NEW UML CAPABILITY FOR MEASUREMENTS OF NUCLEAR DATA: CAPTURE GAMMAS FROM MN-56

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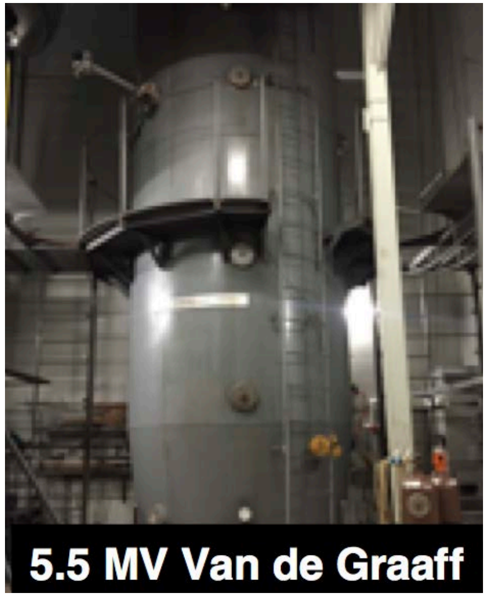
Learning with Purpose

MOTIVATIONS

- Importance of the neutron-induced reactions in applications and basic science
- Fission, capture, inelastic …
- WANDA 2020
- Education – student training

- Neutrons at UML:
  - 1MW Reactor produced thermal and fast neutrons
  - VdG produced in charged particle reactions: p,d, He, ions.

UMass Lowell Van de Graaff accelerator

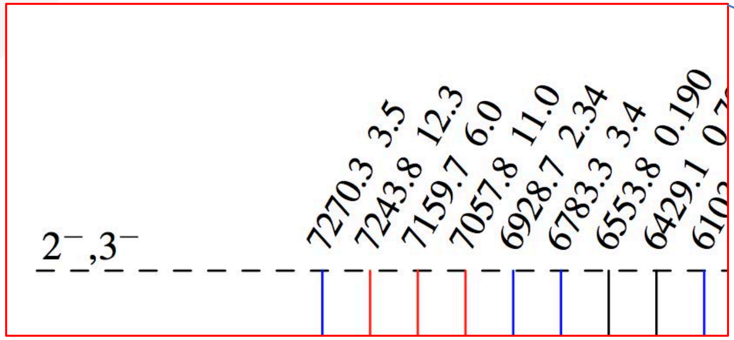


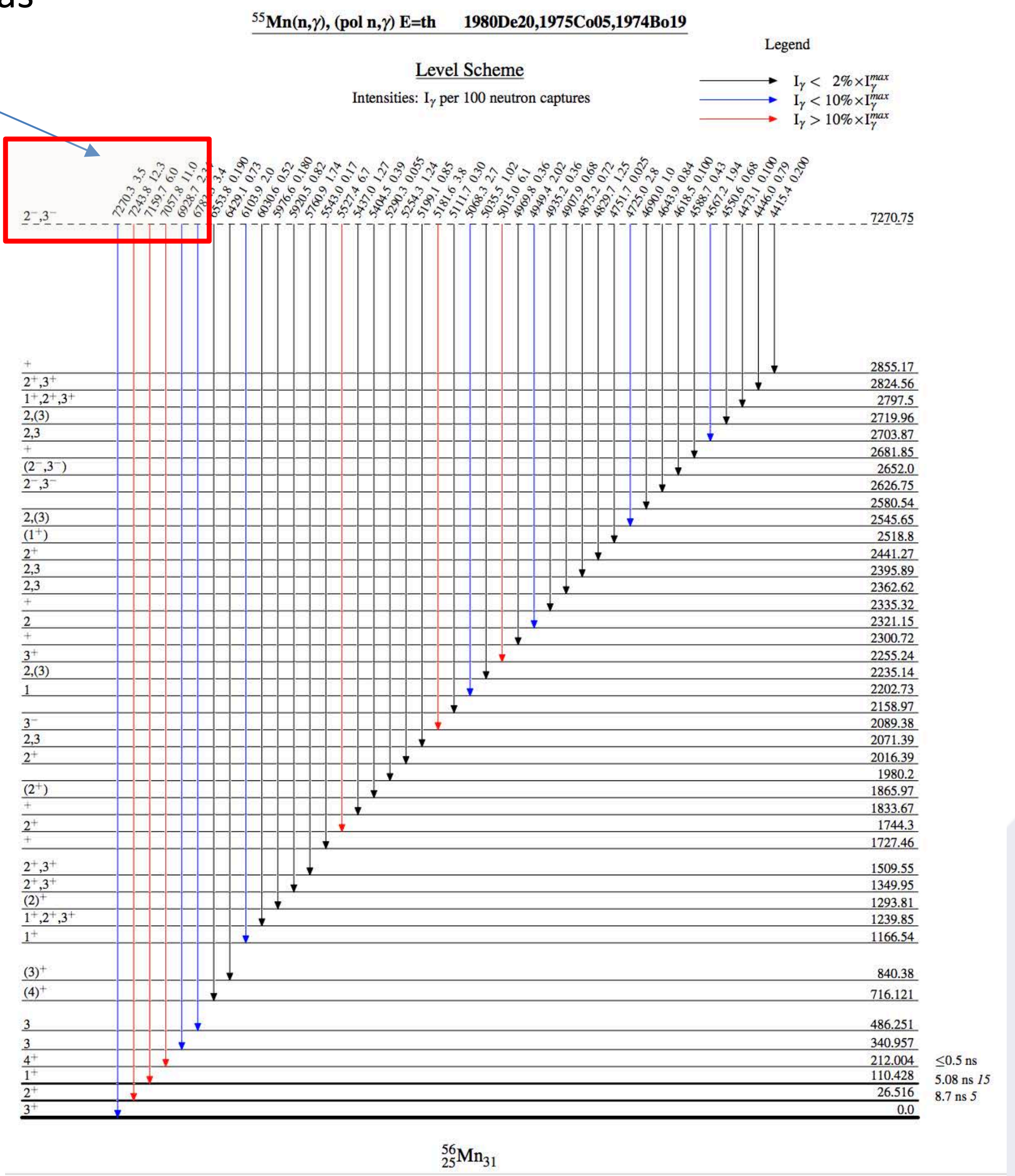
- sub ns pulsing
- Mono-energetic netrons via Li7(p,n)

UMass Lowell 1MW Research Reactor (UMLRR)

CAPTURE GAMMA

Mn-56 capture gammas (ENDSF)





- In US, not many new measurements
- Data is typically older obtained with single HPGe shielded detector
- Pileup/dead-time correction and normalization procedures can be complicated
- Gaps and discrepancies found in data
- Improve ENDF to ENDSF correspondence

CAPTURE GAMMA

Mn-56 capture gammas (ENDSF)
7058 keV (11.0 %) ??
212 keV (10.6 %) ??

- In US, not many new measurements
- Data is typically older obtained with single HPGe shielded detector
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- Gaps and discrepancies found in data
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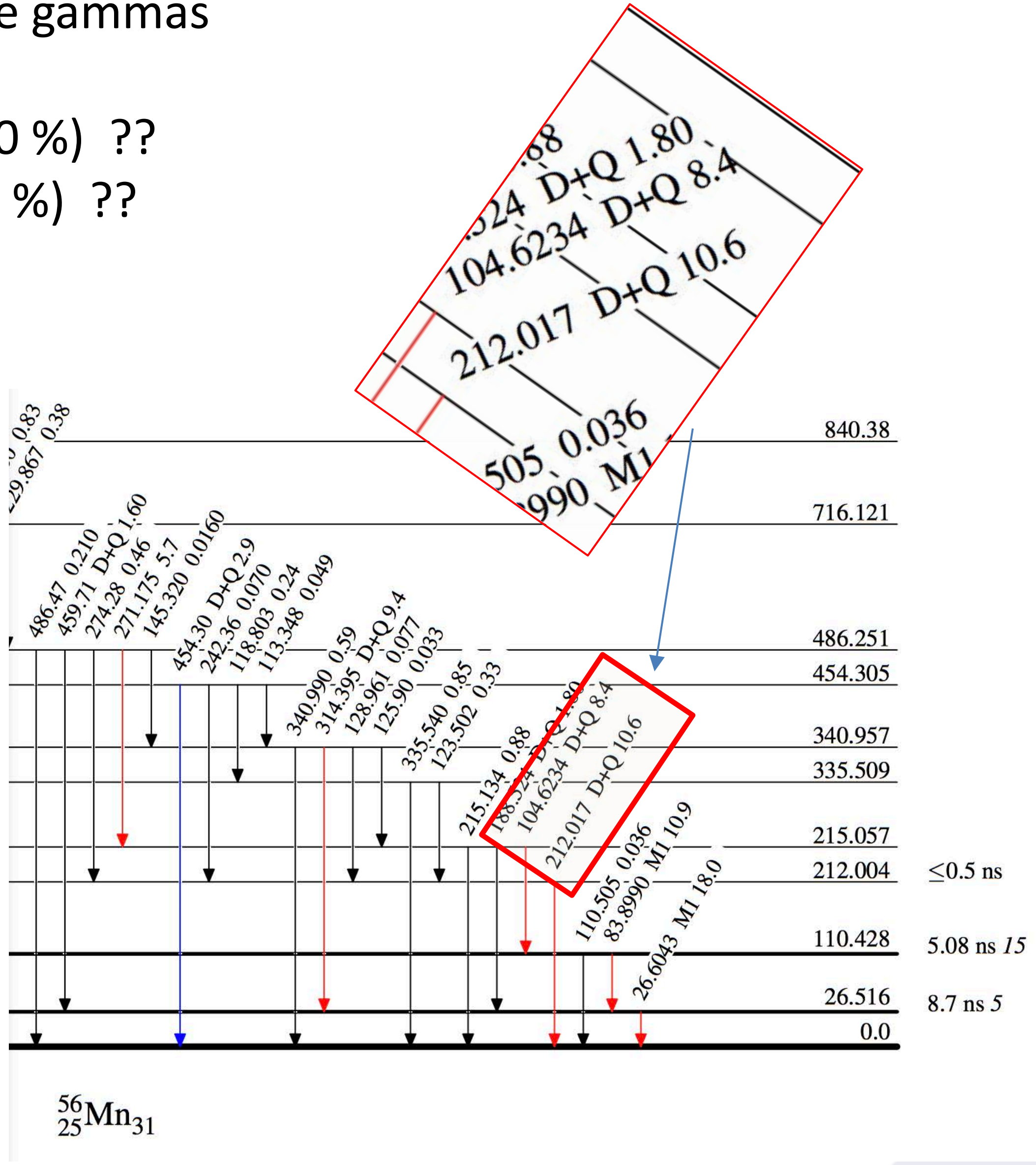
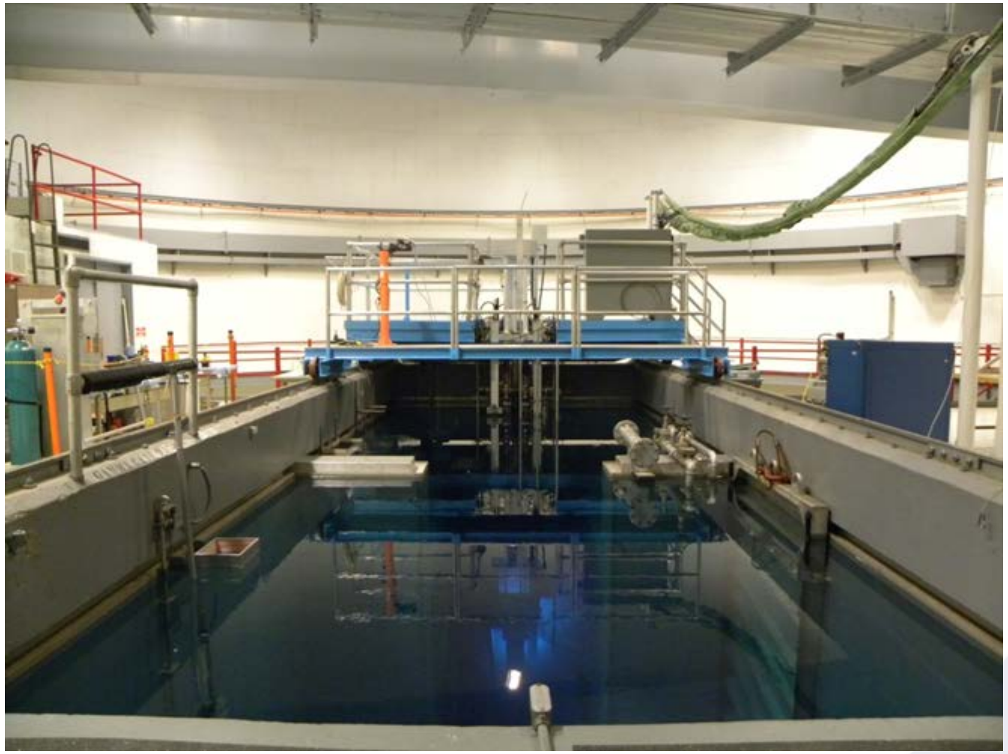


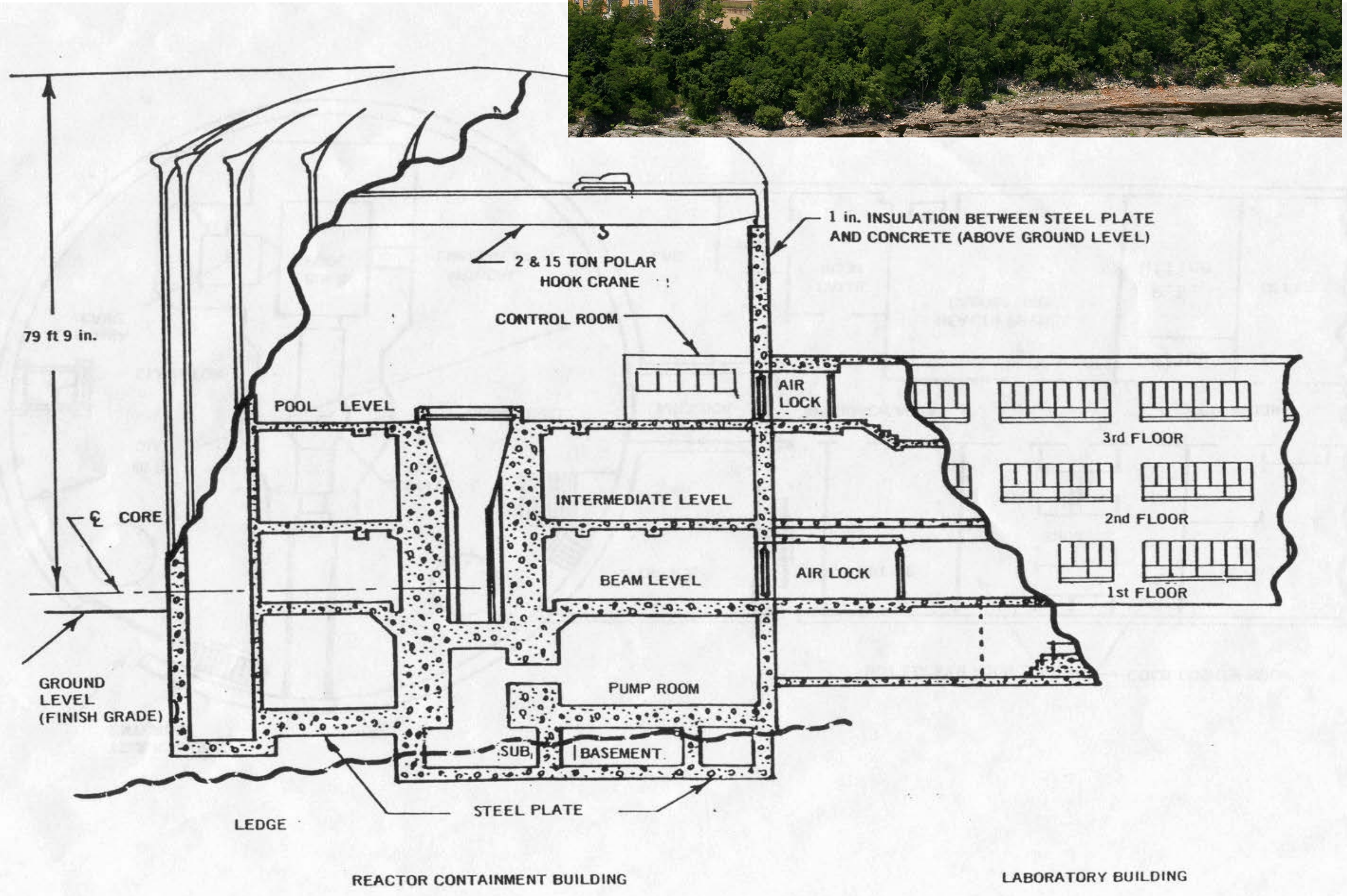
UMASS LOWELL RESEARCH REACTOR (UMLRR)

- Open pool with 75,000 gallons of demineralized water
- High-density, steel reinforced concrete (Approx. 1000 tons) surrounds the pool
- 1 MW power
- 2.5 x 10^{13} neutrons/cm^2/s in core
- Many facilities available for research including thermal column, beam ports, fast neutron irradiator, pneumatic sample irradiation system.



UMLRR DESIGN OVERVIEW - CONTAINMENT BUILDING STRUCTURE

- Steel reinforced concrete
- Welded steel shell
- Extends 30' below grade
- Ventilation isolation system
- Designed and tested to be pressure tight



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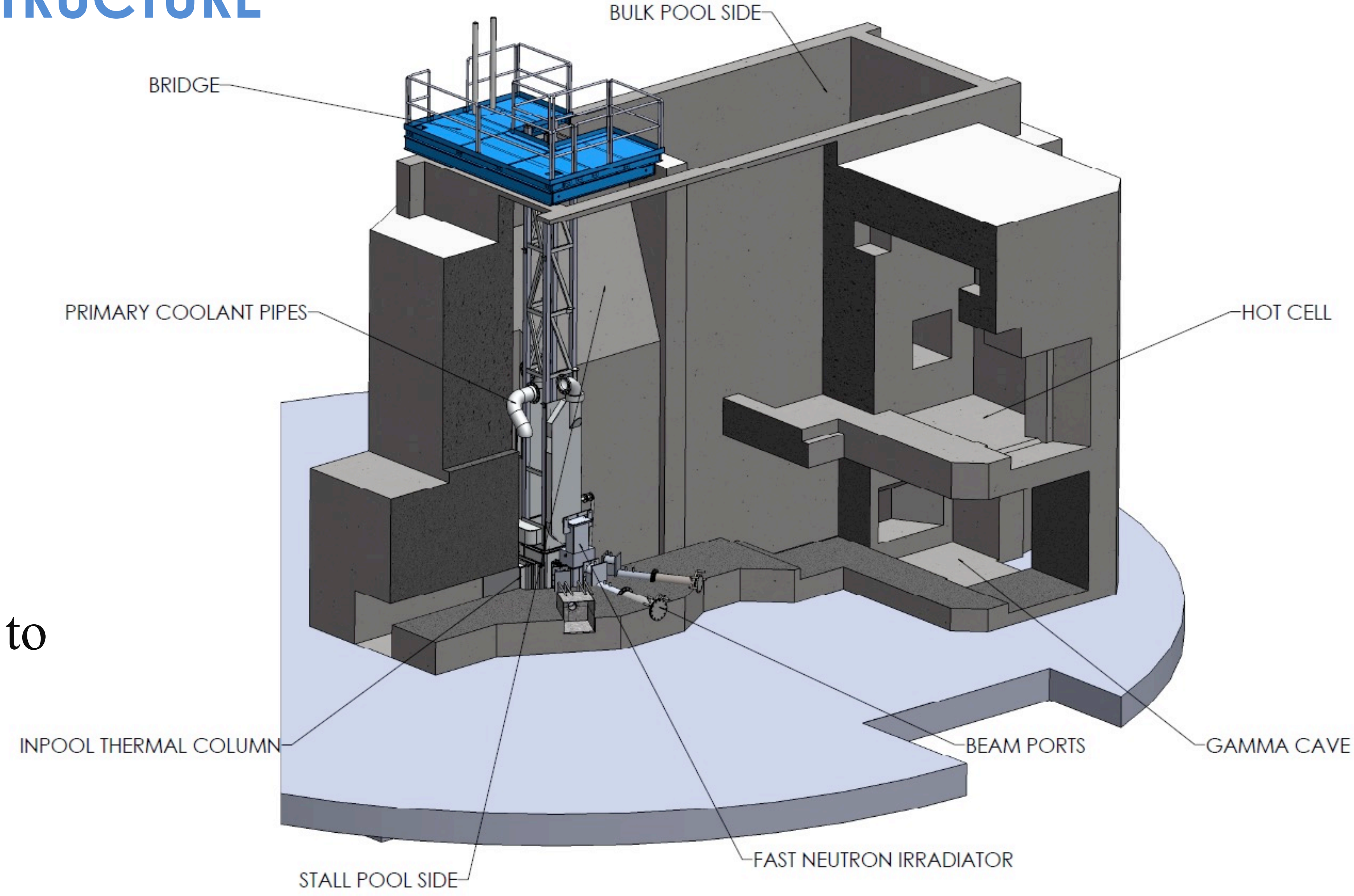
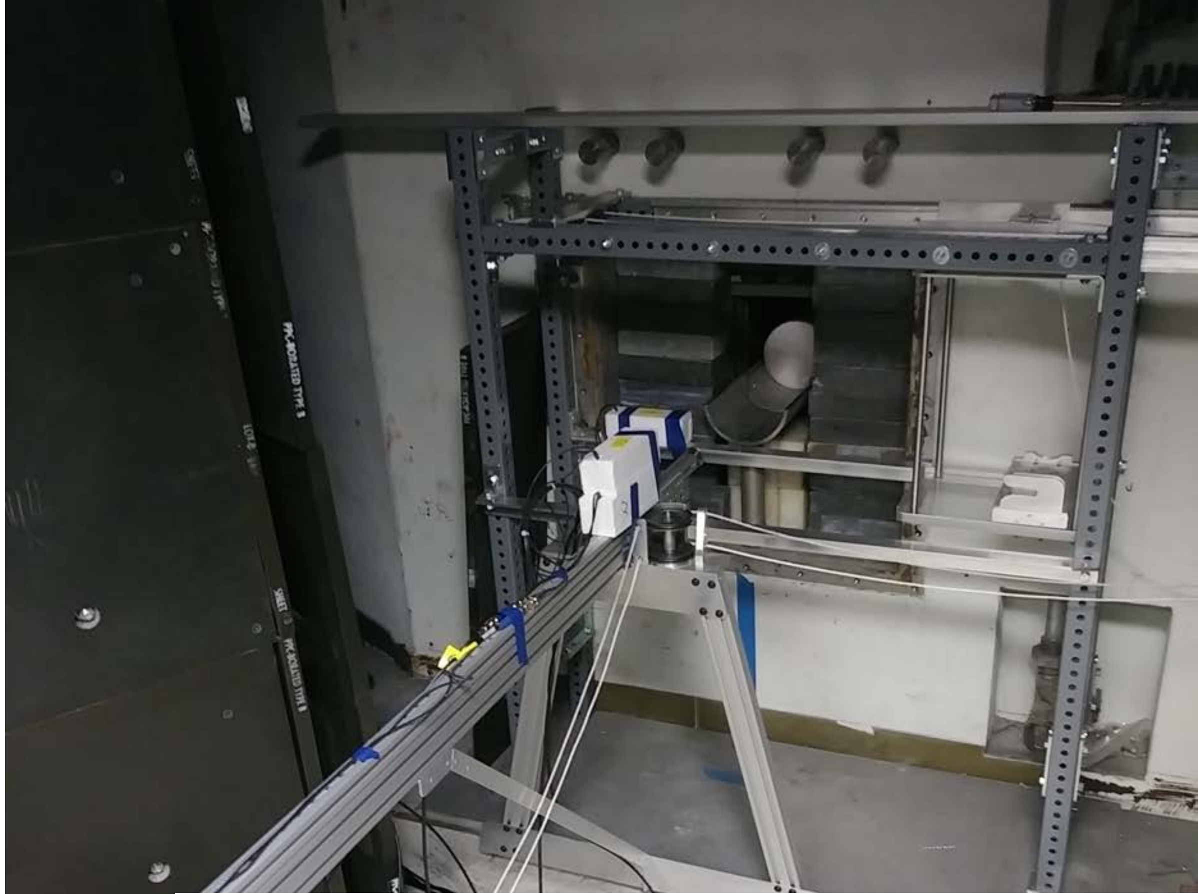
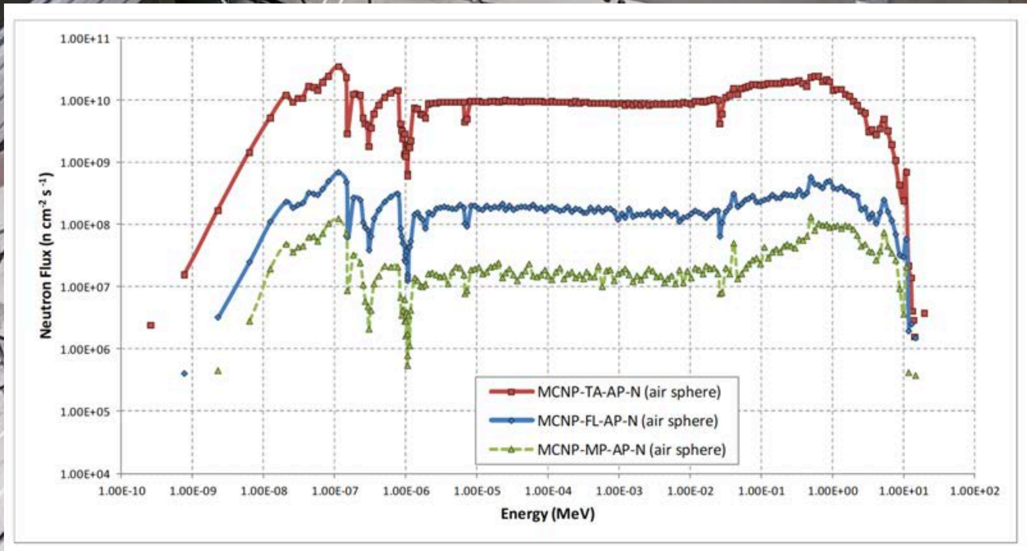


UMLRR FACILITIES OVERVIEW: FAST NEUTRON BEAM PORT

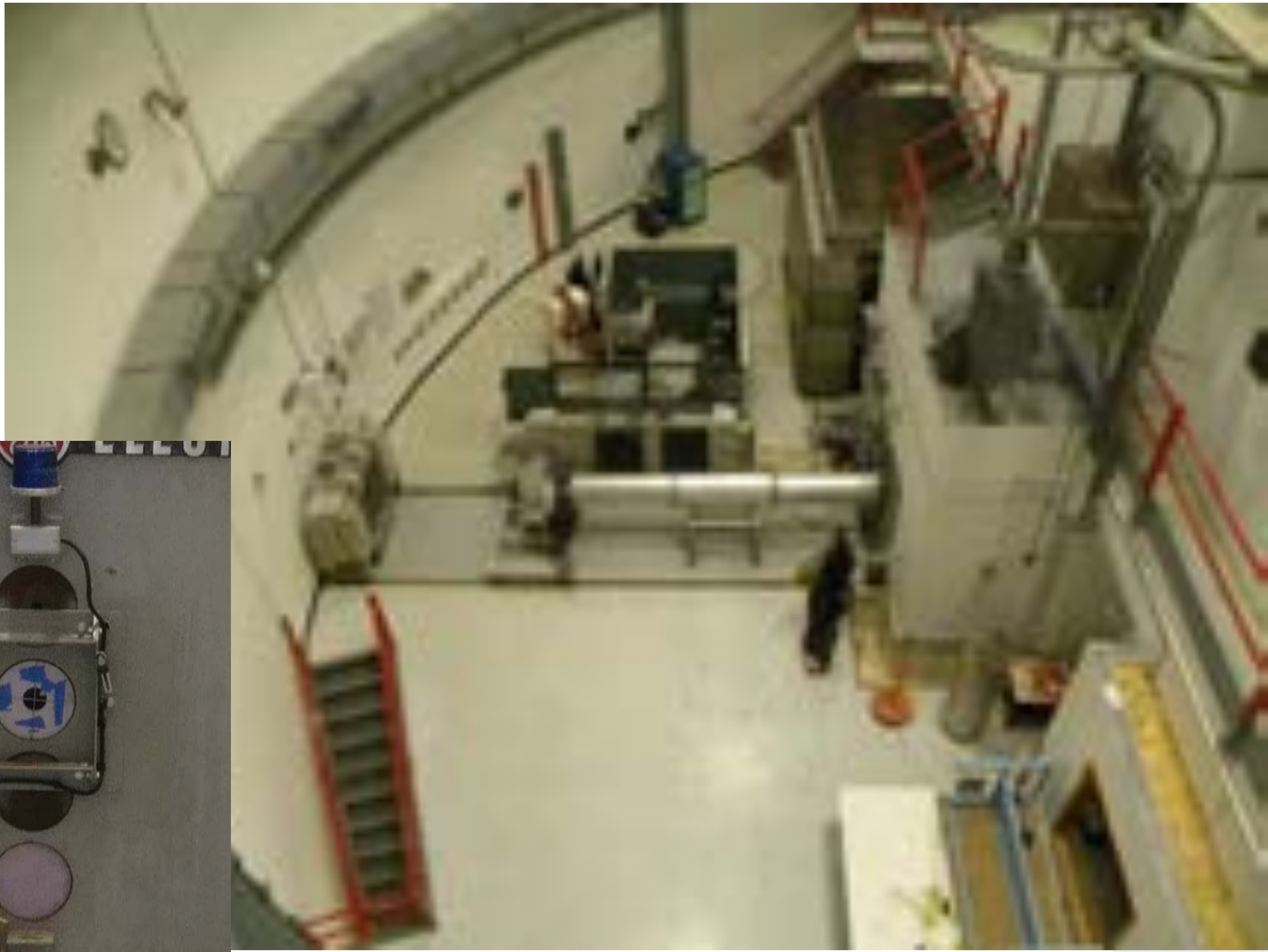
- Shielded bunker, interlock, continuous monitoring.
- 6-inch diameter beam – can be collimated
- External access to switch samples (mobile tray/station – can be automated)
- Accessible neutron fluxes
- Total: ~1 x 10^{12} n/cm^2/s
- Additional shielding/moderation possible

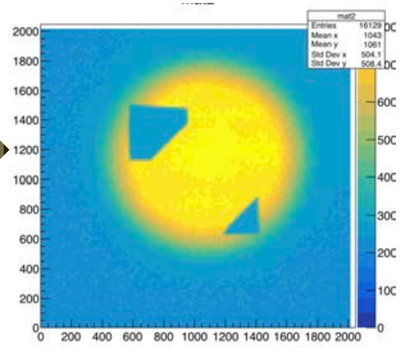


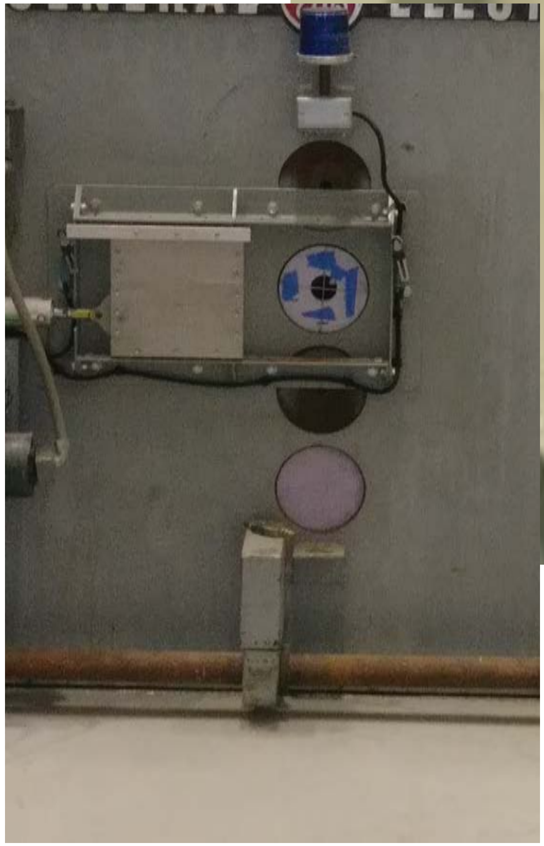


UMLRR FACILITIES OVERVIEW: THERMAL BEAM PORT

- Shown configured for neutron radiography
- Fluxes of ~10^6 n/cm^2/s
- In-pool graphite pile
- Pneumatic shutter
- Beam images:
  - After collimations





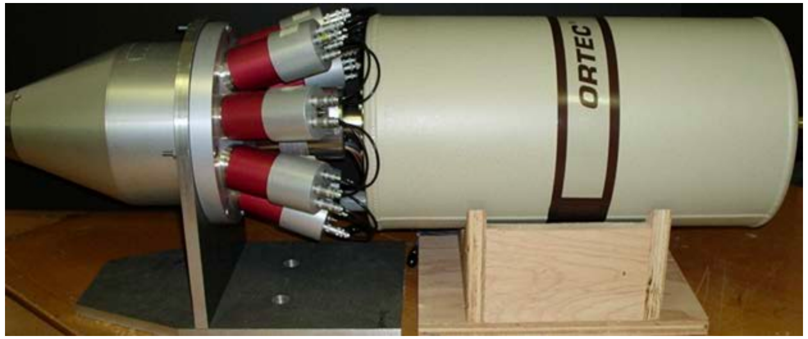


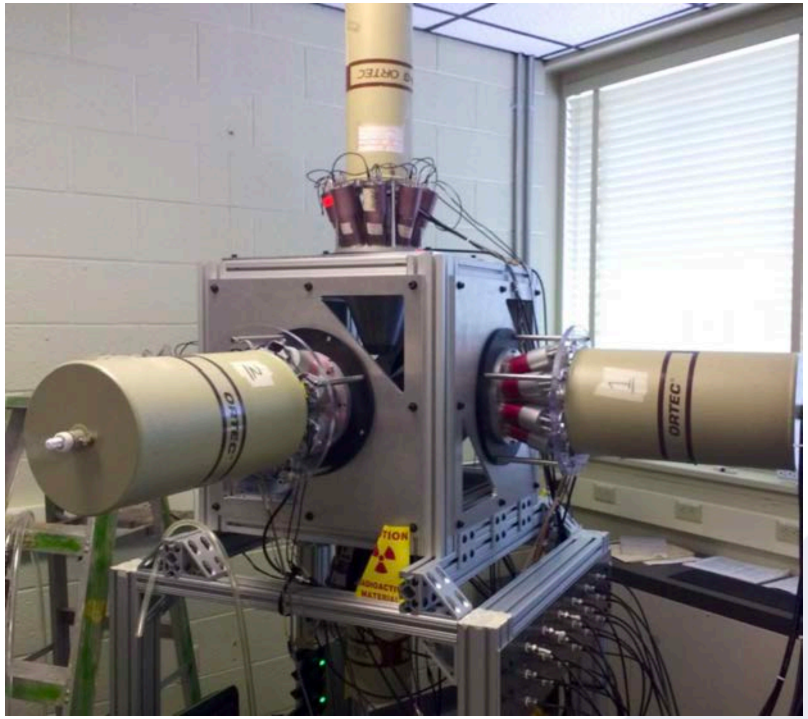
UML – MIXED ARRAY OF DETECTORS (MAD) MEASUREMENTS

- UML Radiation Laboratory has a large pool of different neutron/gamma radiation detectors including:
- HPGe, BGO, NaI, CLYC
- Anticompton BGO/NaI HPGe detectors
- Several 5”, 3” and 2” NaI(Tl)

The SCANS array of C^7LYC detectors in a 4x4 geometry.

BGO/NaI actively shielded HPGe detectors

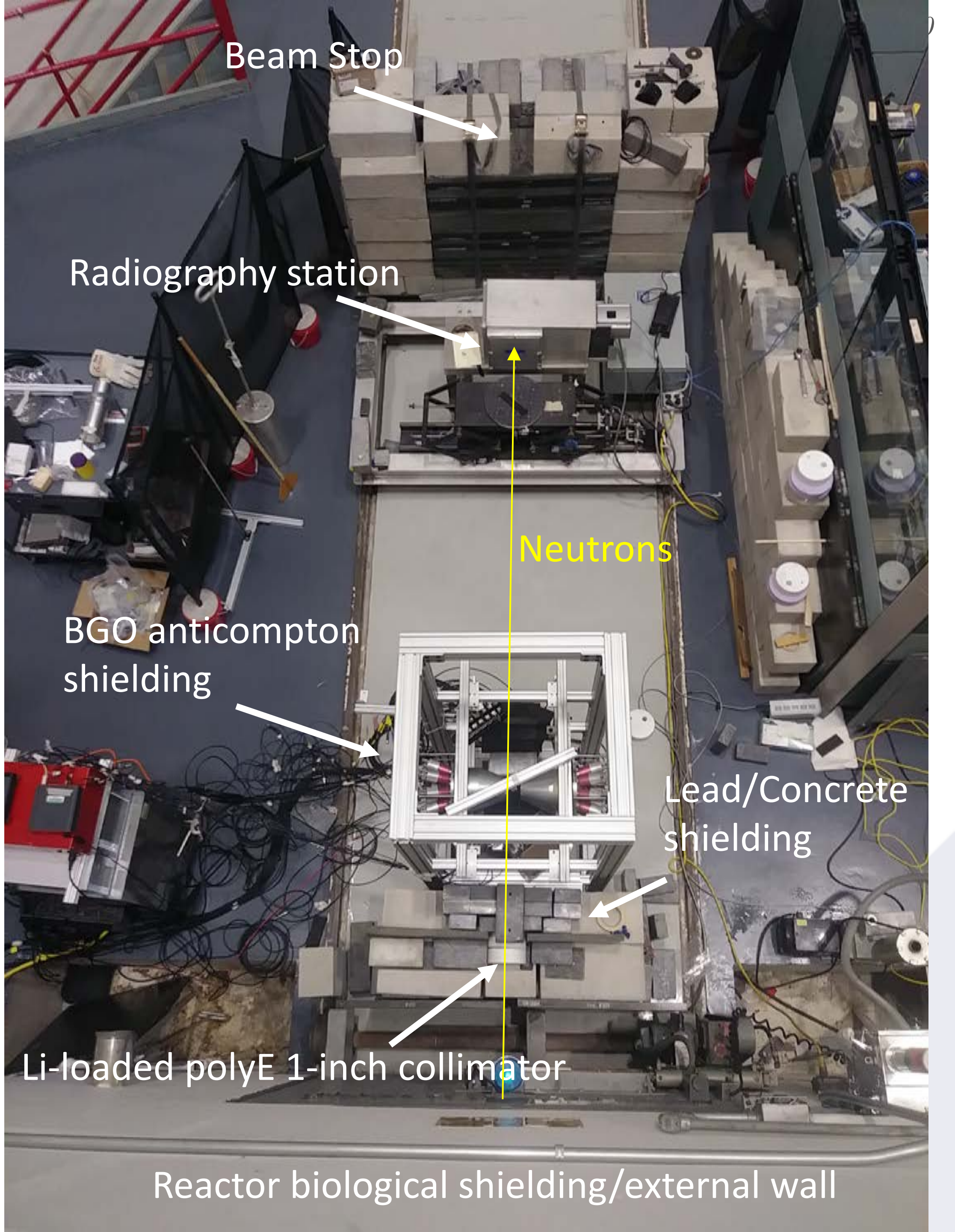




LARA array consisting of 6 anti-compton HPGe assemblies.

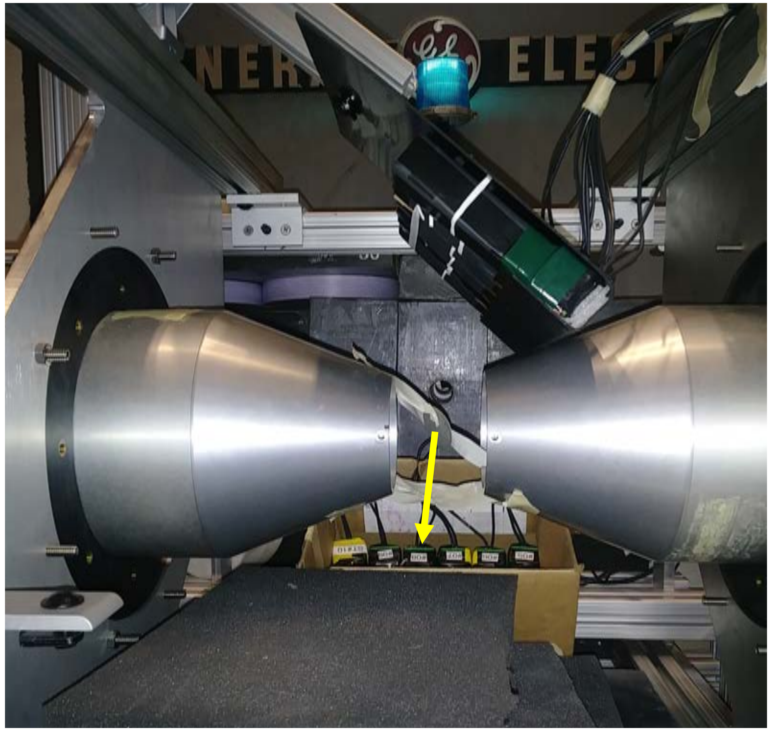
UML – MIXED ARRAY OF DETECTORS (MAD) MEASUREMENTS – SEP 2020

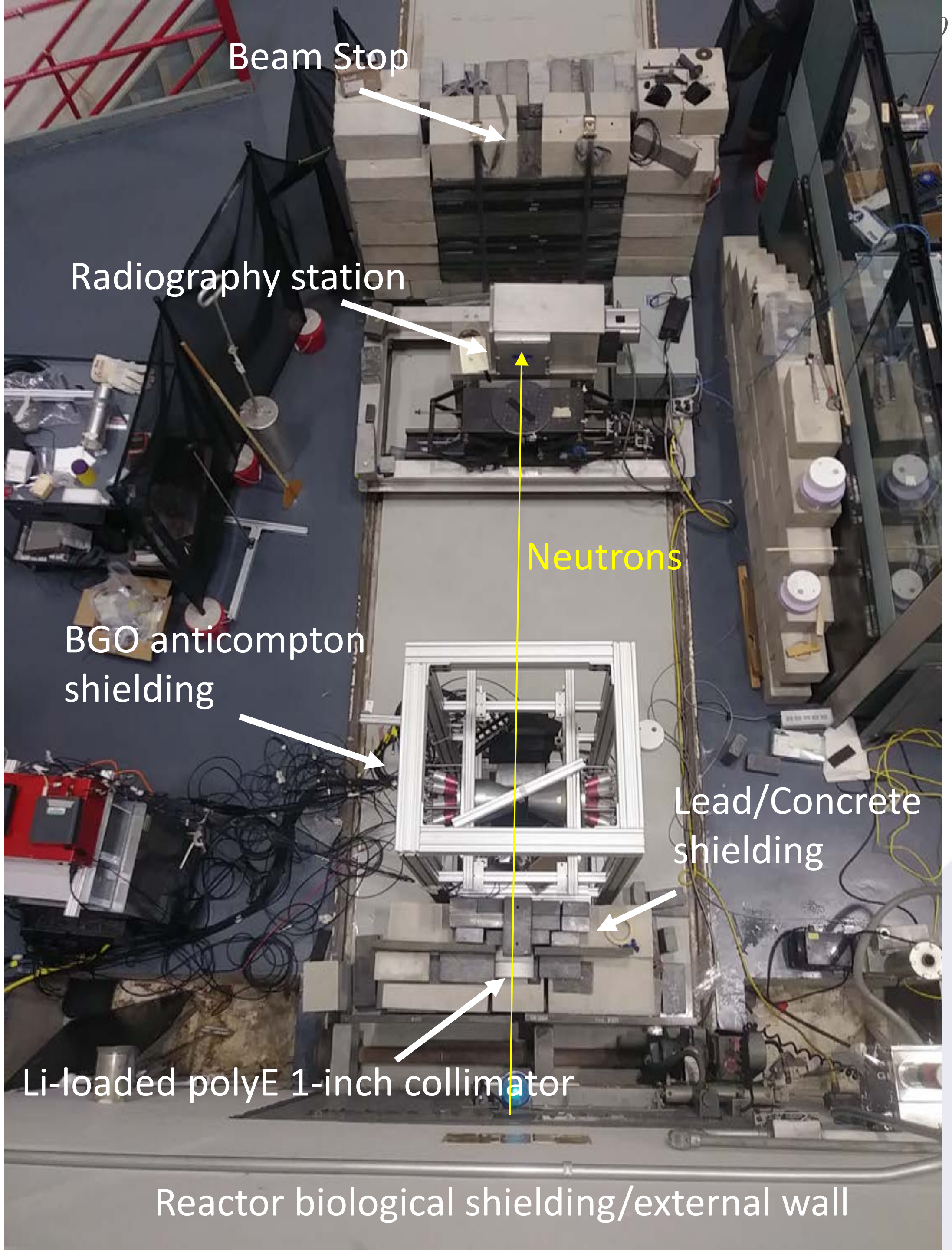
- Feasibility studies
- Detectors are installed around the collimated neutron
- Beam collimation down to 1” inch using Li-loaded polyE
- Additional Pb cylinders (5 inches) inserted in the beam tube (upstream)
- Sep 11, 2020 MAD setup included:
- 1 x HPGe + BGO/NaI shield
- 12 x stilbene detectors
- 3” CLYK scintillator
- 5” and 2 x 2” NaI(Tl) scintillator



UML – MIXED ARRAY OF DETECTORS (MAD) MEASUREMENTS – SEP 2020

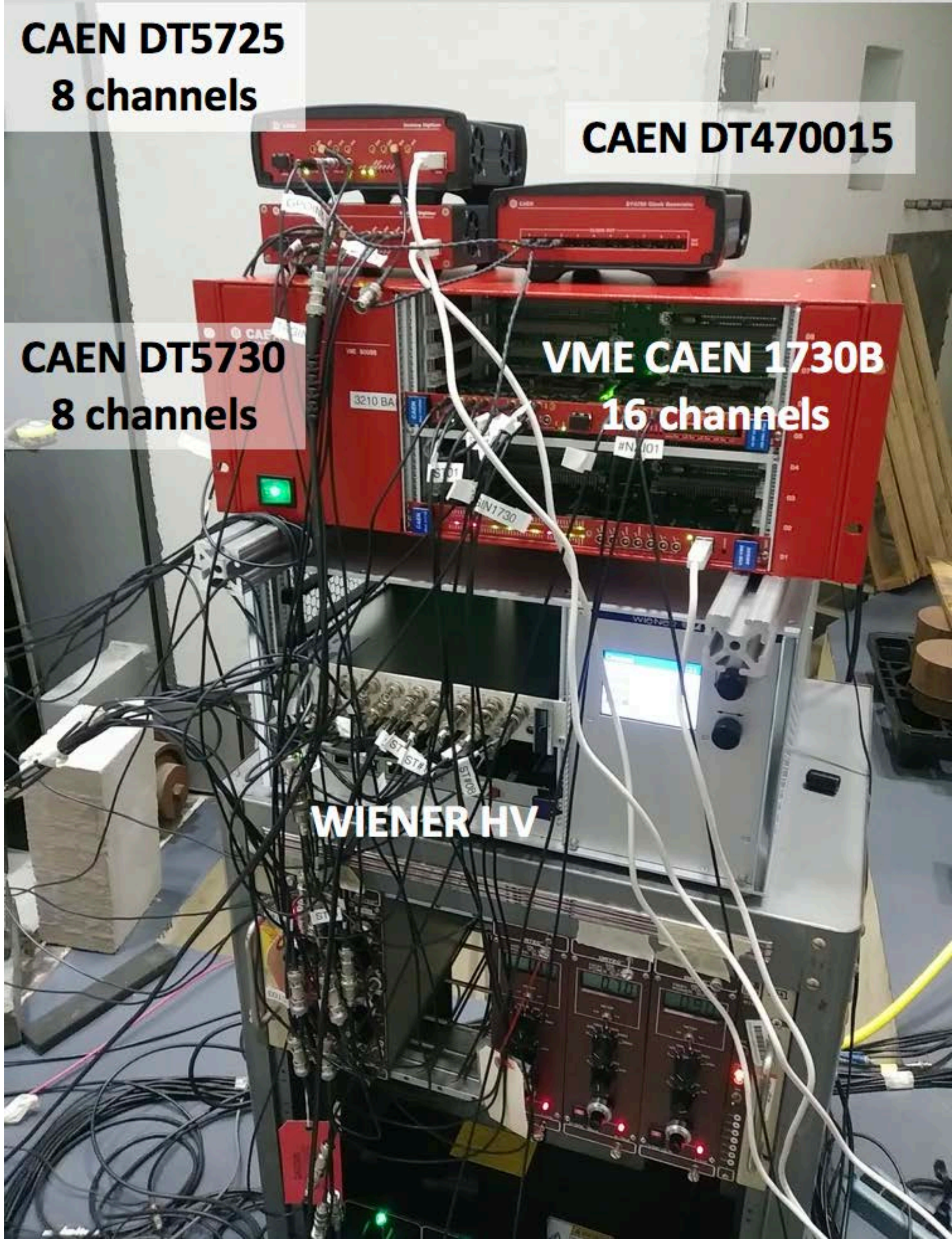
- Feasibility studies
- Test DAQ system
- Evaluate backgrounds and data rates at different reactor power
- Take preliminary data on Mn, B, Cd, Gd





UML – DATA ACQUISITION

- UMLDAQ – based on CAEN hardware, software drivers and C++ libraries
- Asynchronous data acquisition using FPGA digital pulse processing
- 24 channel 14-bit 500-MHz CAEN V1730 and DT5730
- 8 channel 12-bit 250-MHz CAEN DT5725
- Clock syncing – DT4700
- In house DAQ frontend and backend codes
- Off-line coincidence analysis down to ~10 ns

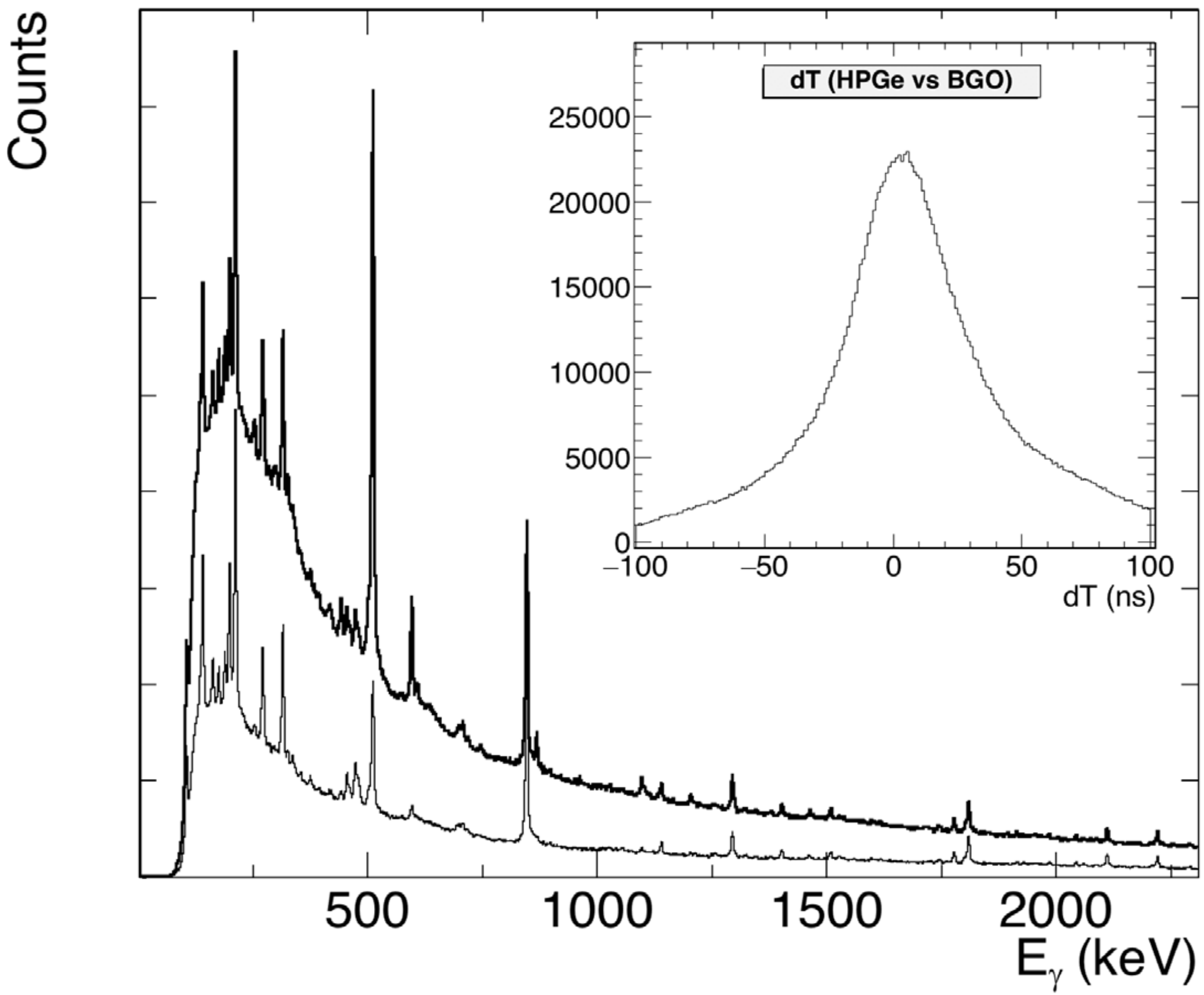


UML – DATA ON ^{55}MN(N,G)

- Compton suppression obtained from the off-line analysis in 200 ns coincidence window (shown in the inset)

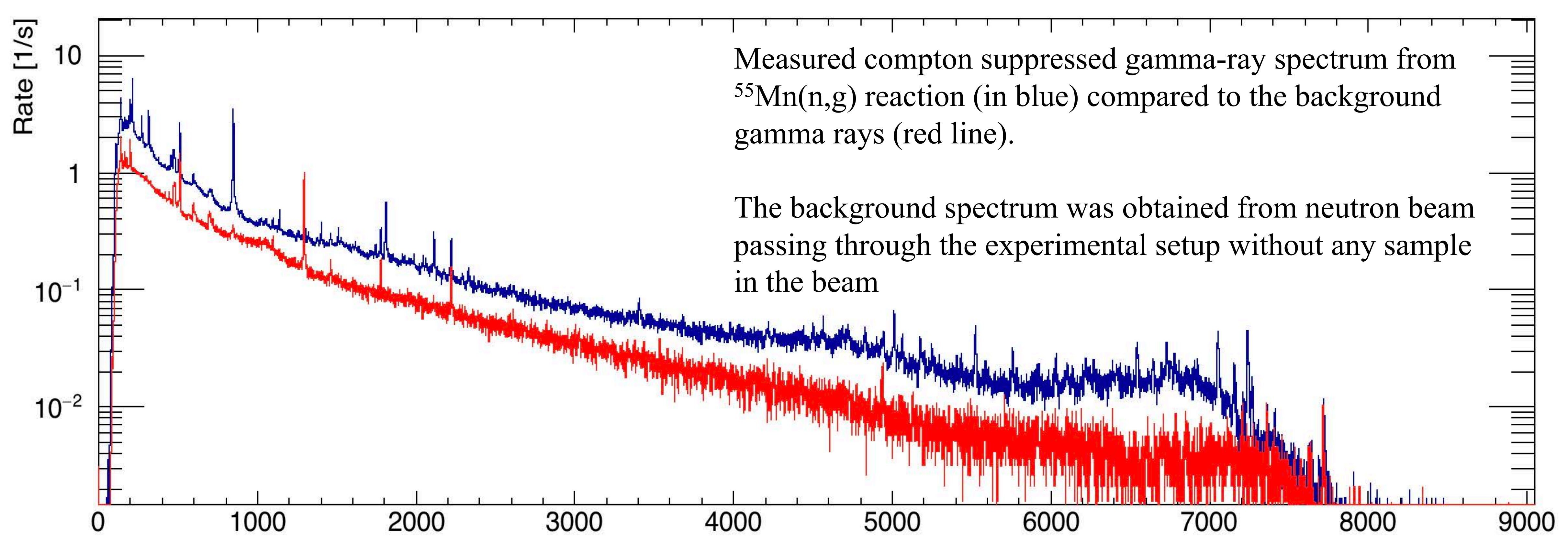
- The width of the coincidence can be varied in the analysis

- Mn-55 is a good sample – monoisotopic,
- beta decays ($T_{1/2}$=2.6 h) and and can be nicely counted

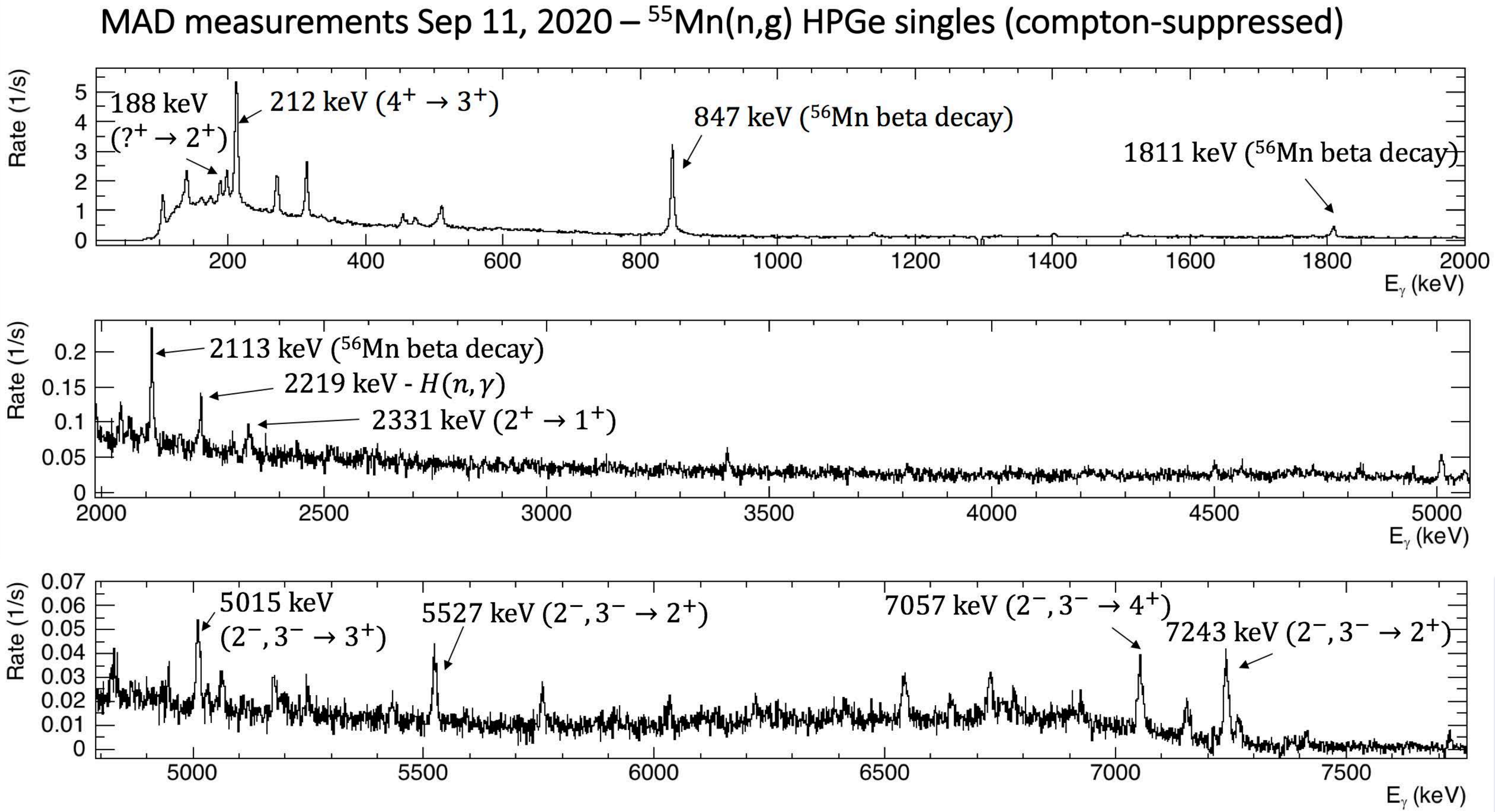


UML – DATA ON ^{55}MN(N,G)

- Data obtained at full reactor power of 1 MW
- DAQ handles high rates well

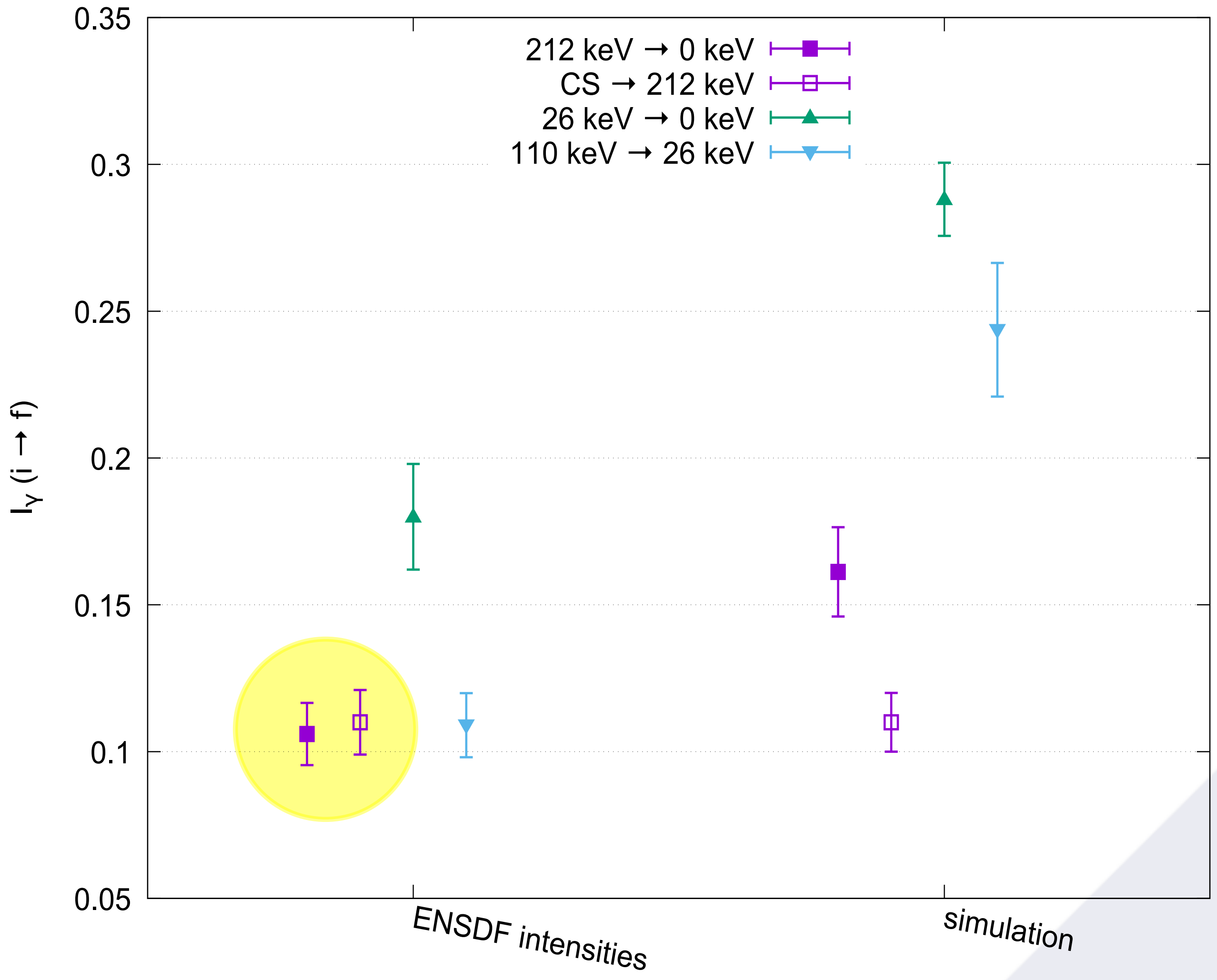


UML – DATA ON ^{55}MN(N,G)



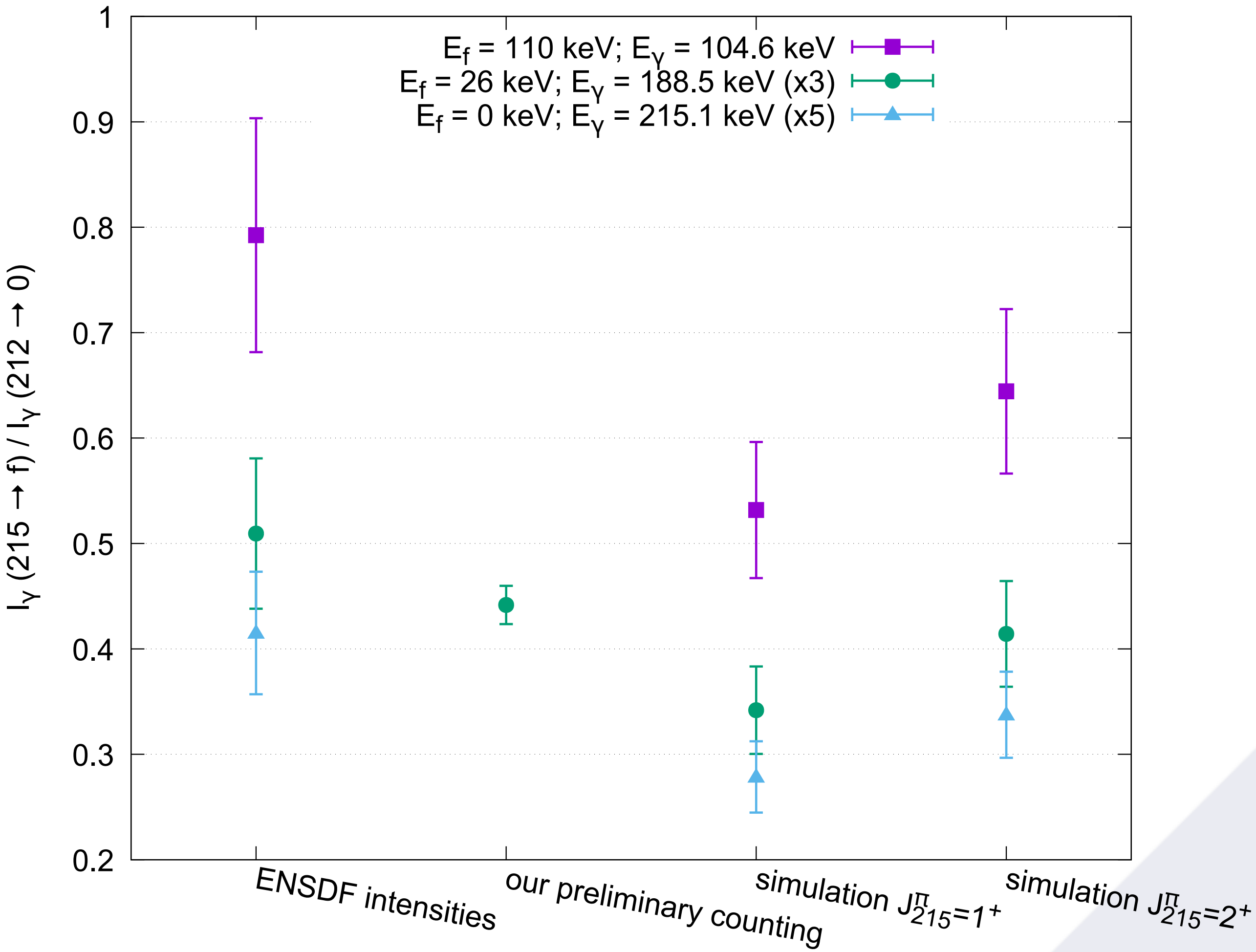
UML – DATA ON ^{55}MN(N,G)

- Closer look at ENDSF 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)



UML – DATA ON ^{55}MN(N,G)

- Can we use statistical model of de-excitation to assign spin and parity of the levels? (gamma – gamma coincidences)
- In collaboration with Charles University, Prague, we tested sensitivity of discrete level feedings using DICEBOX (Valenta, Krticka)
- The first uncertain spin assignment in the ENSDF evaluation is that of the 215-keV level citing two options $J^{\pi} = 1^{+}, 2^{+}$. In simulations, the population of the level increases from ~13% for $J^{\pi} = 1^{+}$ to ~16% for $J^{\pi} = 2^{+}$.

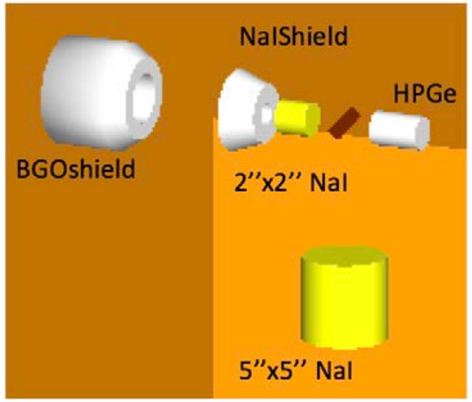


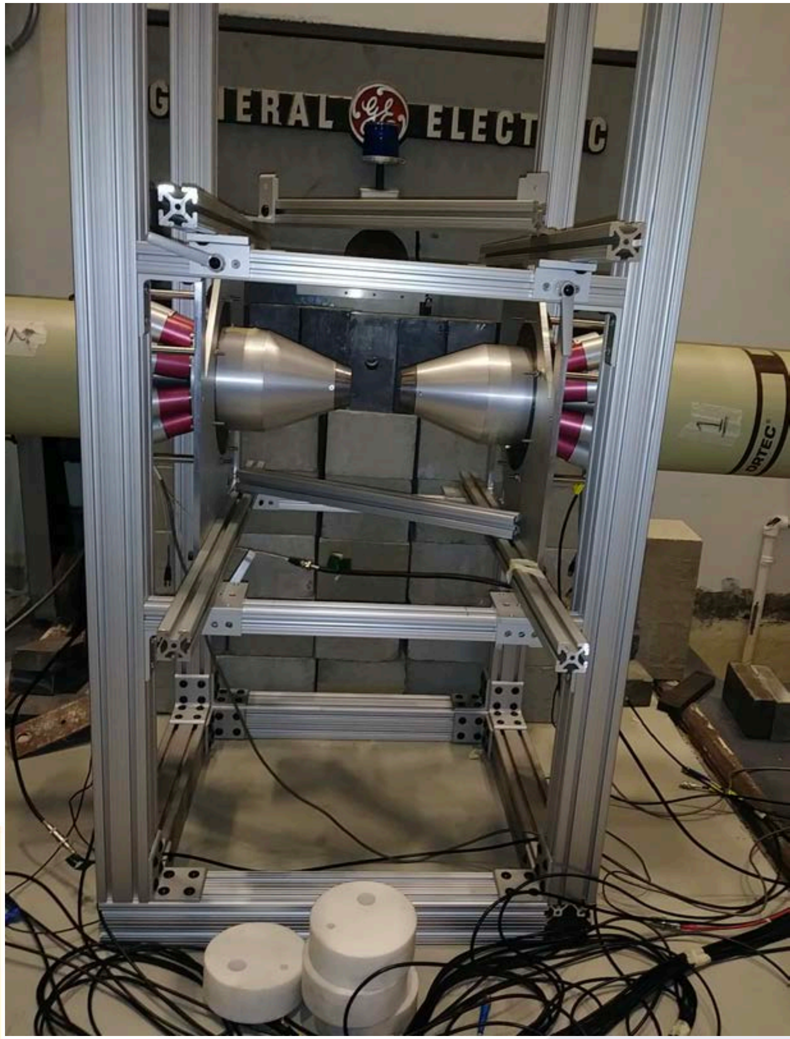
UML – NEW DATA ON ^{55}MN(N,G) – JANUARY 2021

- New experiment is planned in 2021
- We will use 2 x HPGe detectors to measure g-g matrix
  - 5" NaI, 3" NaI
  - 12 Stilbene detectors (active (n,g) tagging ?)

- Proposal submitted to DOE, Office of Science

- Lot of work needs to be done:
  - Benchmarking using Geant4 simulations (work started)
  - Statistical de-excitation simulations (DICEBOX)
  - Dead-time and pileup determination
  - Gain stabilization and matching





NEW UML CAPABILITY FOR MEASUREMENTS OF NUCLEAR DATA: CAPTURE GAMMAS FROM MN-56

- Acknowledgements:
  - Students: **R. Stanescu**, H. Green, Physics and Applied Physics, UML
  - UML Reactor Staff: S. Snay, T. Regan, L. Bobek, UML
  - P. Bender, P. Chowdhury, A. Rogers, K. Lister, UML
  - E. Ricard-McCutchan, S. Zhu, A. Sonzogni, Broookhaven National Lab.
  - S. Valenta and M. Krticka, Charles University, Prague, Czech Republic
  - G. Rusev, LANL

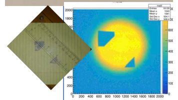
UML Research Reactor

1 MW thermal power, open-pool, demineralized water, MTR flat plate fuel design, NRC licensed

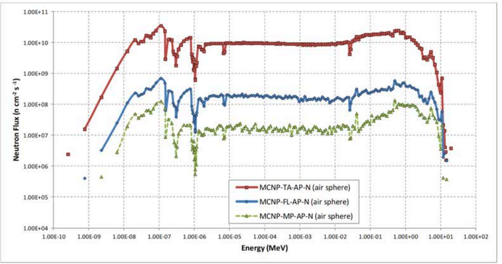
https://www.uml.edu/research/radlab/neutron-facilities.aspx

Contact: L. Bobek, T. Regan, M. Jandel (marian_jandel@uml.edu)

- **THERMAL NEUTRON BEAM**
  - Pneumatic shutter
  - 6-inch diameter beam – can be collimated
  - Total thermal flux: ~6 x 10^5 n/cm^2/s
  - Easy access, low gamma contamination, parallel beam (good collimation)

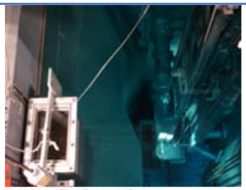


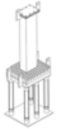
- **FAST NEUTRON BEAM**
  - Shielded bunker, interlock, continuous monitoring.
  - 6-inch diameter beam – can be collimated
  - External access to switch samples (mobile tray/station – can be automated)
  - <u>Broad Group Fluxes (n/cm^2-sec)</u>
  - Accessible neutron fluxes
  - Total: ~1 x 10^{12} n/cm^2/s
  - Additional shielding/moderation possible

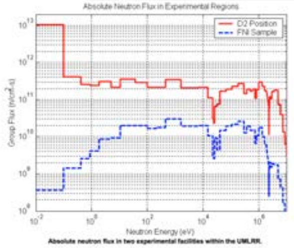


MCNP neutron flux at three locations along the fast beam port: - green (at the exit on a mobile platform), blue (0.8 m upstream from mobile platform – in the tube), 1.6m upstream from the mobile platform

- **FAST NEUTRON IRRADIATOR**
  - 1 MeV equivalent flux: ~ 10^{11} n/cm^2/s
  - Supports samples as large as 30cm x 30cm x 15cm
  - 1 MeV-equivalent fast neutron flux:
    - ~10^{11}n/cm^2/s
  - Greater than 4000:1 fast-to-thermal flux ratio
  - Neutron/Gamma ratio of 7x10^9 n/cm^2 per rad







1. J. R. White, A. Jirapongmed, L. Bobek, and T. M. Regan, "Design and Initial Testing of an Ex-Core Fast Neutron Irradiator for the UMass-Lowell Research Reactor," 2002 ANS Radiation Protection and Shielding Topical Conference, Santa Fe, NM (April 2002).

- **IN-CORE IRRADIATIONS**
  - Radiation "baskets" are open aluminum sample holders within the reactor core. Three located in the front of the core. One located in the core center.
  - 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 SAMPLE SYSTEM**
  - The pneumatic sample system allows for the rapid movement of small experimental samples through a transport tube to a location external to the reactor core.
  - A timer system permits automatic return of samples for irradiations from 2 seconds to 20 minutes.
  - HPGe counting (low background) station can be placed at the exit
  - Maximum dimensions 4-cm I.D. x 12-cm long and mass less than 300g. Samples typically placed in polyethylene vial 2.5-cm I.D. x 7.5-cm long.Vial is then placed into a polyethylene "rabbit"
  - Maximum neutron flux: ~5.3x 10^{12} n/cm^2/s thermal ~2.5 x 10^{12} n/cm^2/s (fast)

Recent UML measurements on LEU, Mn

- Published first feasibility measurements on U235(n,f) prompt fission gamma rays
- New measurements carried out in summer 2020 with large NaI (5’’x5’’)