.34	1.87	1.94 ± 0.52	*
7058.99	11	9.17	9.57 ± 1.09	11.20 ± 0.97
7159.7	5.96	4.84	5.28 ± 0.68	5.56 ± 0.83
7242.79	12.3	10.22	9.67 ± 0.79	9.83 ± 0.82

PhD thesis of Alex Howe (in progress)

M. Jandel, CSEWG 2024, BNL Nov 5, 2024

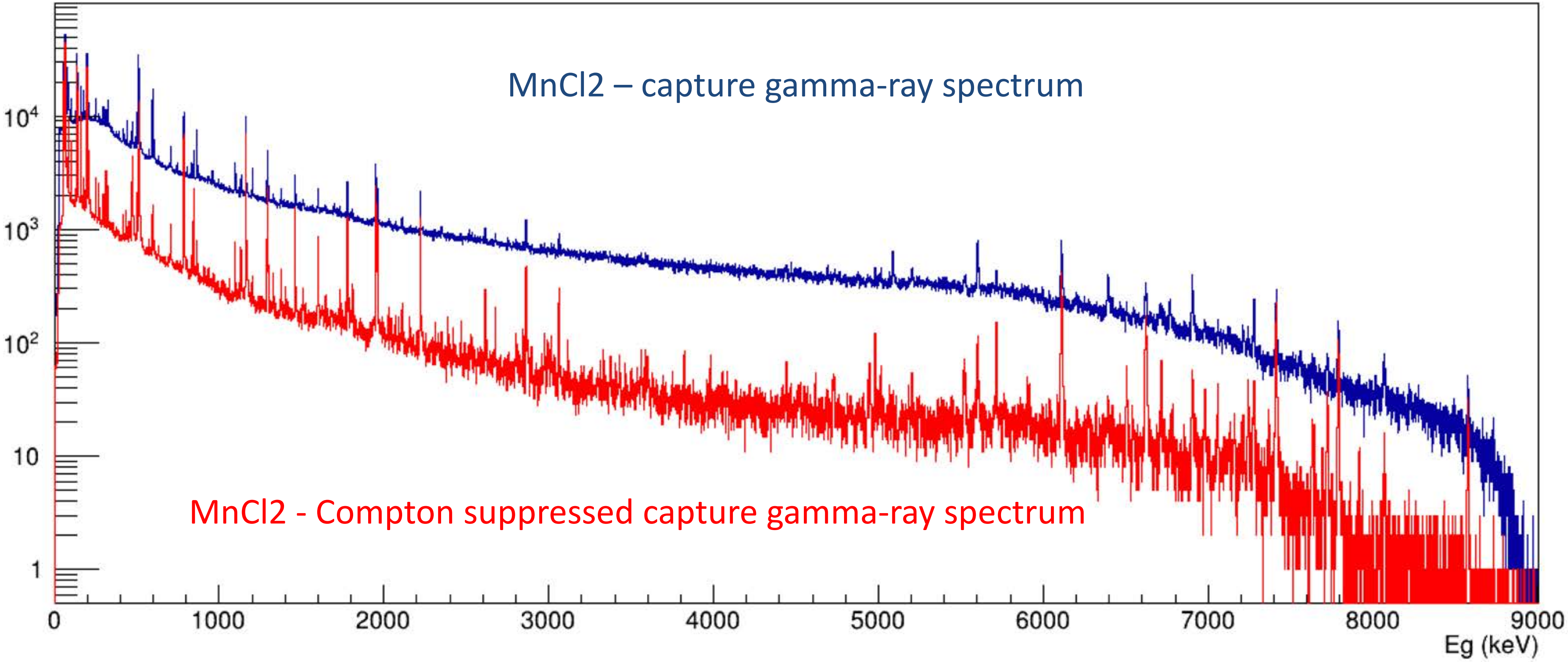
MNCL2 – PRELIMINARY – FAIRARRAY 2024

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



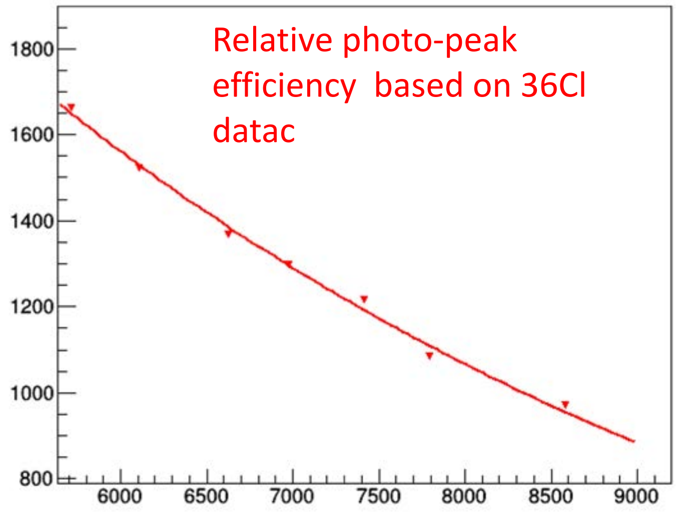
MNCL2 –PRELIMINARY – FAIRRAY 2024

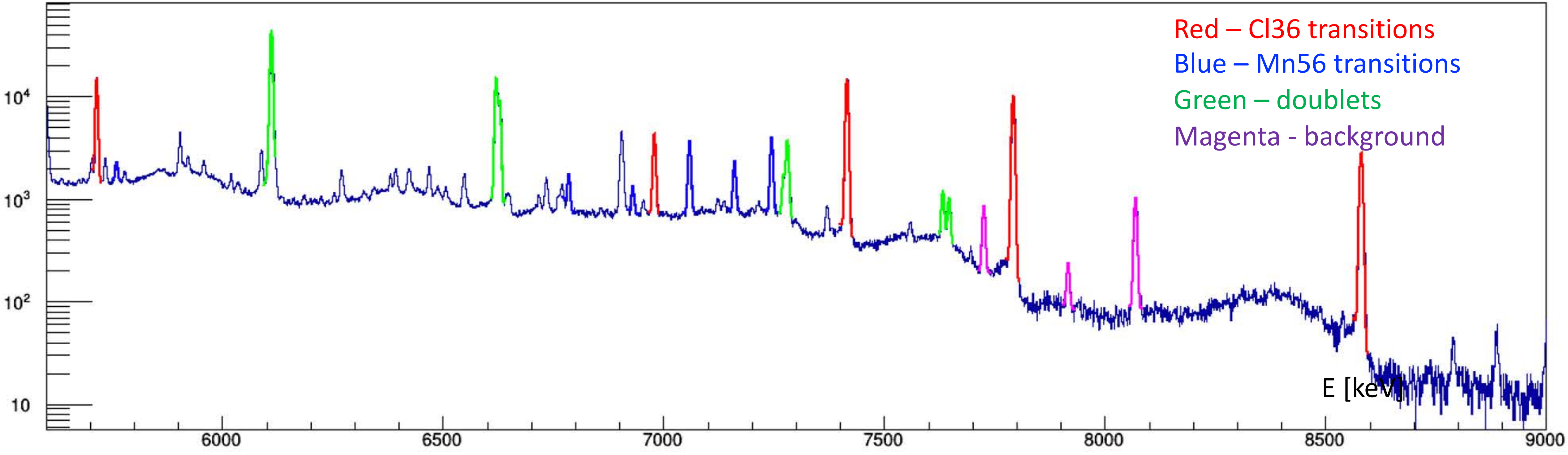
- Sample of 1.16 g of $MnCl_2$
- Sigma Aldrich



MNCL2 – PRELIMINARY – FAIRARRAY 2024

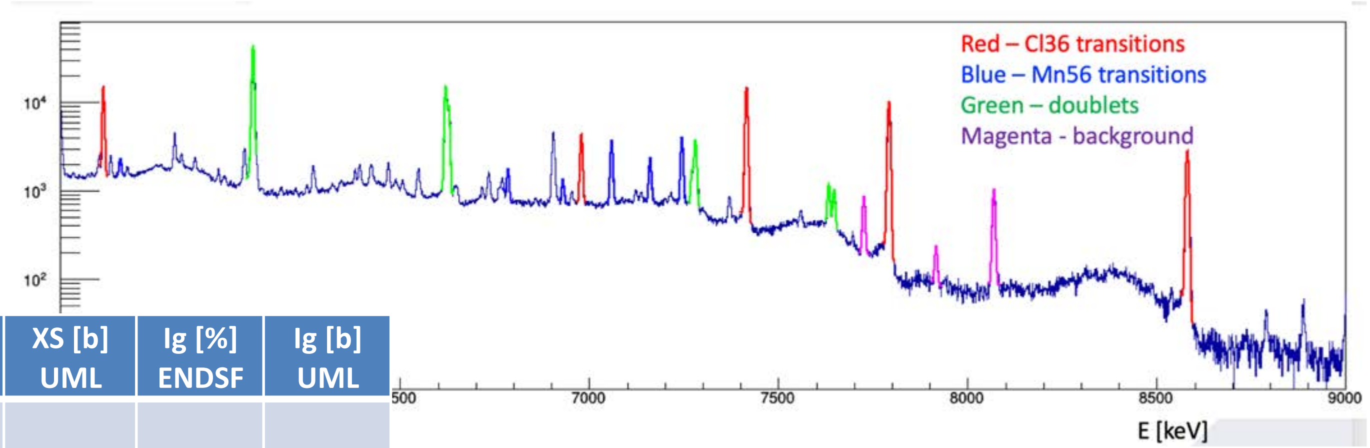
- Sample of 1.16 g of $MnCl_2$
- Running at 1 MW (21 hours shown)
- Data needs subtraction of blank sample background !
- PRELIMMINARY analysis



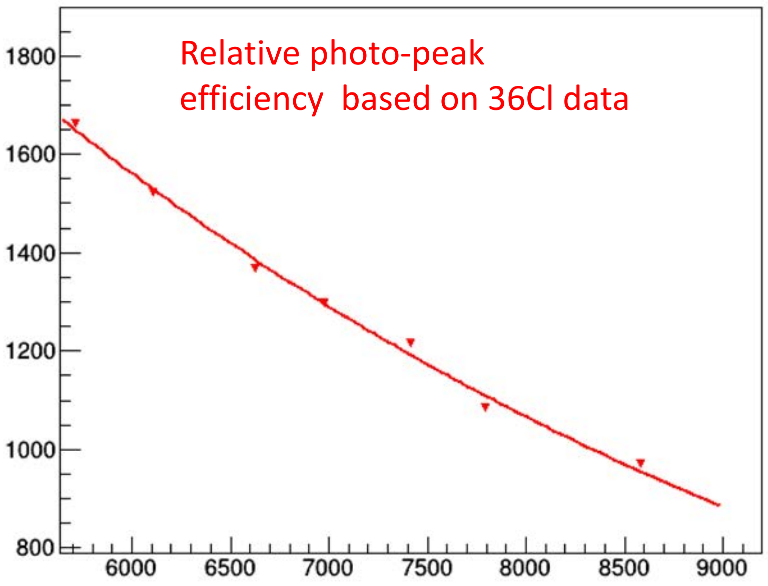


MNCL2 – PRELIMINARY – FAIRRAY 2024

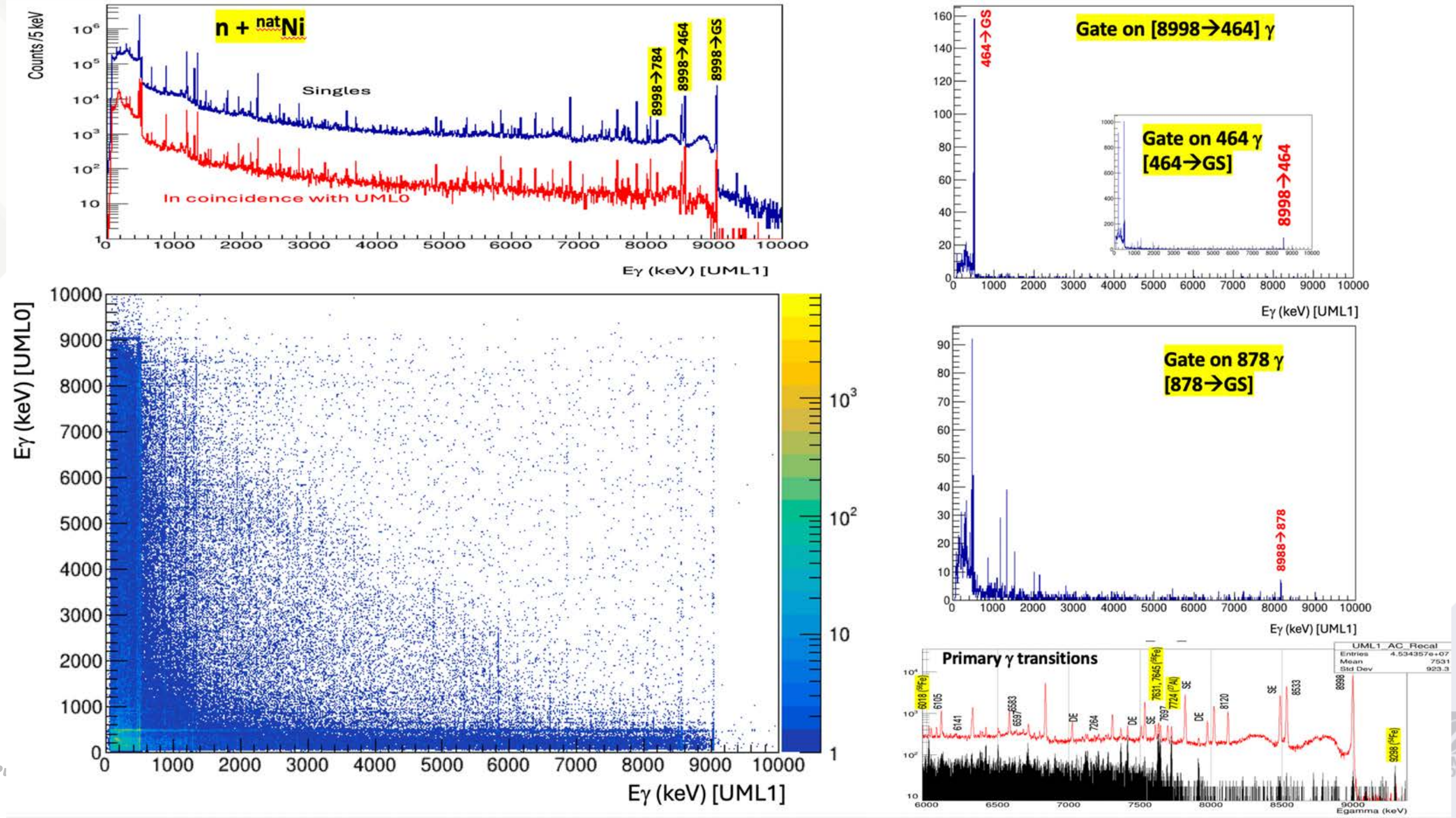
- Sample of 1.16 g of $MnCl_2$
- Running at 1 MW (~21 hours shown)



	E [keV]	XS [b] ENDSF	XS [b] UML	XS [b] ENDSF	XS [b] UML	Ig [%] ENDSF	Ig [b] UML
^{36}Cl	8578.7	0.883	0.99				
^{36}Cl	7790.45	2.66	2.66				
^{56}Mn	7270.3			0.42	0.47	3.5	3.15
^{56}Mn	7243.8			1.38	1.64	12.3	10.35
^{56}Mn	7159.7			0.64	0.80	5.96	4.81
^{56}Mn	7057.8			1.17	1.47	11	8.76
^{36}Cl	6977.95	0.741	0.70	1.40	0		
^{56}Mn	6928.7			0.23	0.31	2.34	1.70
^{56}Mn	6783.3			0.31	0.46	3.42	2.31
^{36}Cl	6627.94	1.47	1.32				
^{36}Cl	6619.73	2.53	2.30				
^{36}Cl	6110.98	6.59	5.64				
^{56}Mn	6103.9				0.27	2	3.85

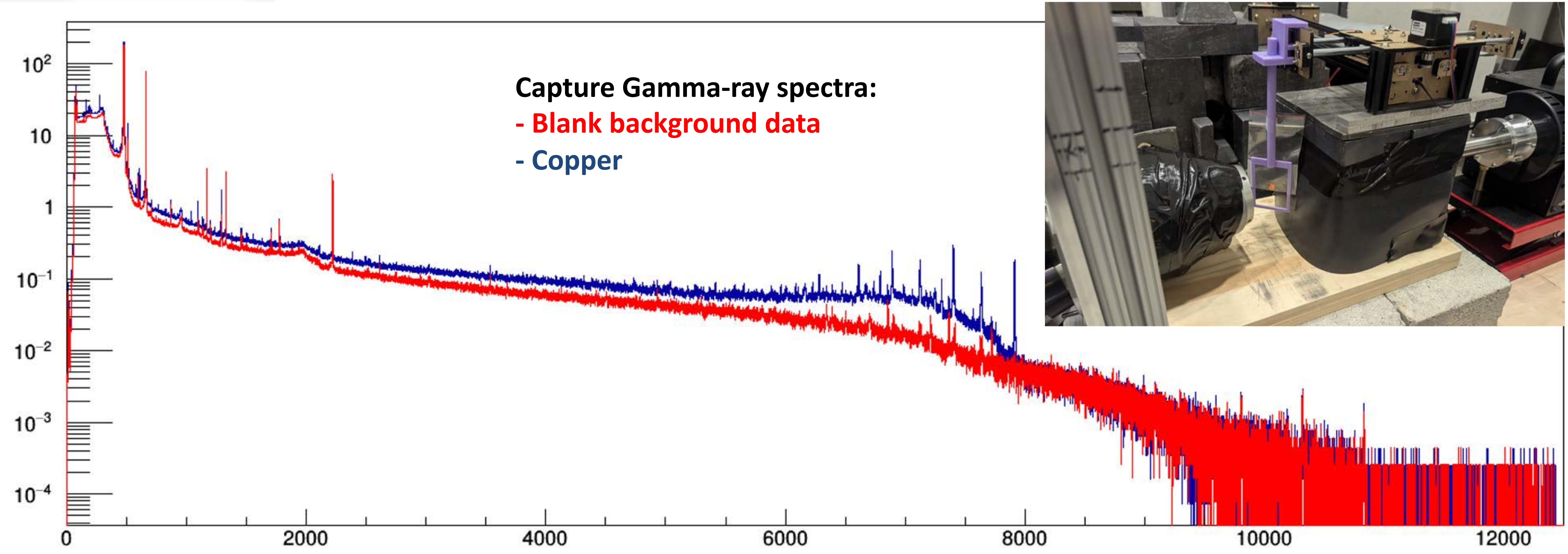


NICKEL (N,G) DATA – 10 HOURS AT 500 KW
BNL ANALYSIS LED BY SHUYA OTA

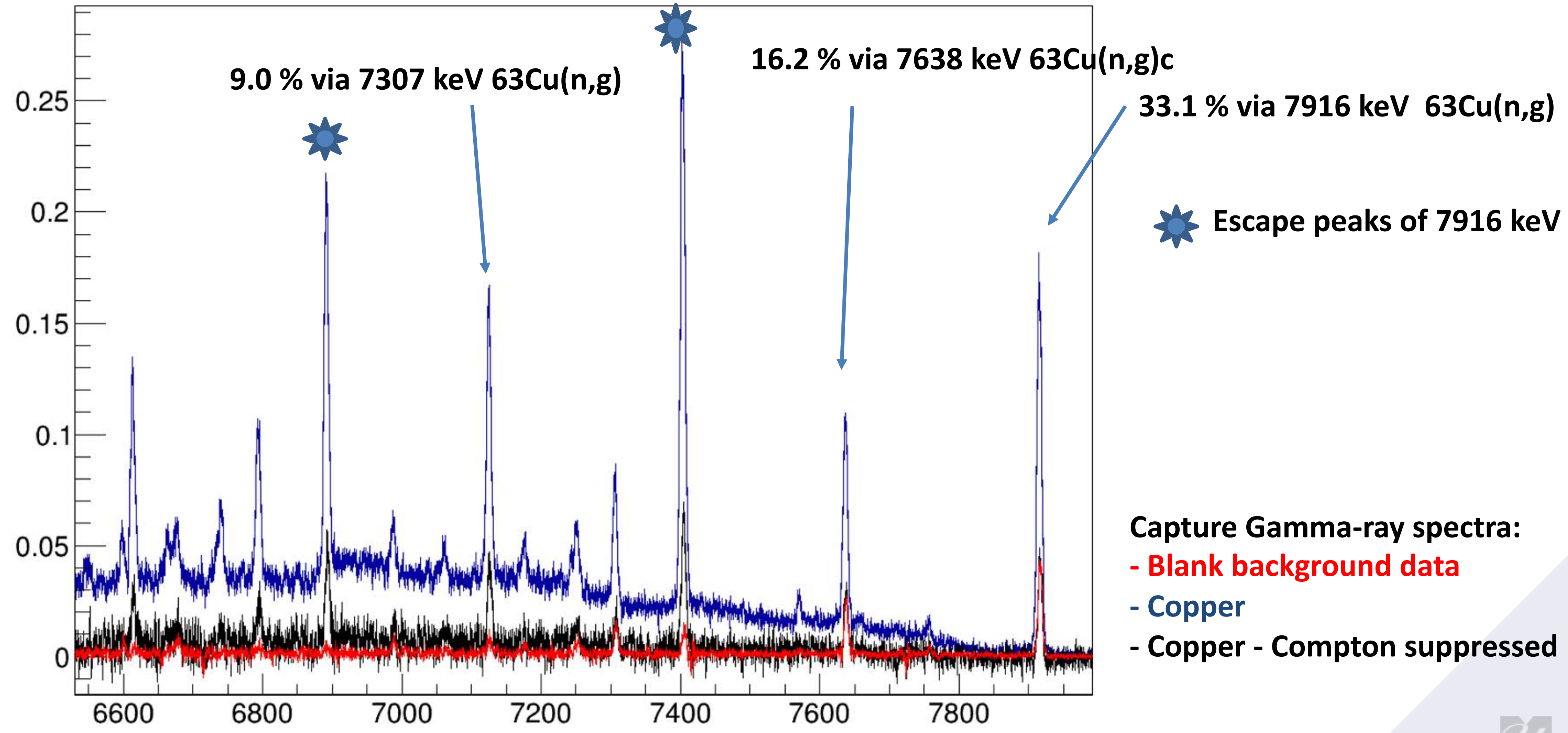


COPPER –PRELIMINARY – FAIRRAY 2024 AUGUST

- Sample of 1g of natural Copper – only 1.5 hours acquired
- 0-12 MeV spectrum – Cs137 + Co60 taped to the detectors



COPPER –PRELIMINARY – FAIRRAY 2024 AUGUST (1.5 HOUR)



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

CURRENT PROJECTS AT UML THERMAL NEUTRON BEAM

- First feasibility measurements (2019-2023) with Mixed Array of Detectors lead to funded projects and FAIRRAY (2024):
- Measurements of capture gamma rays
  - DOE Office of Science: Mn-56 (2023-2025)
  - DOE Office of Science: Cu, Ni, Cr (2023-2026)
    - **New HPGe e-cooled detectors arrived in Junee 2024**
    - **New Collaboration with BNL (co-PI Shuya Ota)**
  - NSF Career: Gd (2022-2027)
- NNSA: CENTAUR2.0 Texas A&M led SSAA consortium
  - Future fission reaction studies (2024-2029)

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.

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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

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