SOLVING THE MN55 PUZZLE

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Learning with Purpose

Nuclear Applications and Nuclear Data Group at UML

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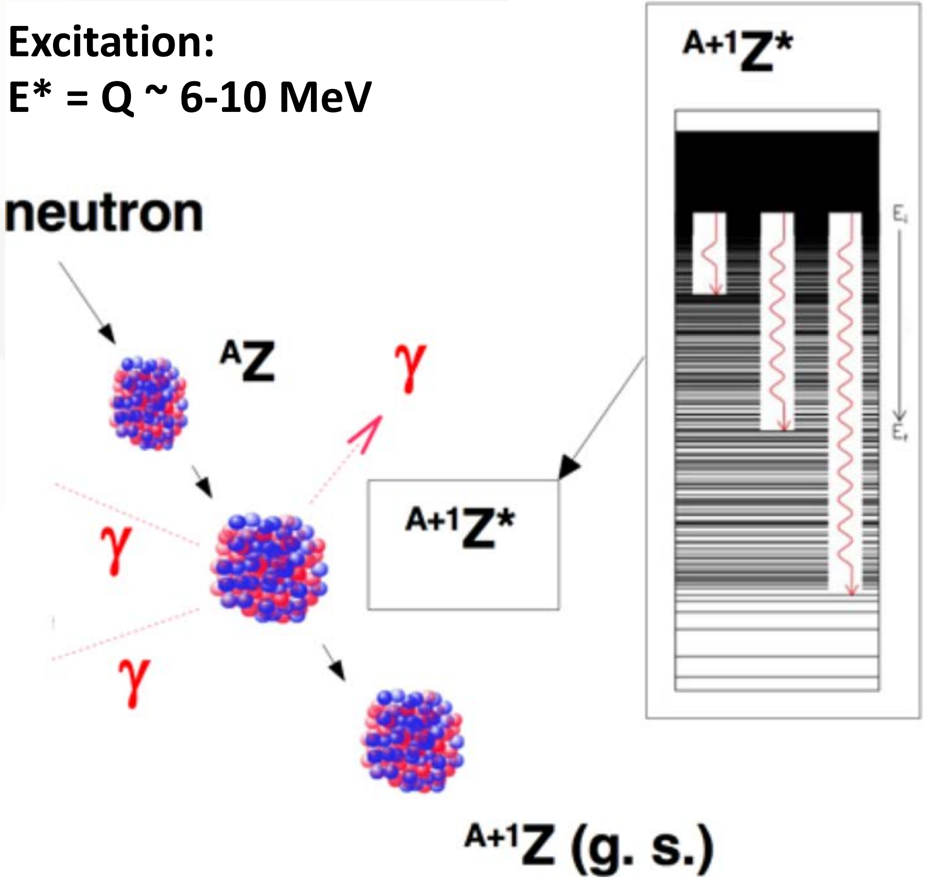
MN56 CAPTURE GAMMA-RAY MEASUREMENTS

- 1 MW Research Reactor
- What's new:
  - New collimation
  - New sample holder
  - New samples – MnCl vs Mn
  - New detectors
  - New collaborations
- Preliminary Data
- Plans for new production data measurements in summer 2024

NEUTRON CAPTURE – NUCLEAR DATA AND BEYOND
LEVELS AND GAMMA-RAY STRENGTHS, CROSS SECTIONS

Excitation:
E* = Q ~ 6-10 MeV



Measurements

Cross sections

$$\langle \sigma_{n\gamma} \rangle = \frac{\pi g_n}{k_n^2} \frac{T_n T_\gamma}{T} M_{WF}$$

gamma spectra

$$T_{\Pi L}(E_\gamma) = 2\pi \frac{\langle \Gamma_{i\gamma} \rangle}{D(E_x)} = 2\pi E_\gamma^{2L+1} f_{\Pi L}(E_\gamma).$$

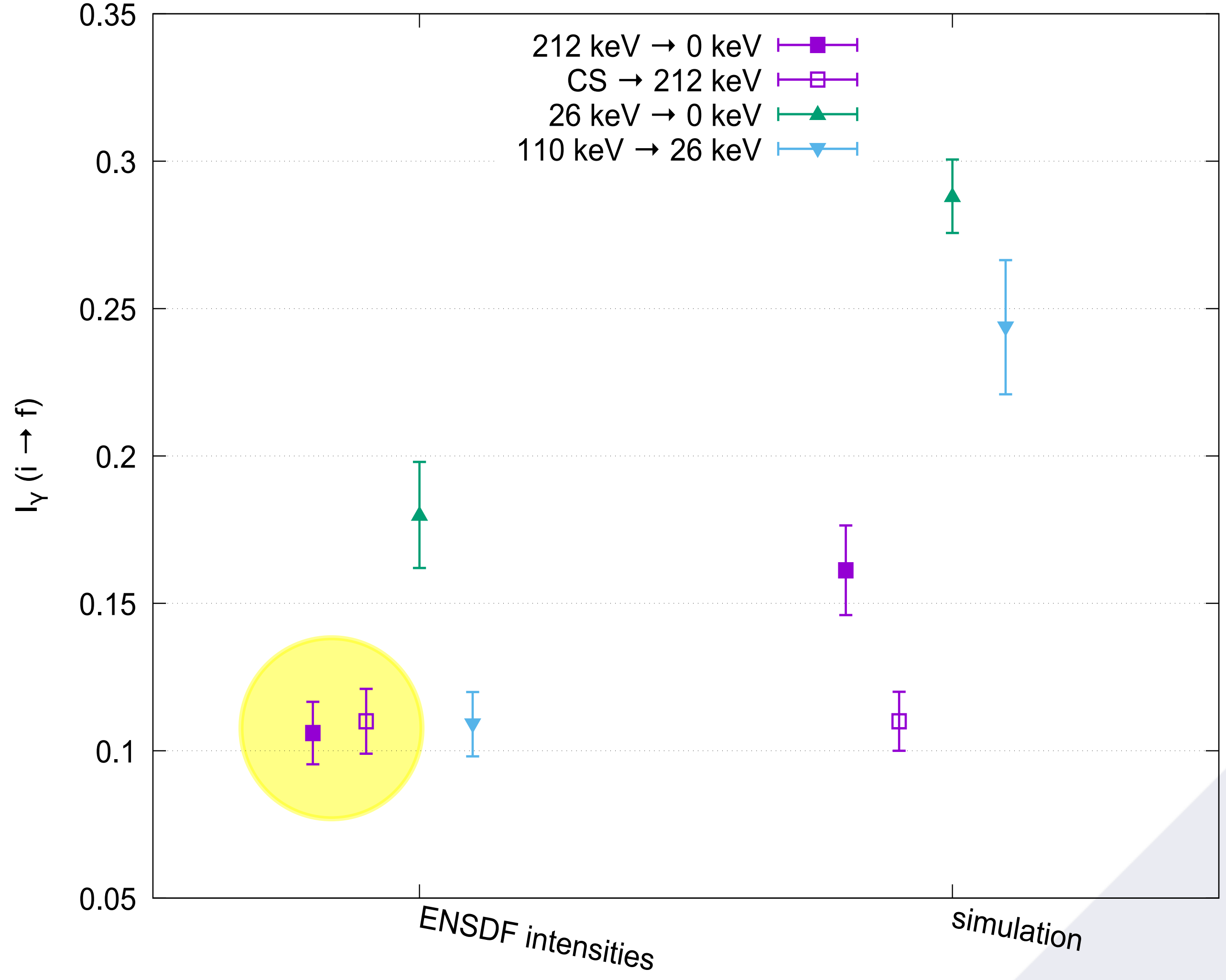
$$T_\gamma = \sum_{J^\pi \Pi L} \int_0^{E'} 2\pi E_\gamma^{(2L+1)} f_{\Pi L}(E_\gamma)\, \rho(E_x, J^\pi) dE_x,$$

Deduced fundamental properties

Excited compound nucleus cools down via gamma-ray cascade to the ground state

UML – DATA ON ^{55}MN(N,G)

- Closer look at ENSDF evaluation revealed need for revisiting the data:
- The primary transition to the 212-keV level has practically the same intensity as the only transition depopulating the level.
- Other transitions near the ground state seem to have low intensities (statistical de-excitation show factor of 2 more feeding)

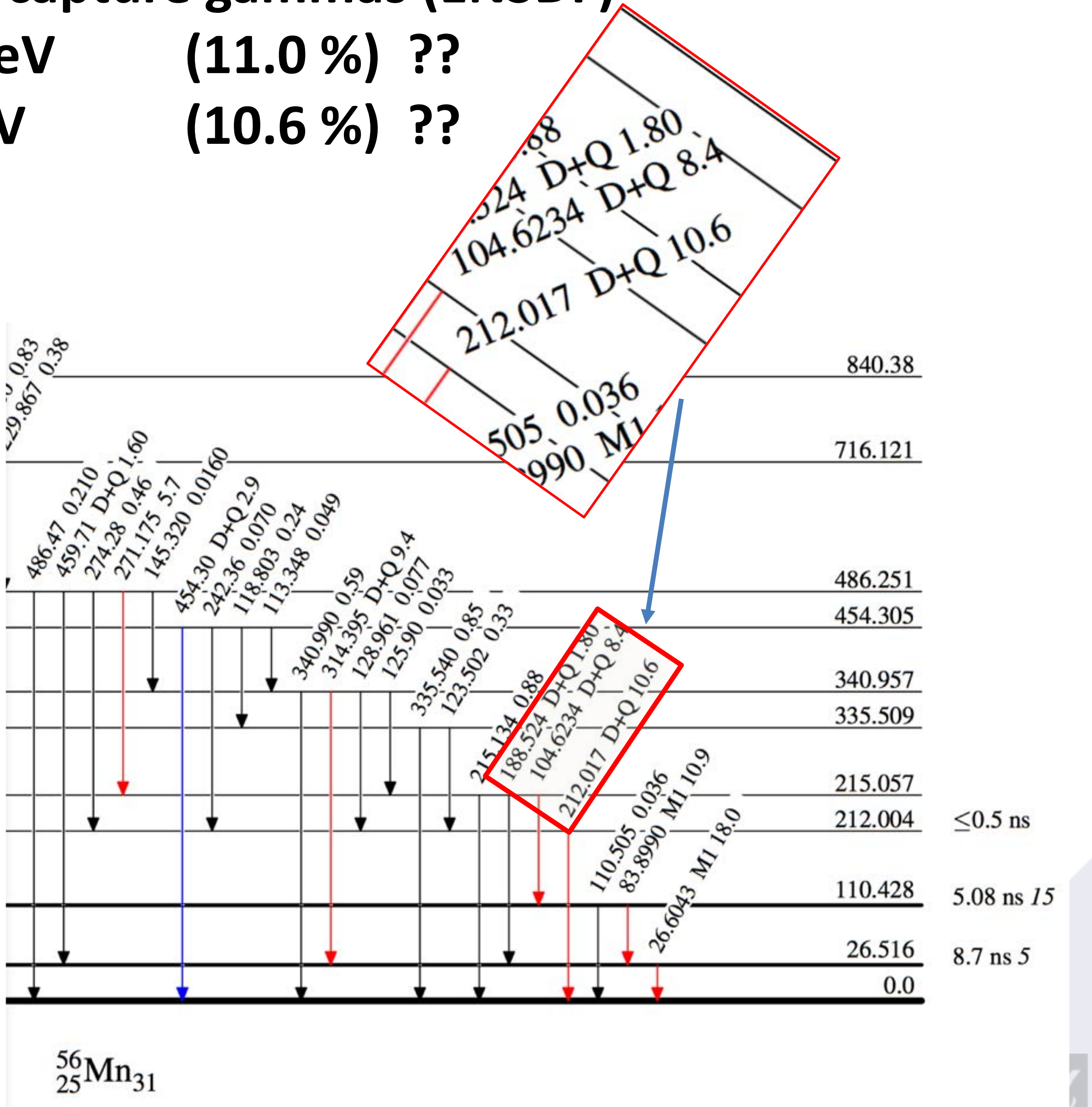


CAPTURE GAMMA DATA

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

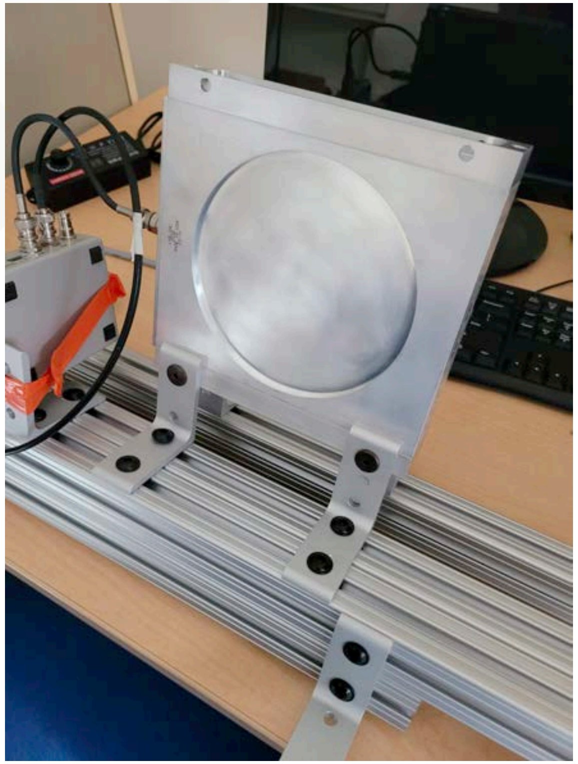


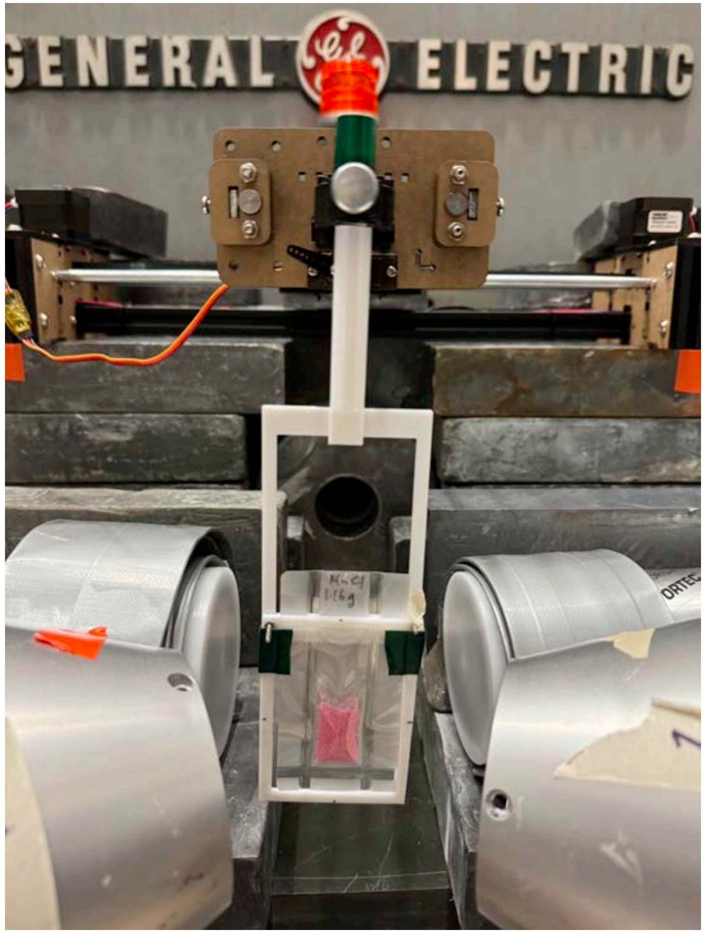
NOV 2023 – JAN 2024 SETUP

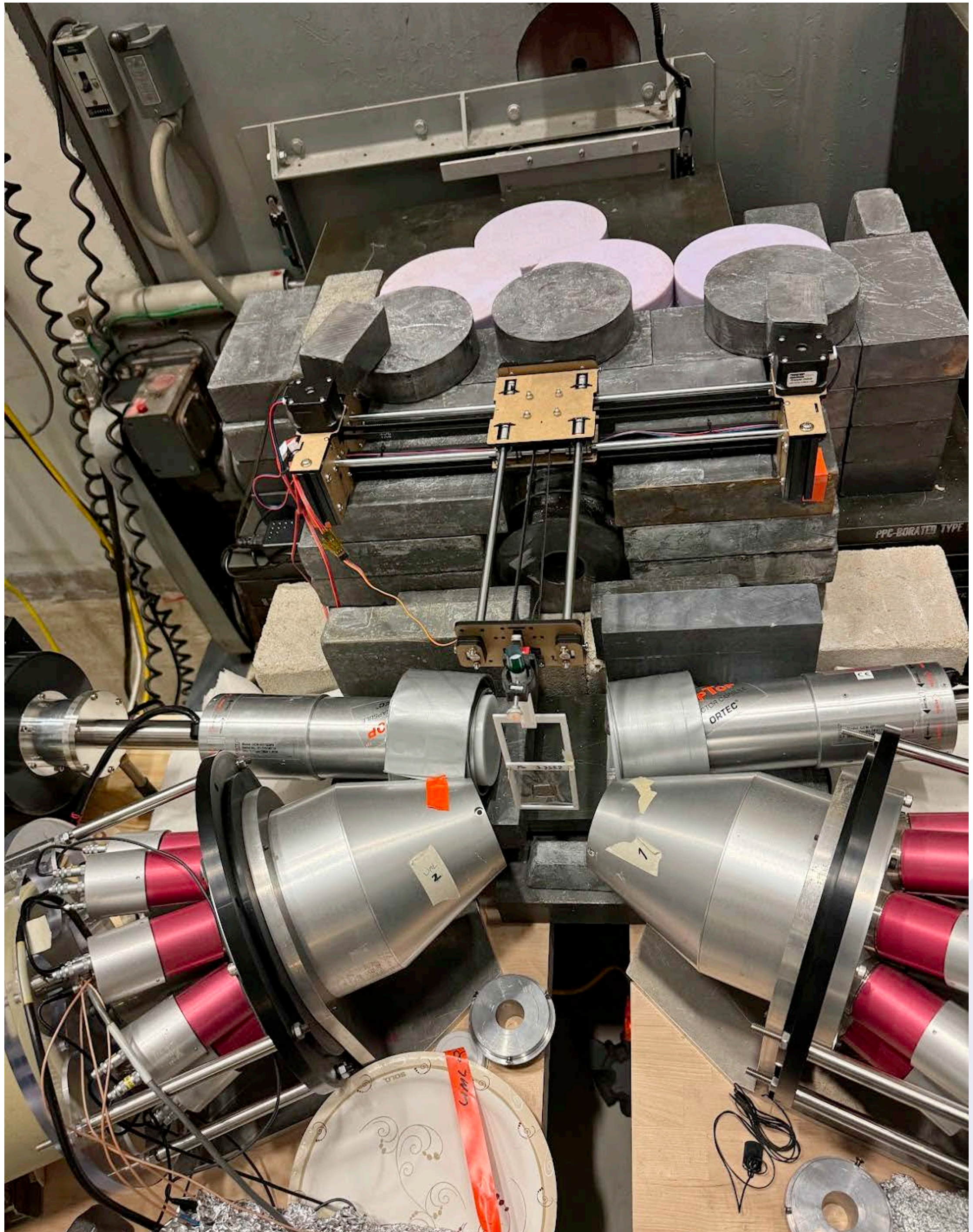
- 2 x HPGe (30%) w Compton Active Shielding (LN2)
- 2 x HPGe (30%) – Ecooled (BNL)

NOV 2023 – JAN 2024 SETUP

- Sample positioning – high precision stepper motors – we adopted a xy(z) plotter
- Neutron beam BF3 monitor (LNDinc)
- Student built preamps



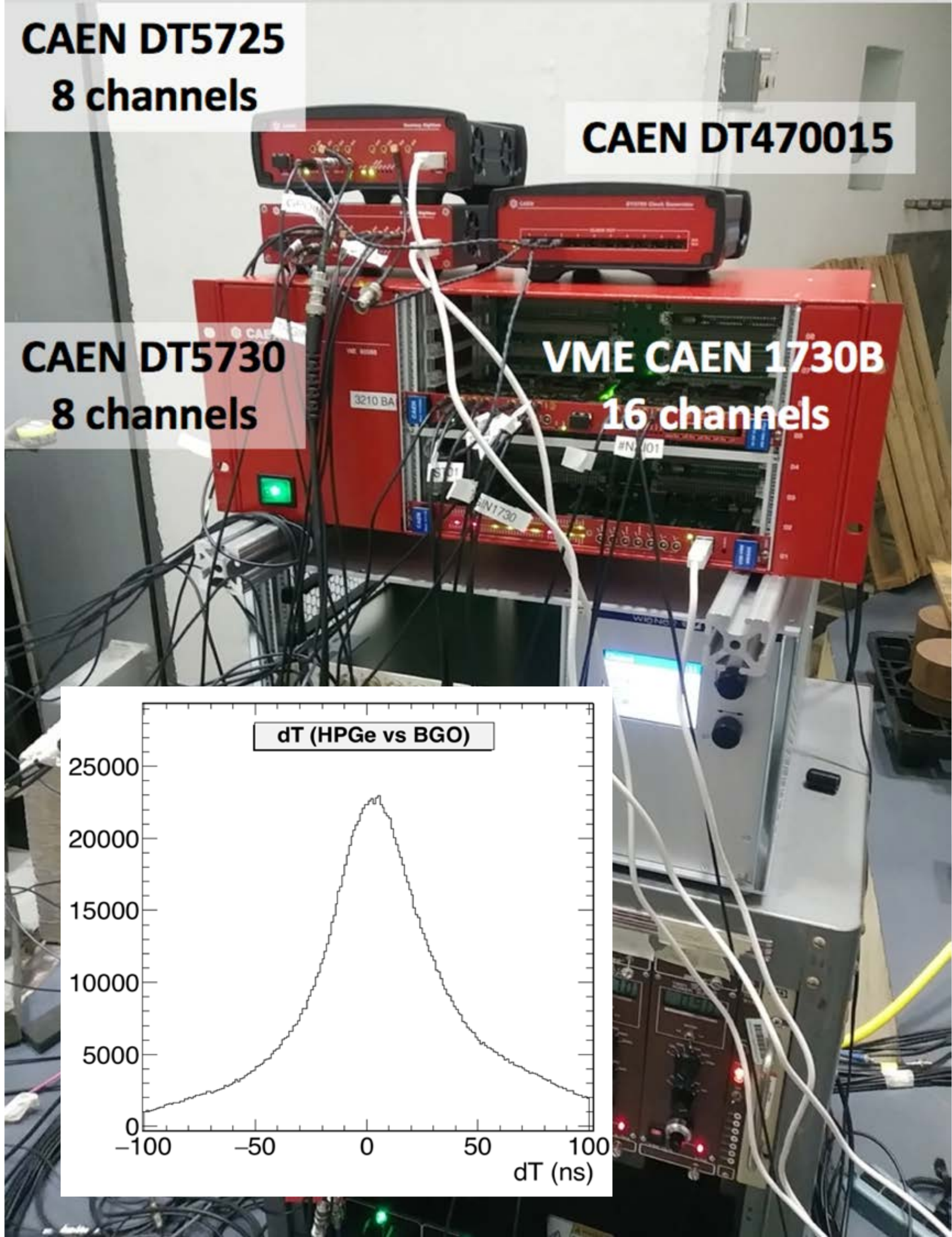




UMLDAQ – DATA ACQUISITION

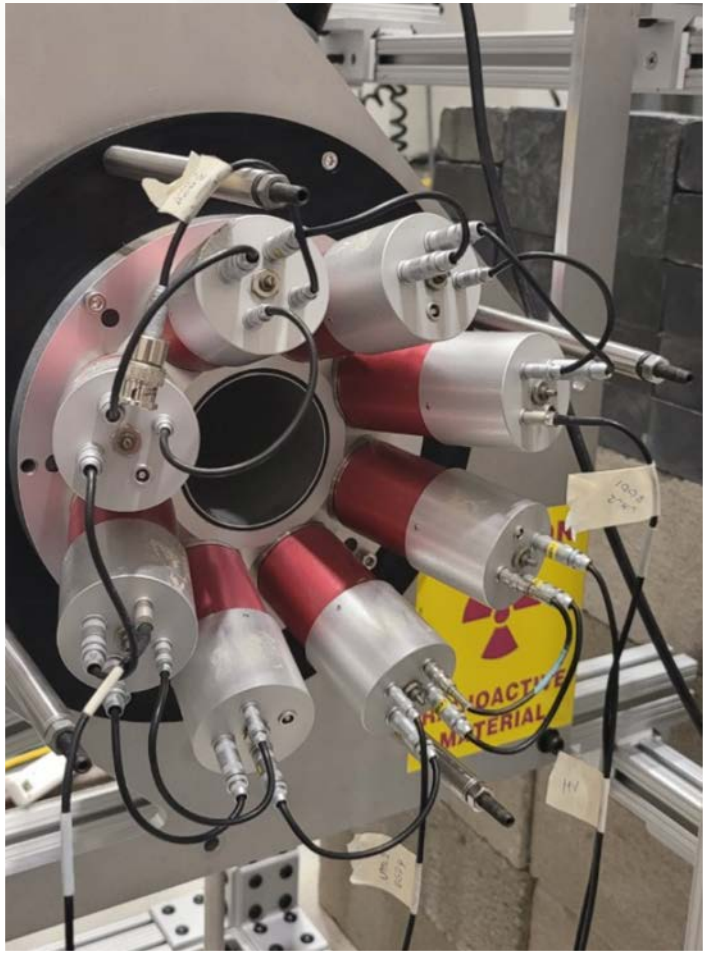
- UMLDAQ – based on CAEN hardware, software drivers and C++ libraries
- Asynchronous data acquisition using FPGA digital pulse processing
- VME based:
- 16 channel 14-bit 500-MHz CAEN V1730
- Two 8 channel x 14-bit 500-MHz CAEN V1730
- In house DAQ frontend and backend codes

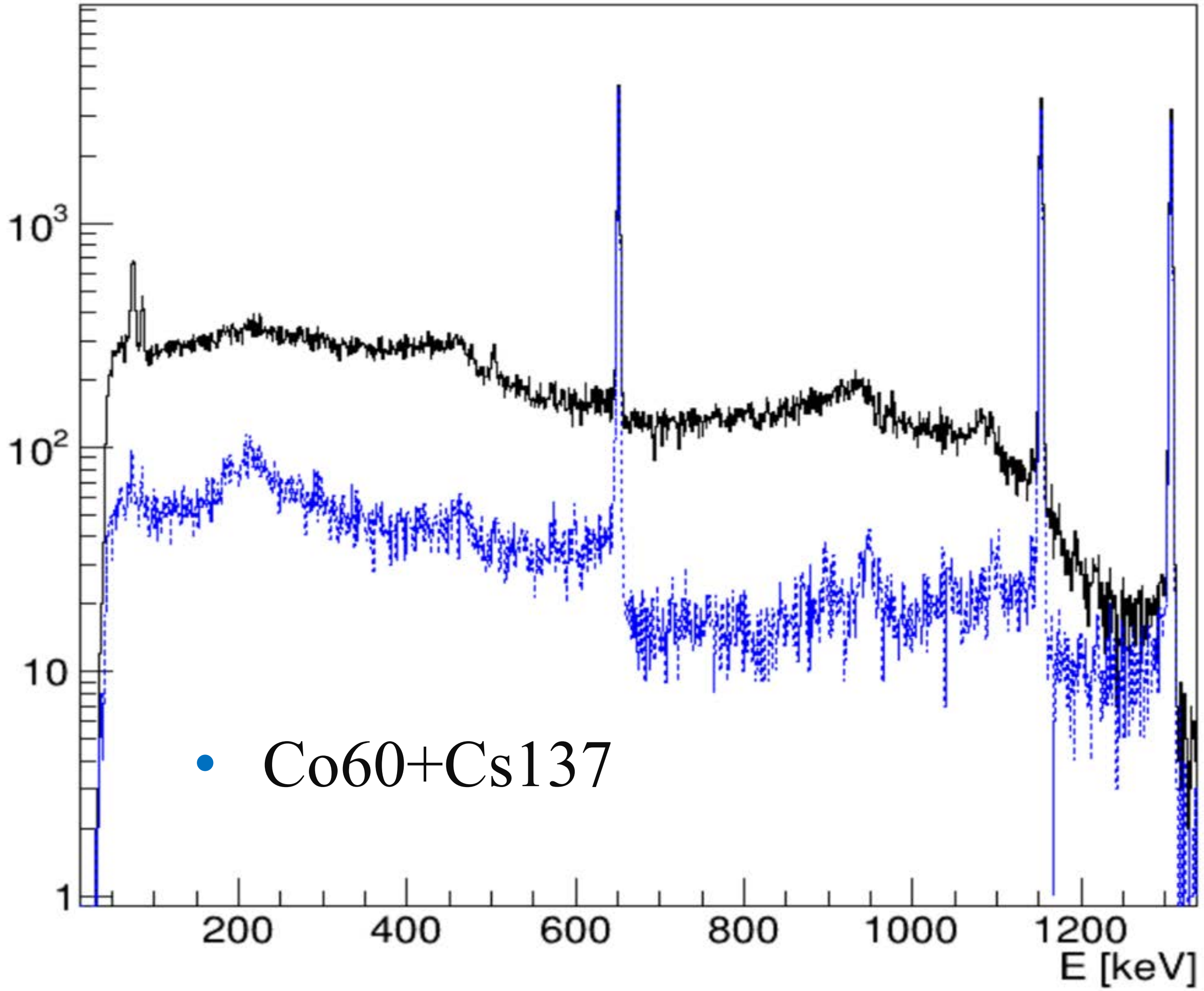
- HPGe are using PHA firmware with trapezoid filter (4 channels)
- BGO/NaI are using PSD firmware using pulse integration (8 channels)
- BF3 is also on PHA firmware (1 channel)



RECENT IMPROVEMENTS: COMPTON SUPPRESSION

- We split daisy-chained signal into 4 signals from BGO: suppression by almost an order of magnitude. (for Mn capture ~ factor of ~10)

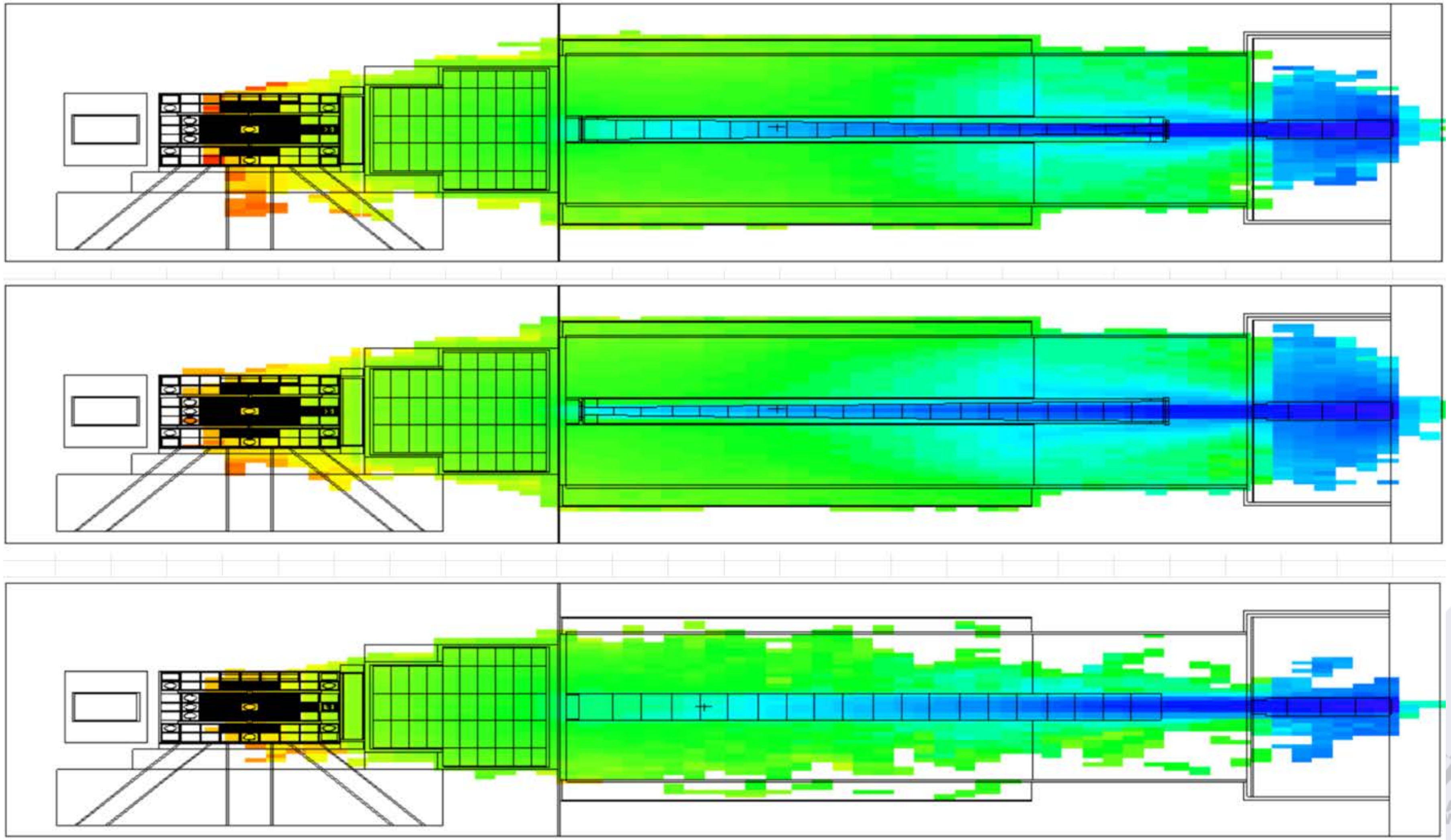




- Co60+Cs137

NEW NEUTRON COLLIMATION

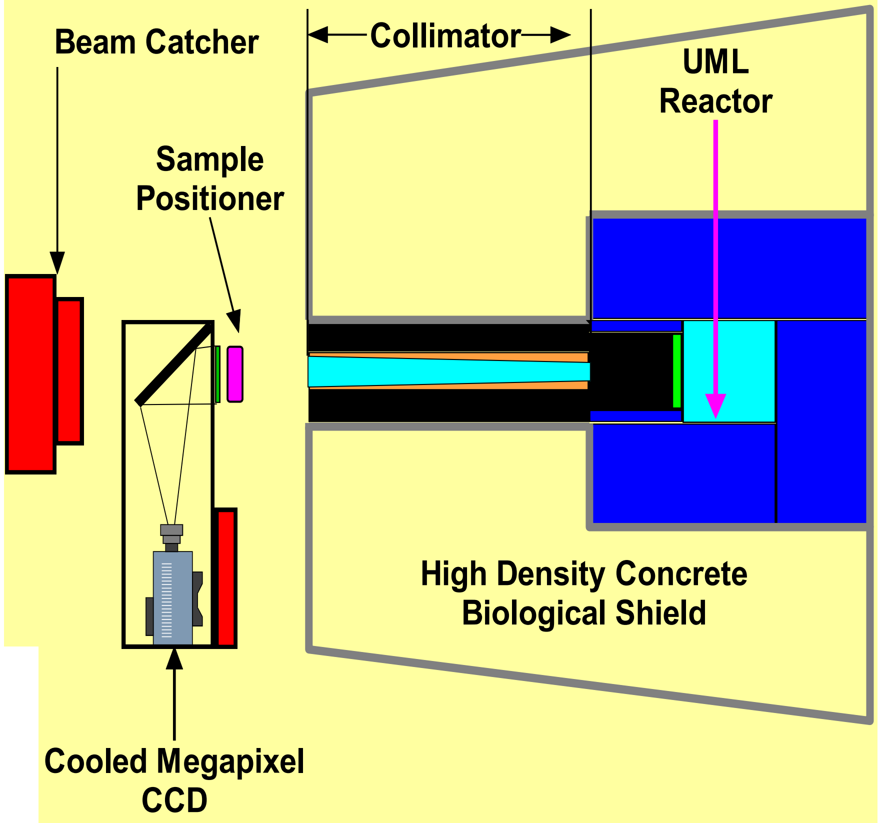
- The main developments between June – September were dedicated to new collimation of thermal neutrons
- MCNP6 (Konomi) and Geant4 (Jandel) simulations of the full thermal column assembly were designed and guided the setup
- Internal collimator
  - Standard conf.
  - Flipped
  - Removed

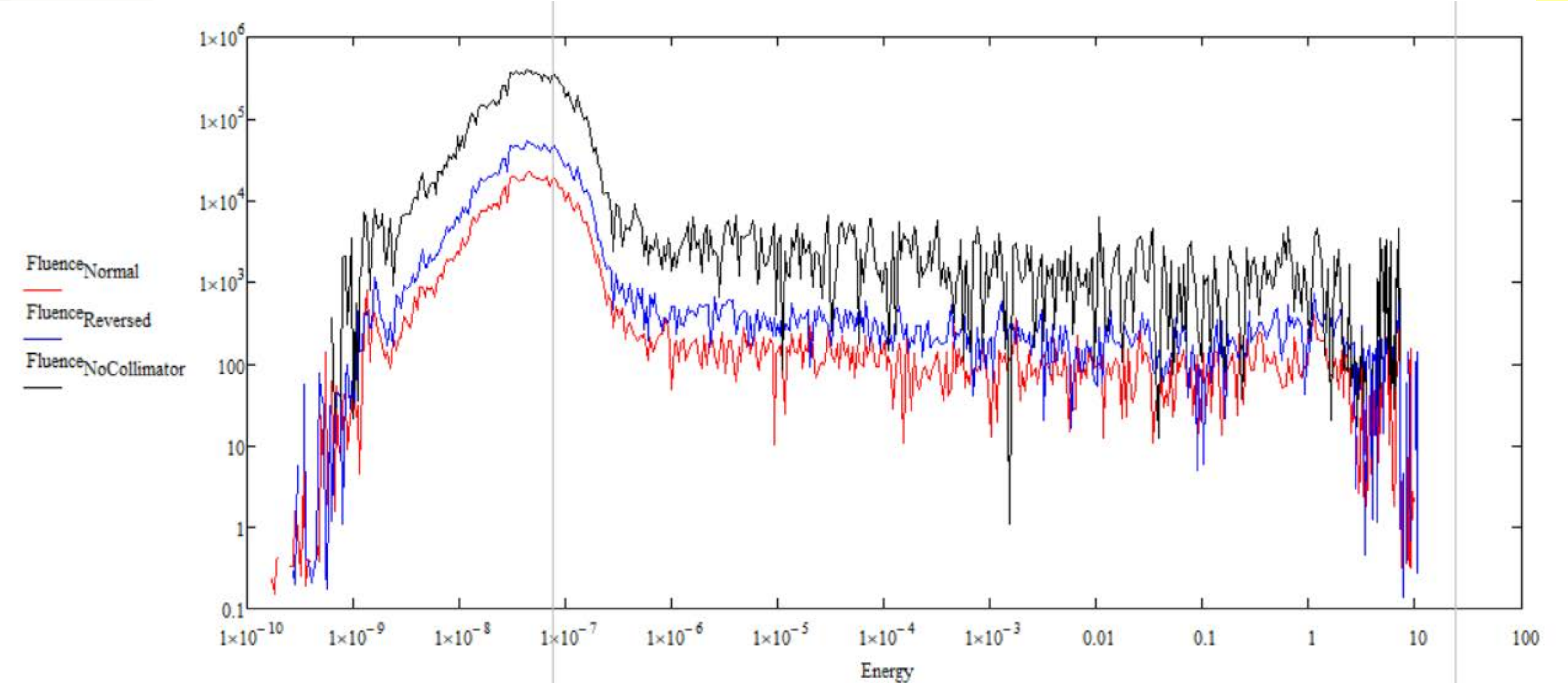


MCNP6 neutron flux simulations by Ksenofon Konomi, UML

NEUTRON BEAM

- Courtesy of Ksenofon Konomi (Reactor's staff engineer)
- The calculations in MCNP6 are underway – full reactor core/shielding and thermal column, graphite pile is included. This needs to happen in stages and several calculations are coupled to get the flux at sample position in the center of our setup.
- Flux at the exit of the biological shielding) with existing collimator in place

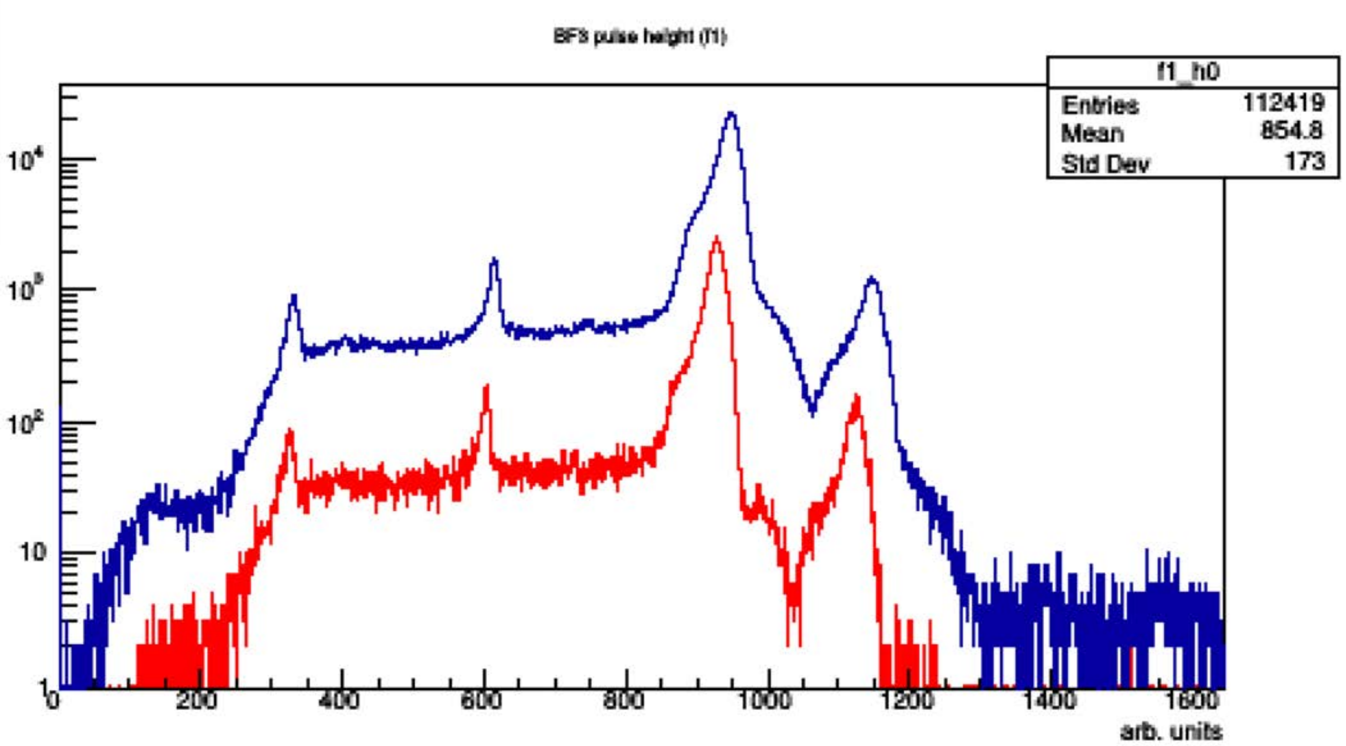




Collimator can be flipped or removed to gain **18 x** more flux per MCNP6 simulations

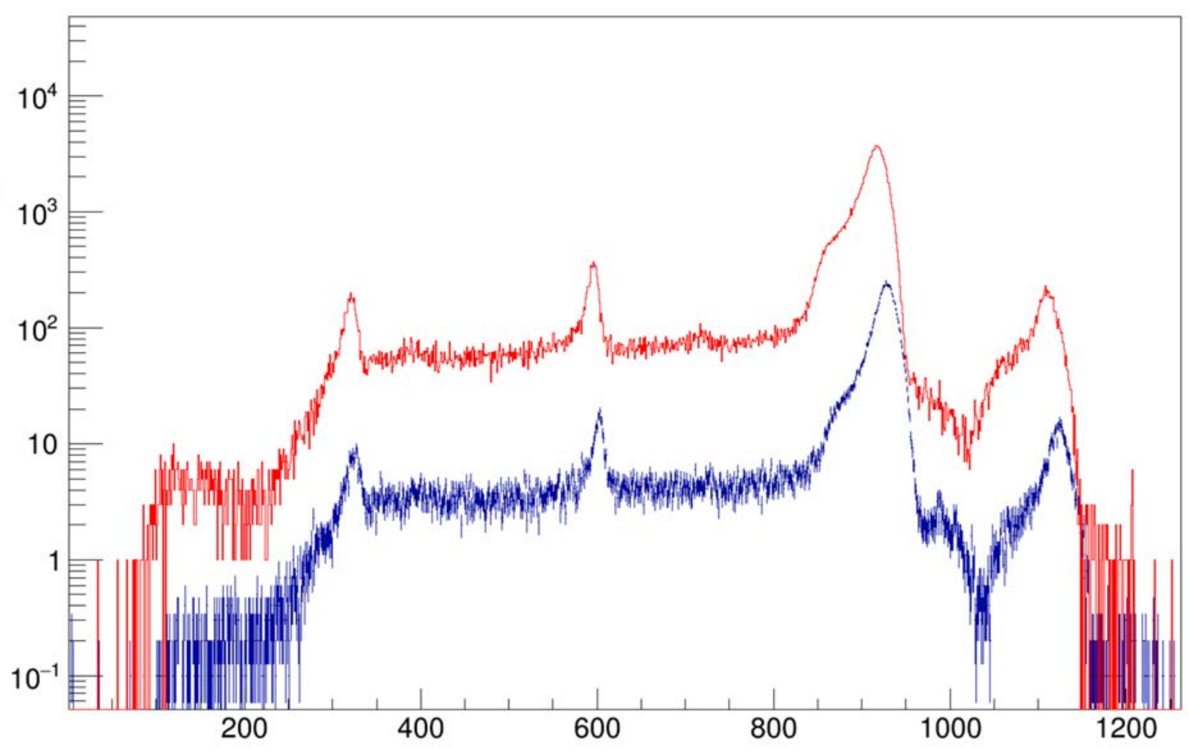
NEUTRON BEAM – ACTUAL MEASUREMENTS – JUNE 2023

- (June 2023) We have confirmed enhancement of neutron intensity by a factor of **11.7** 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**



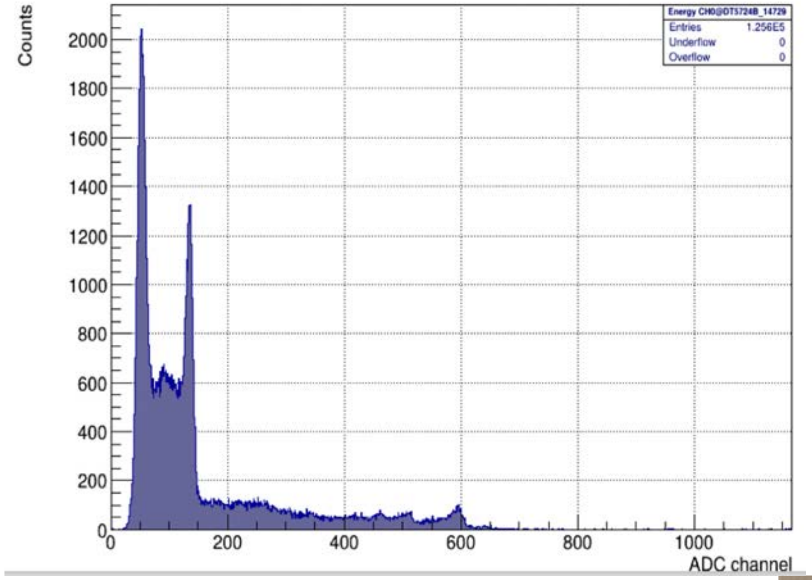
NEUTRON BEAM

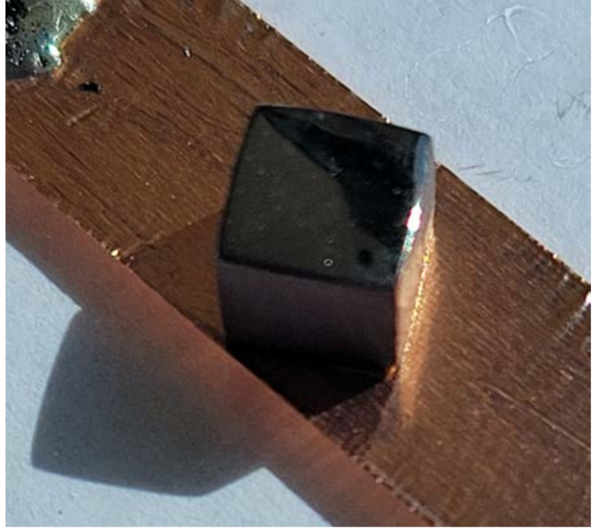
- We redesigned the collimation, and were able to gain 18x neutrons compared to original configuration
- M. Wooldridge will measure the neutron flux (Capstone Project – Spring 2024) with Cd slit and actuator to get the profile of neutron beam



CZT - LOW ENERGY, X-RAY DETECTORS

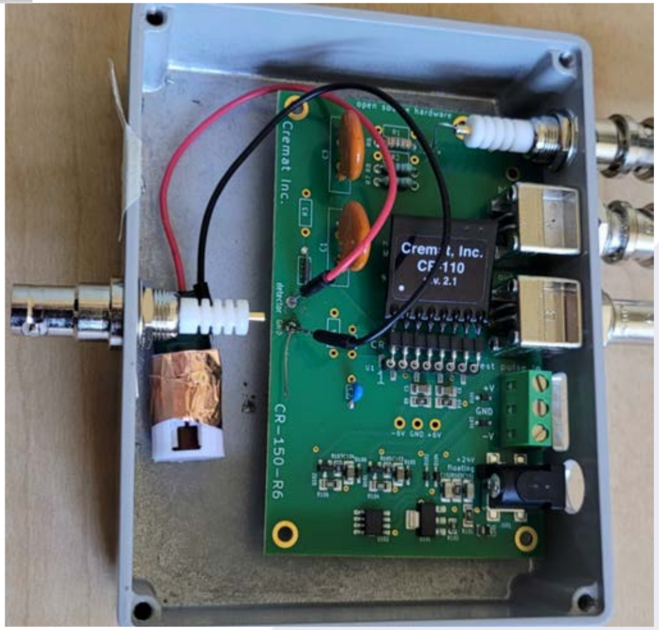
- CZT detectors: crystals from Kromek
- First spectra of Ba-133 (M. Krueger Capstone Project)
- Enclosure design by UMass Lowell
- Design of new boards (by **M. McGlynn – KCS college summer scholarship recipient**) – based on CREMAT chips and design



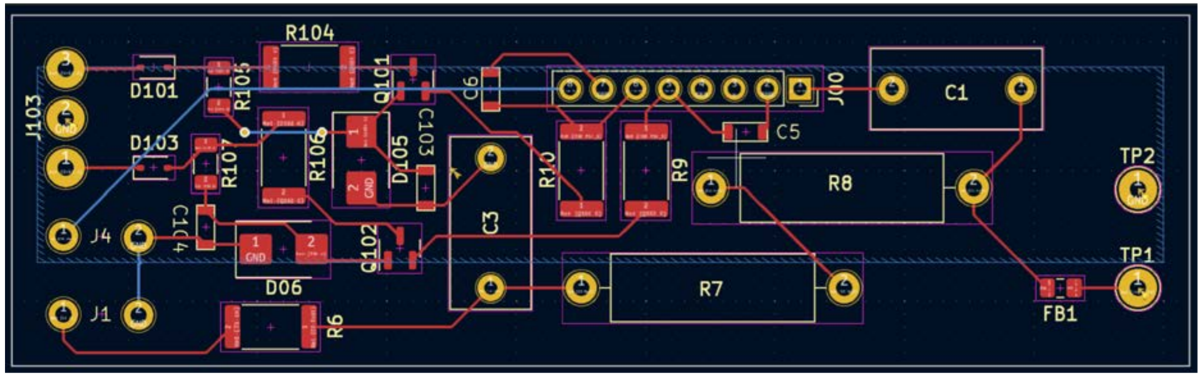


CZT: 5 x 5 x 5 mm^3

CREMAT PA test board

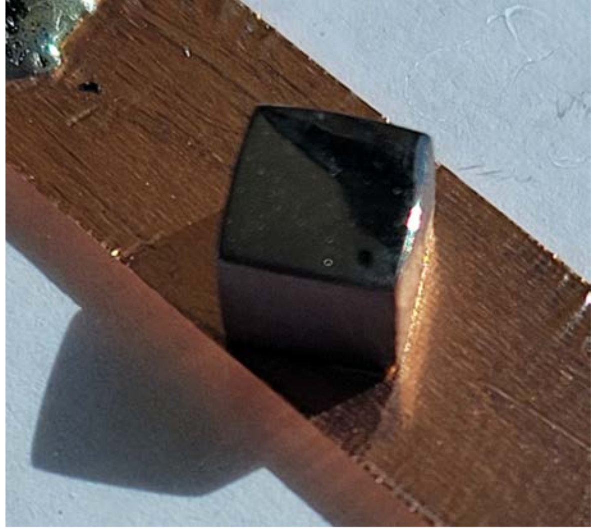


UMass Lowell design of the PA



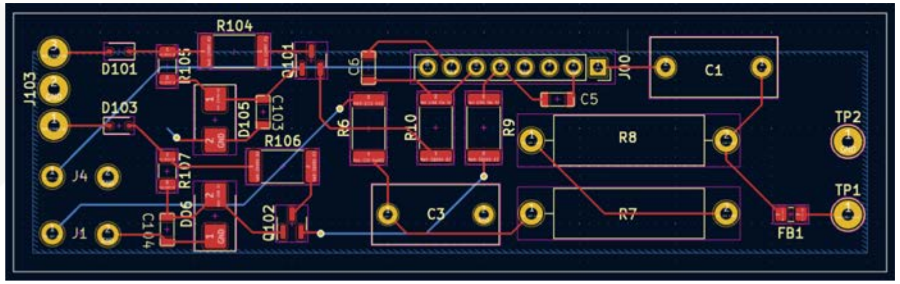
CZT - LOW ENERGY, X-RAY DETECTORS

- CZT detectors: crystals from Kromek
- The second iteration of the preamp boards (by **D. Fernandez**) who joined the group in Sep 2023



CZT: 5 x 5 x 5 mm^3

UMass Lowell design v2.2 of the PA by Daniel Fernandez



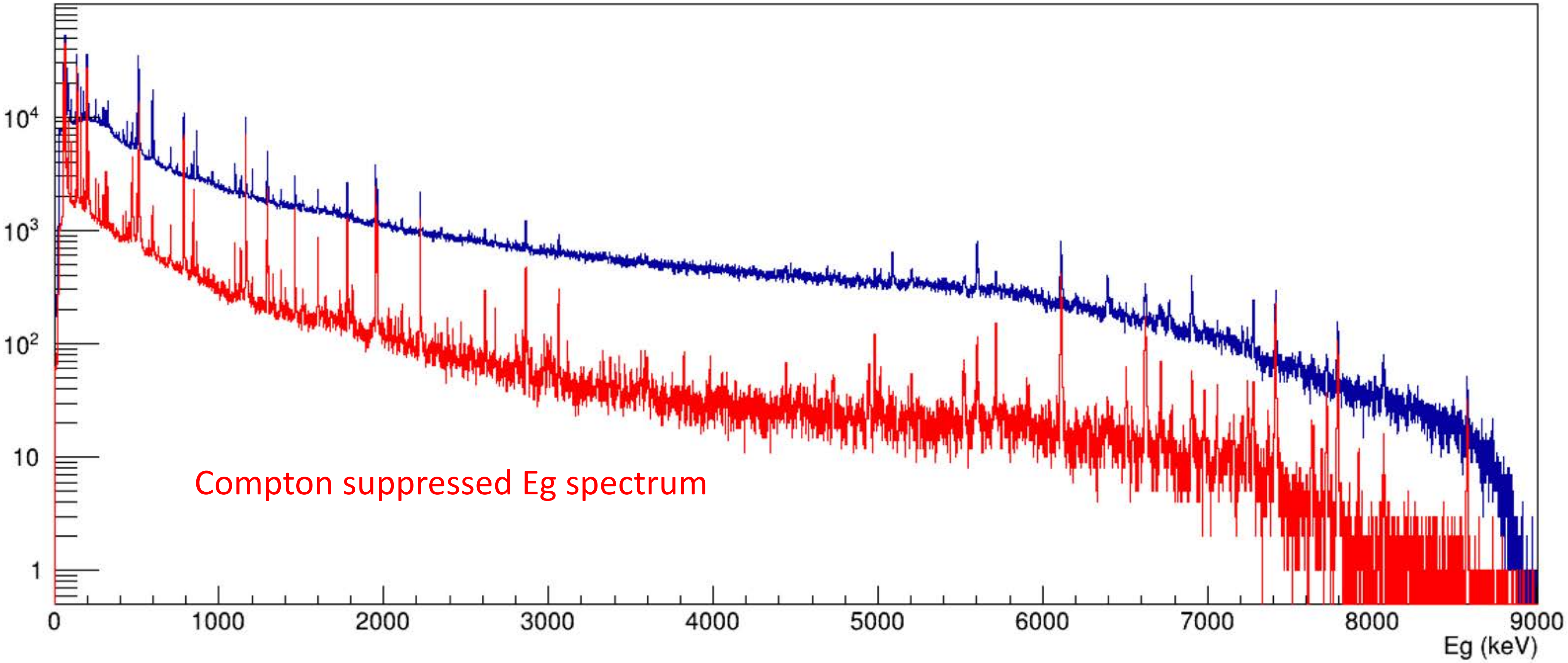
NOV 2023 – JAN 2024 TUNEUP EXPERIMENTS

- 4 graduate students
- 2 undergrads
- 3 months of experiments

- A lot of data was taken on different samples, different sizes and composition
- Mn, MnCl, Gd, Ni
- Calibration data

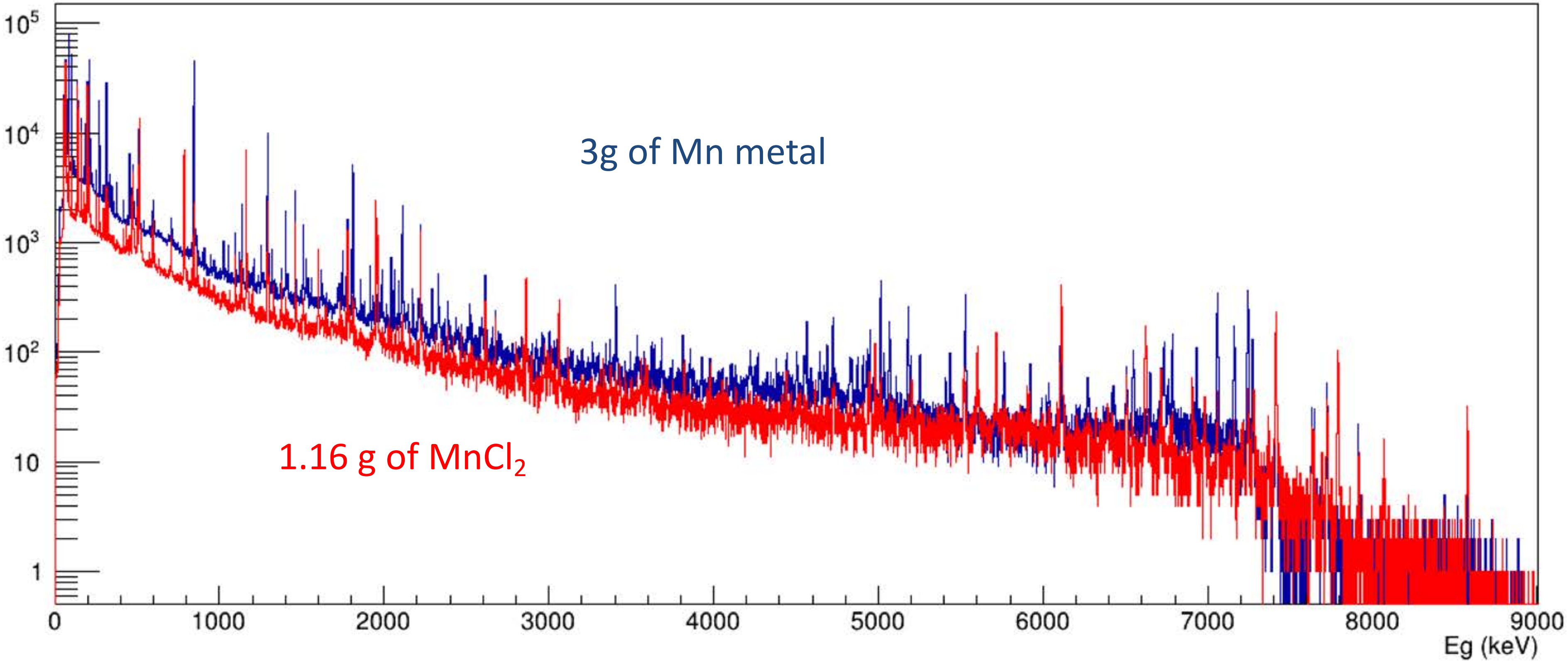
MNCL – VERY PRELIMINARY -

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



MNCL – VERY PRELIMINARY -

- Sample of 1.16 g of $MnCl_2$
- Vs sample of 3g of Mn metal



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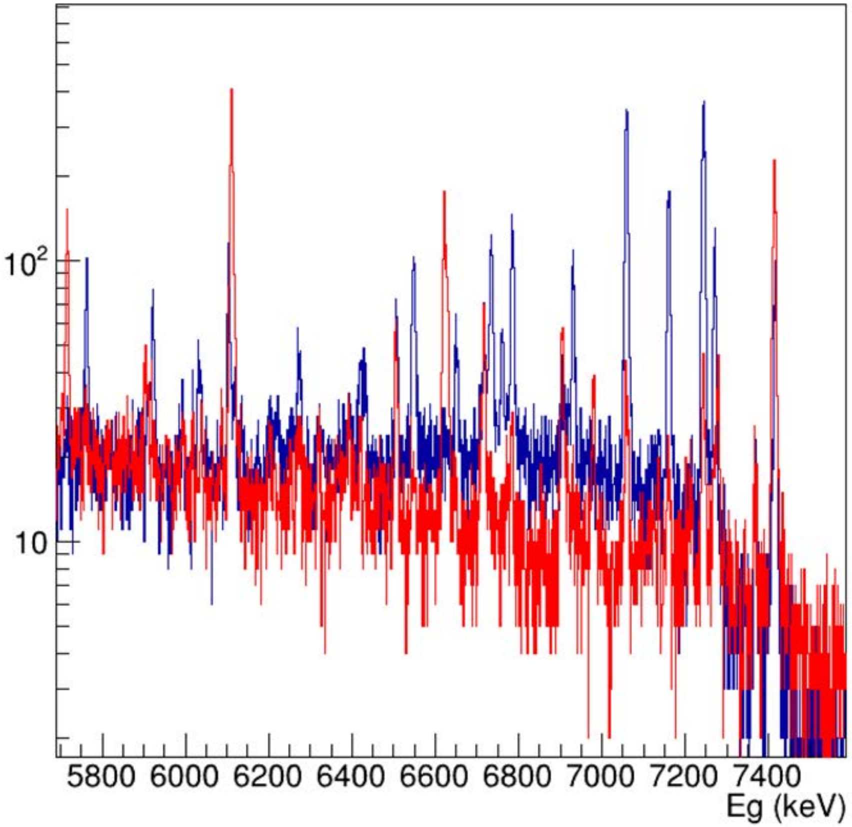

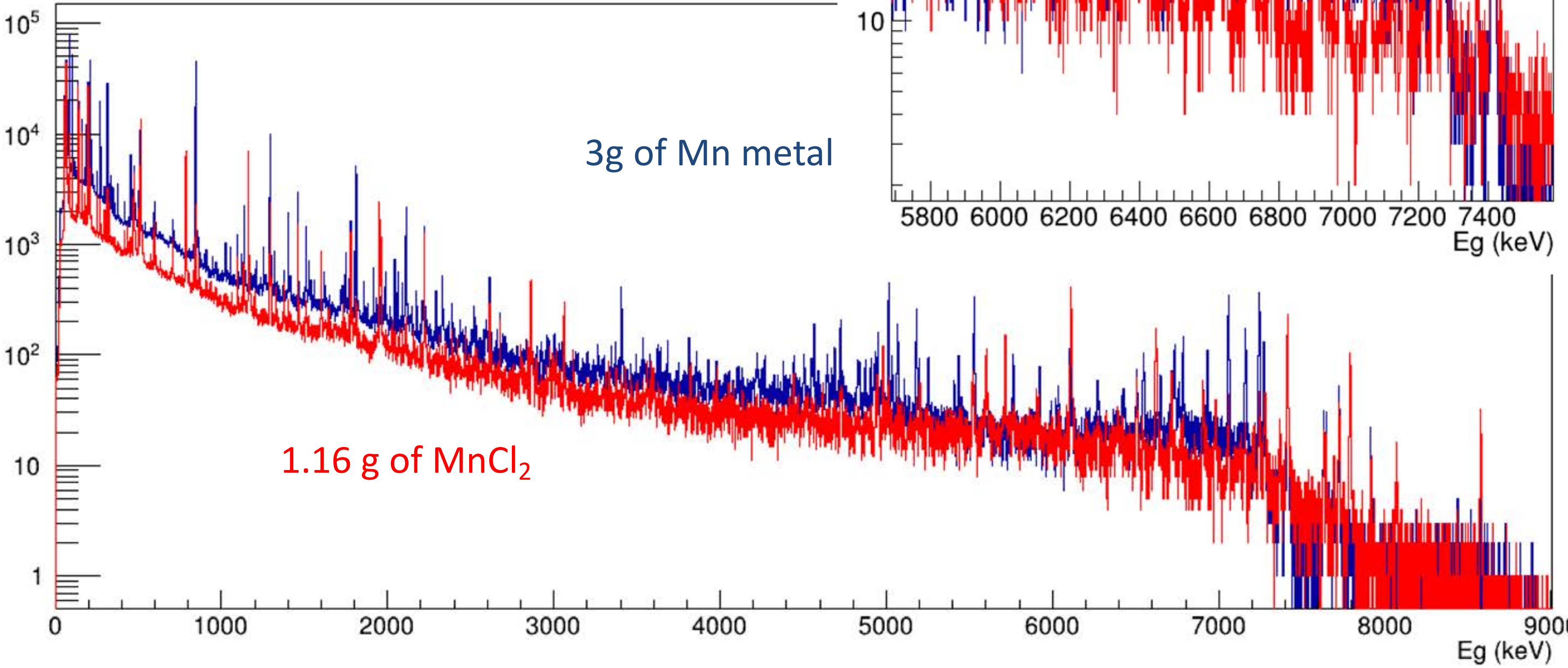

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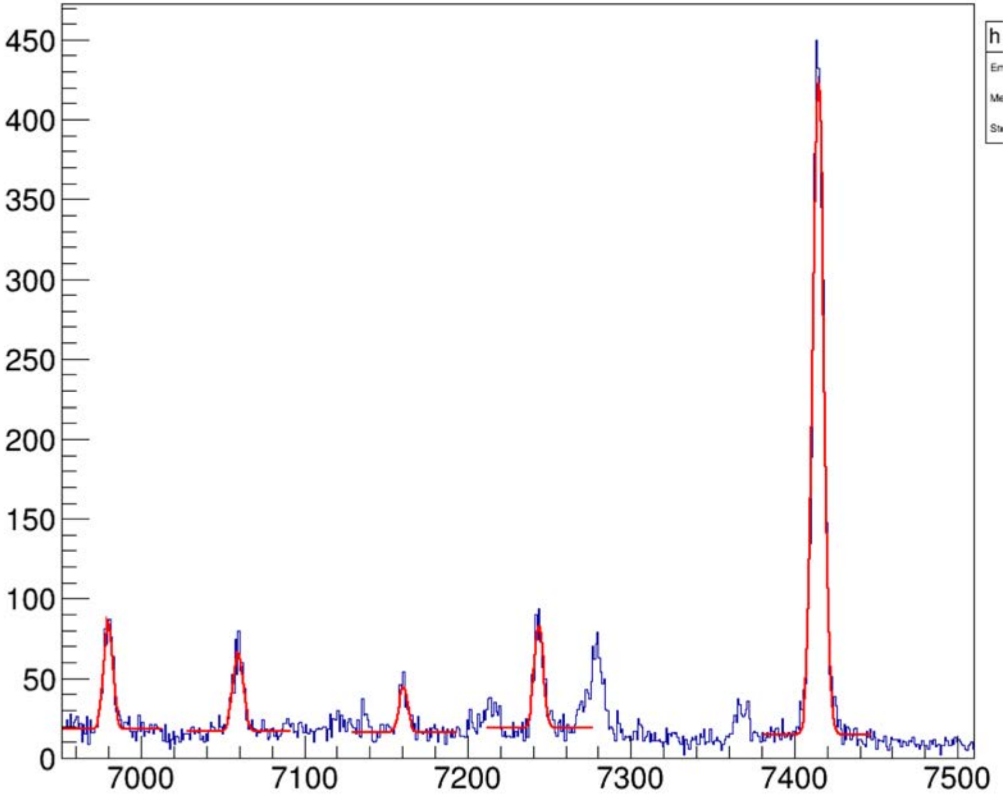
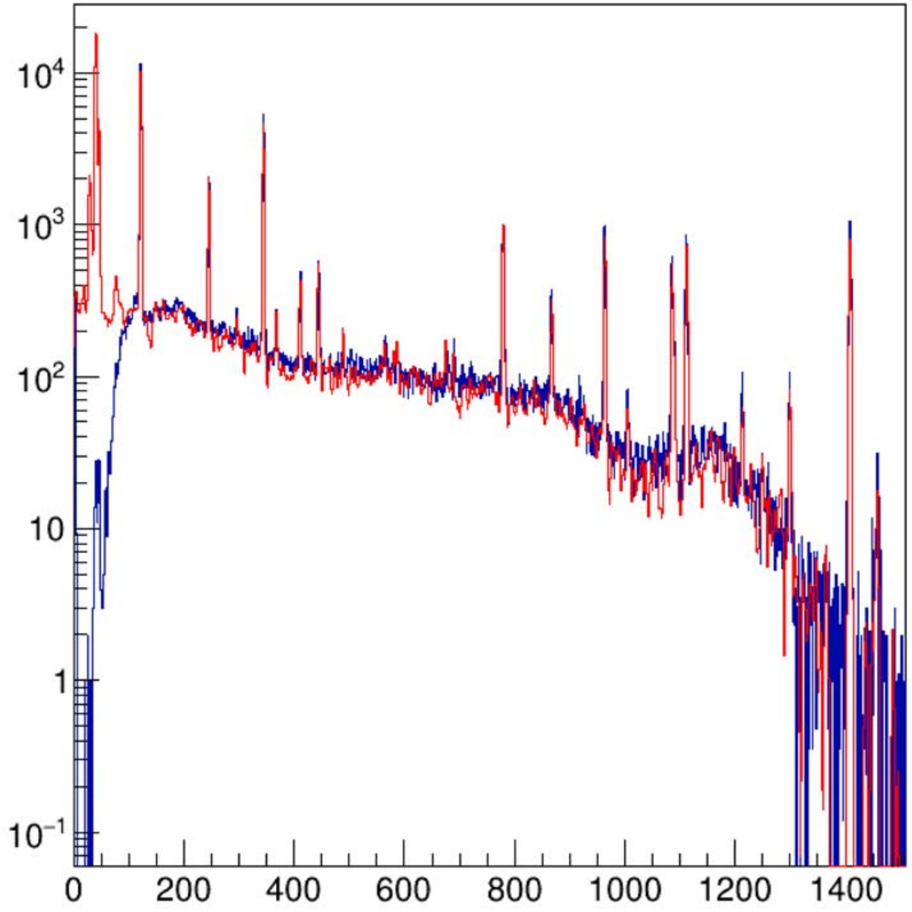
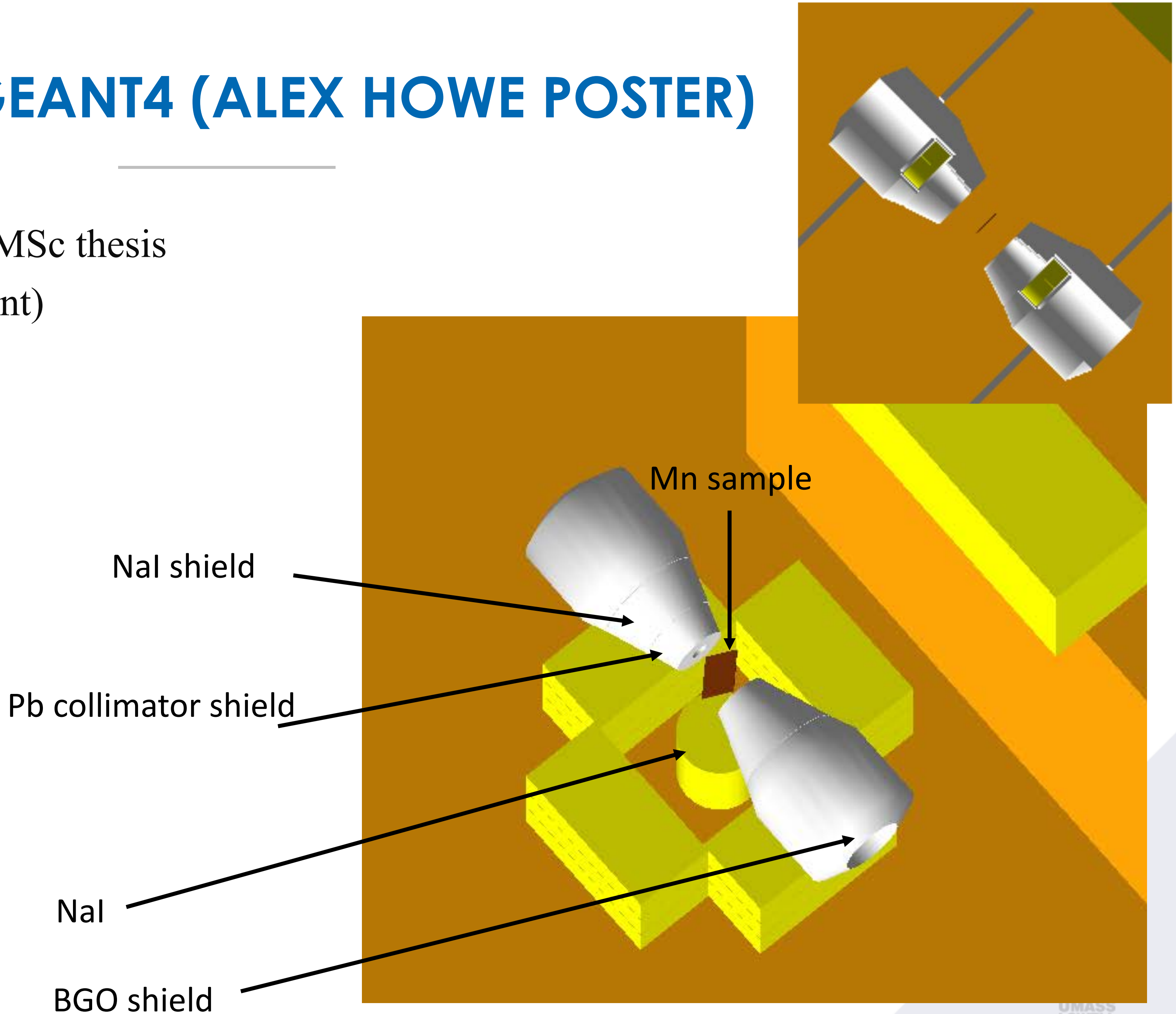


	E (keV)	Ig (ENDSF)	xs (b) (ENSDF)	*Ig UML*
Cl36	7414.1		3.29(5)	
Mn56	7243.8	0.123	1.64	*0.1344*
Mn56	7159.7	0.0596	0.811	*0.0428*
Mn56	7057.8	0.11	1.496	*0.0892*

RADIATION TRANSPORT: GEANT4 (ALEX HOWE POSTER)

- A. Howe, graduate student, part of his MSc thesis
- (Eu-152: red - Geant4, blue – experiment)





UML – MN56 CAPTURE GAMMAS VS DICEBOX

- DICEBOX simulations were performed for various level density models (constant temperature, Back shifted Fermi gas and QRPA/Thalys) and photon strength function models
- The effort is ongoing in both simulations and data analysis

Table 2: Intensity of the γ-rays from thermal neutron capture reaction ^{55}Mn + n, the energies are taken from ENSDF [1]. Our preliminary results, I_γ^{UML}, are compared to the values from EGAF and ENSDF [1] databases, and to intensities simulated with DICEBOX. The uncertainty of simulated values includes the spread between different model combinations as well as the uncertainty over nuclear realizations for given model combination.

E_γ (keV)	I_γ^{EGAF} (per 100 neutron captures)	I_γ^{ENSDF}	I_γ^{UML}	$I_\gamma^{DICEBOX}$
104.6234(20)	13.0(4)	8.4	??	9.97(28)
212.017(6)	15.9(5)	10.6	11.9	16.40(27)
271.175(9)	7.04(56)	5.7	5.9	6.39(30)
314.395(10)	10.9(3)	9.4	8.5	8.55(24)
1401.7(10)	3.5*	0.88	3.4	–
1705.4(10)	1.39	1.39	< 0.5	–
1747.0(10)	3.31	3.31	1.77	–
1915.2(10)	2.0	2.5	1.35	–

CURRENT PROJECTS AT UML THERMAL NEUTRON BEAM

- Funded projects
- Measurements of capture gamma rays
  - DOE Office of Science: Mn-56 (2023-2025)
  - DOE Office of Science (FAIR): Cu, Ni, Cr (2023-2026)
    - **New HPGe e-cooled detectors arriving April 2024**
    - **New Collaboration with BNL (co-PI Shuya Ota)**
  - NSF Career: Gd (2022-2027)
- NNSA: CENTAUR2.0 Texas A&M led SSAA consortium
  - fission reaction studies (2024-2029)

PRODUCTION DATA: MN56 CAPTURE GAMMA-RAY MEASUREMENTS

- Plans for new production data measurements in summer 2024
- New detectors will be installed in May and stay near the thermal column for a long time.
- Data will be obtained continuously when reactor will be operating.
- Dedicated 3-4 weeks or more to Mn data acquisition in M June.

- July – August, we will collect data on Ni, Cu, Cr

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
- UML Grad students: Alex Howe (RA), Daniel Fernandez
- 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.

- Additional Slides

UML – ^{55}MN(N,G) ACTIVATION/DECAY

- Intensity of the thermal capture gamma-rays from ^{55}Mn+n capture reaction. Our preliminary results are compared to the values in the EGAF[EGAF] and ENSDF databases in the table below

$$I_\gamma(E_\gamma) = \frac{Area(E_\gamma)}{\Delta t} \frac{1}{\varepsilon(E_\gamma)} \frac{1}{\Phi \, N_{^{55}\mathrm{Mn}} \, \sigma_\gamma^0},$$

Eg [keV]	Ig[%] EGAF	Ig[%] ENSDF	Ig[%] UML
212	15.9	10.6	11.9
271.2	7.04	5.7	5.9
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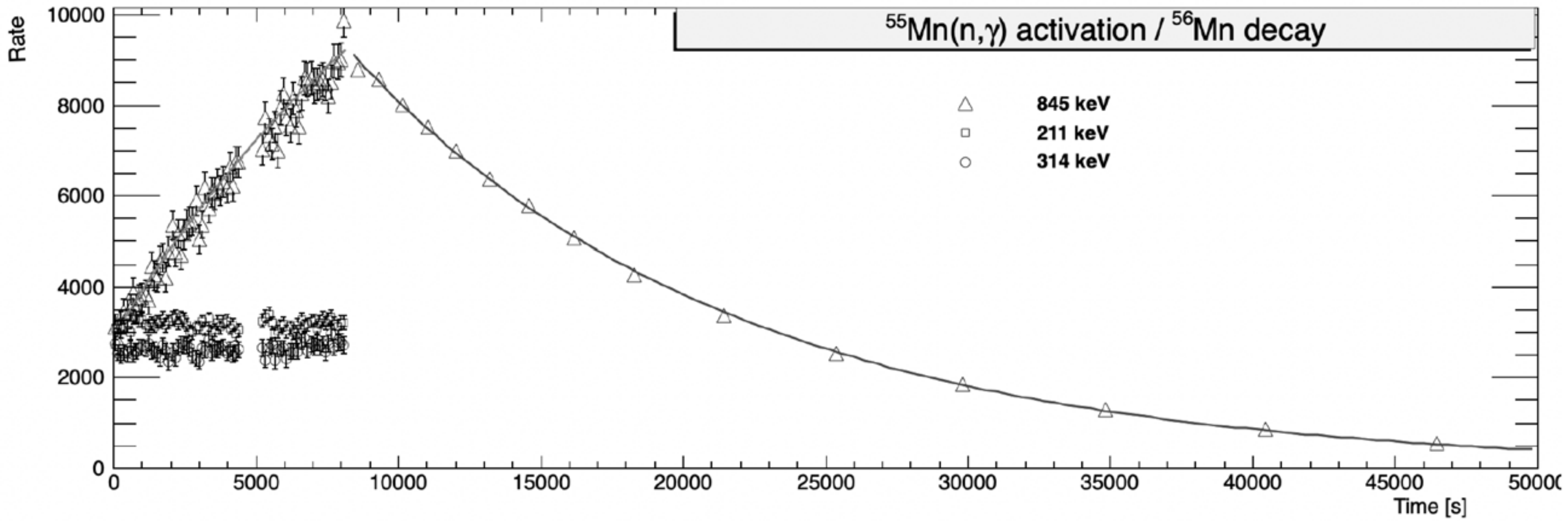

Solving the Diff. Eq. for number of Mn56 nuclei K(t) (M. McGlynn Capstone project)

$$\frac{dK(t)}{dt} = -\lambda K(t) + \Phi N_{Mn55}\sigma_{ng}$$

$$K(t) = \frac{\Phi N_{Mn55}\sigma_{ng}}{\lambda}\left(1 - e^{-\lambda t_{irr}}\right)$$

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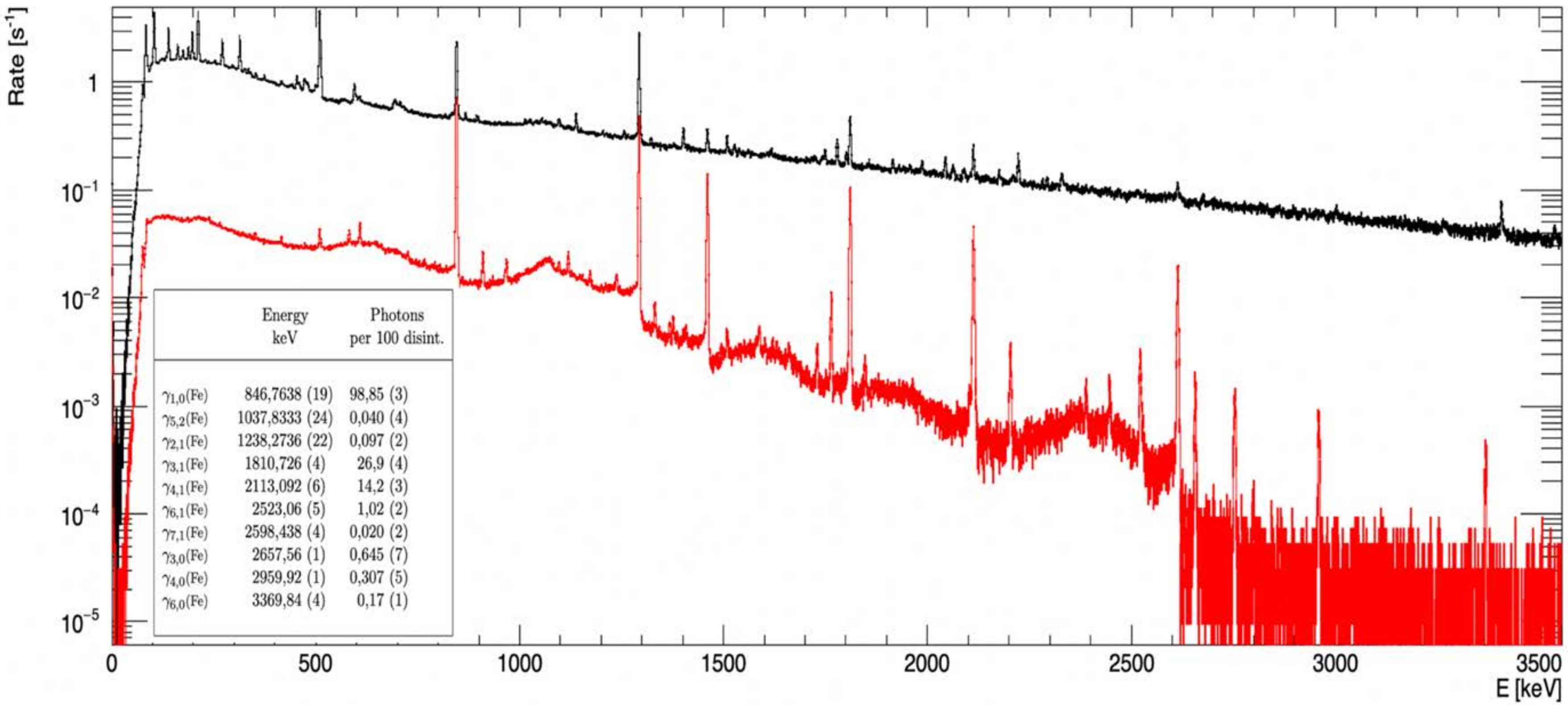
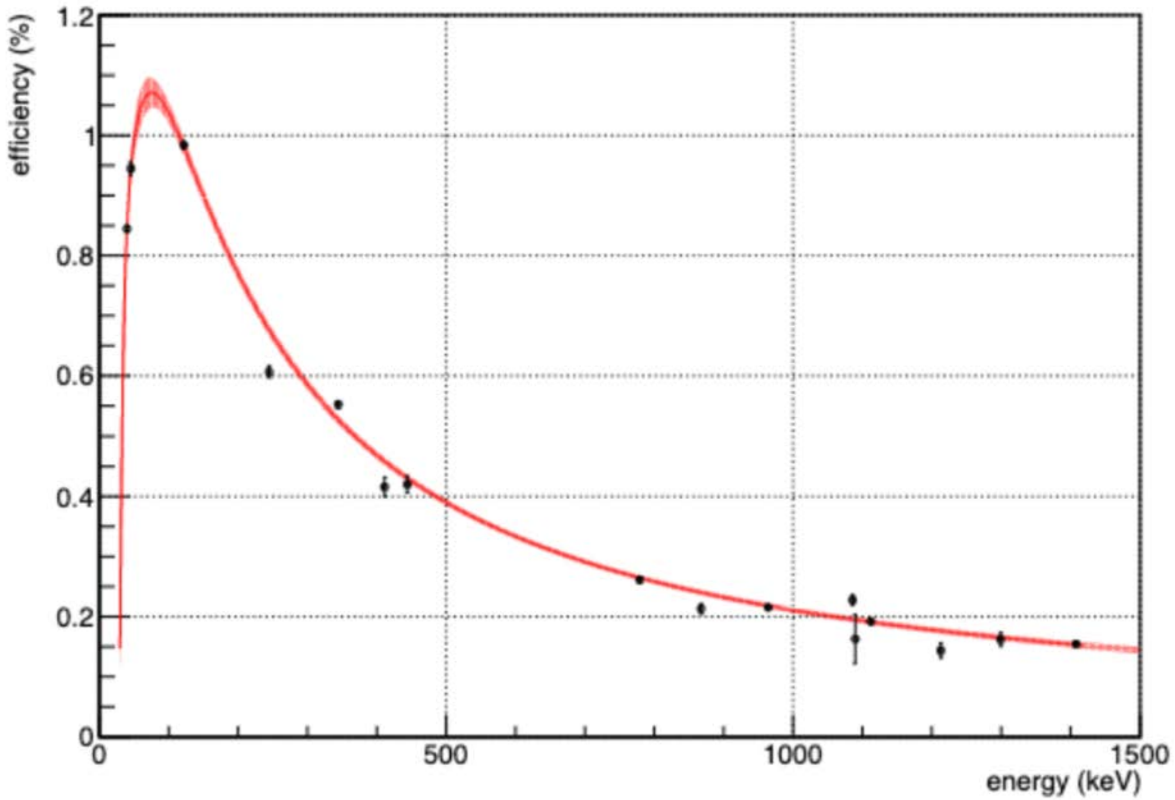
PGNAA spectrum from ^{55}Mn(n,g) (top) / b-decay of Mn56 (below)



UML – ISSUES WITH PHOTOPEAK EFFICIENCY DETERMINATIONS

- The partial gamma-ray cross sections or intensities depend in our analysis on photopeak efficiency
- We use NIST 2% certified Eu-152 source
- But need to fix high energies
- Plans to use Cl + n reaction in neutron beam
- Parametrizing the efficiency is also tricky
- We have at least 2-3 parametrizations
- Ultimately, Geant4 simulations will give the best results
- We are spending a lot of time on Geant4-MAD code



Note the non-statistical discrepancies