Detection of Special Nuclear Materials Using Multiple Monoenergetic Gamma Radiography

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Introduction

Detection of special nuclear materials (SNM) in commercial cargo is a standing problem that has received renewed focus since the September 11 attacks

Many approaches:

- Passive detection
- Dual-energy bremsstrahlung scanning
- Delayed activations signals
- Isotope source-based scanning

Ultimately, any field-deployable design needs to be hardy, easy to use, and minimize radiation dose

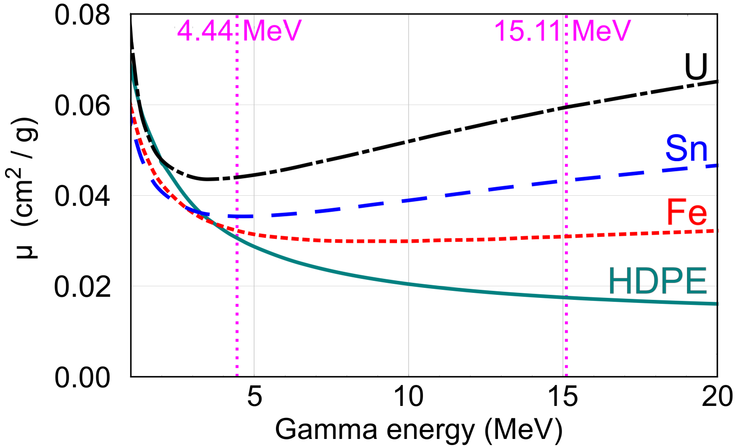
Gamma Ray Beams from Nuclear Reactions

Nuclear reactions are a source of monoenergetic gammas, and provide an interesting possibility for interrogation beams (Multiple Monoenergetic Gamma Radiography (MMGR))

- Radiation dose reduction
- Clean signal (measuring transmission at specific energies)
- May or may not include neutron beam components depending on reaction
- Examples: ^{11}B(d,nγ)^{12}C (4.44 and 15.1 MeV γ-rays), ^{16}O(p,p$'$)^{16}O$*$ (2.7, 6.1, and 6.9 MeV γ-rays)

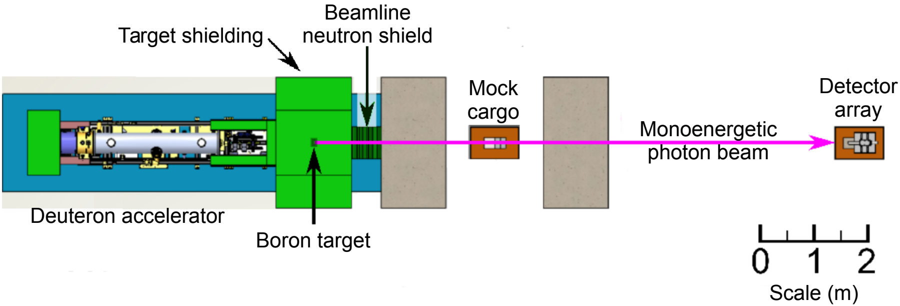
Transmission Gamma Ray Imaging

Goal is to reconstruct material density and atomic number *Z* in a scanned sample (SNM have high *Z*, high density)



Cargo Scan Prototype at MIT-Bates

To test the MMGR concept a mock cargo scanning setup was constructed at the MIT-Bates Research and Engineering Center



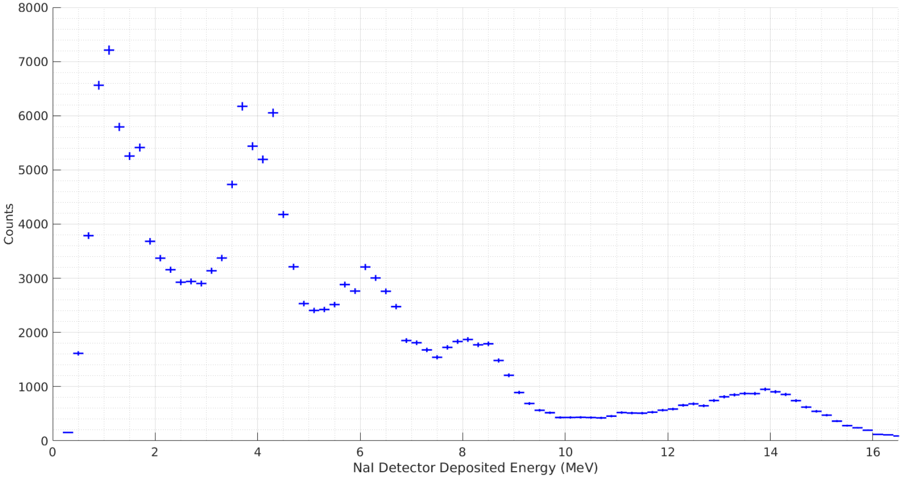
$$^{11}B(d,n\gamma)^{12}C$$

Beam Characterization

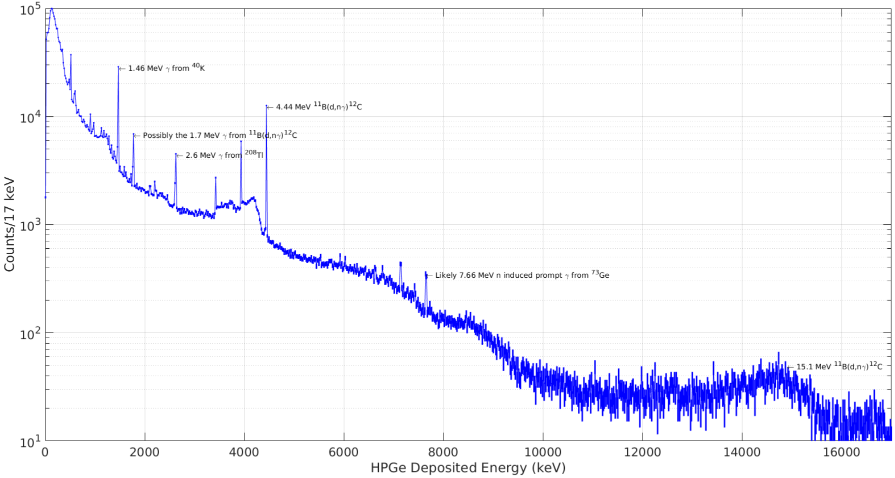
A portion of recent work has focused on characterizing the beam and understanding the raw (no cargo spectrum)

- Typical RFQ current was pulsed-average 10 µA but only 0.5% duty factor ($\sim$1 mA instantaneous)
  - High instantaneous current causes non-negligible pile-up
  - Photons from outside of beam pulse window cause significant low energy background if not extracted
- Detector interactions, efficiency, resolution, etc. play a role in how well you can use the "monoenergetic information"
- Cross section measurements for the $^{11}B(d,n\gamma)^{12}C$ gammas date mostly to the 1950s

Beam Characterization - NaI

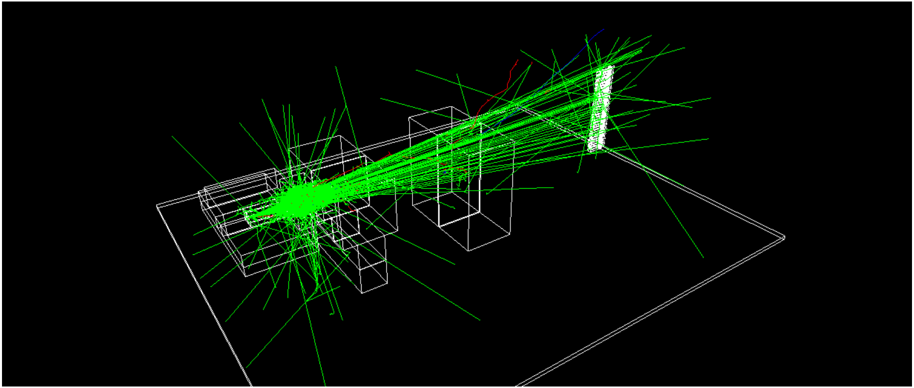


Beam Characterization - HPGe



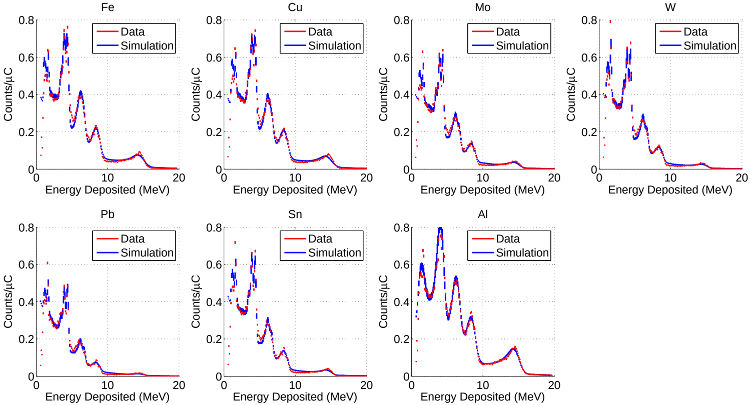
Geant4 Simulation

As part of this analysis, a detailed Geant4 model of the experimental setup was constructed

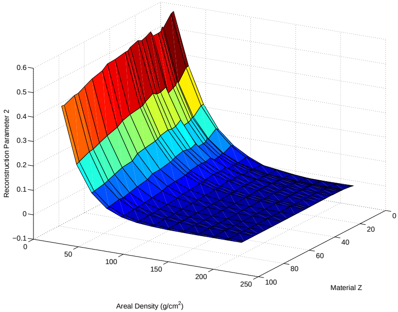


Beam Simulation

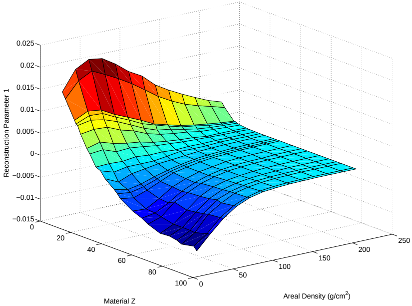
Beam contributions were extracted by fitting detector response to the visible peaks to the data spectra from 7 “simple” configurations



Simulation of the Cargo Parameter Space



Total Transmission



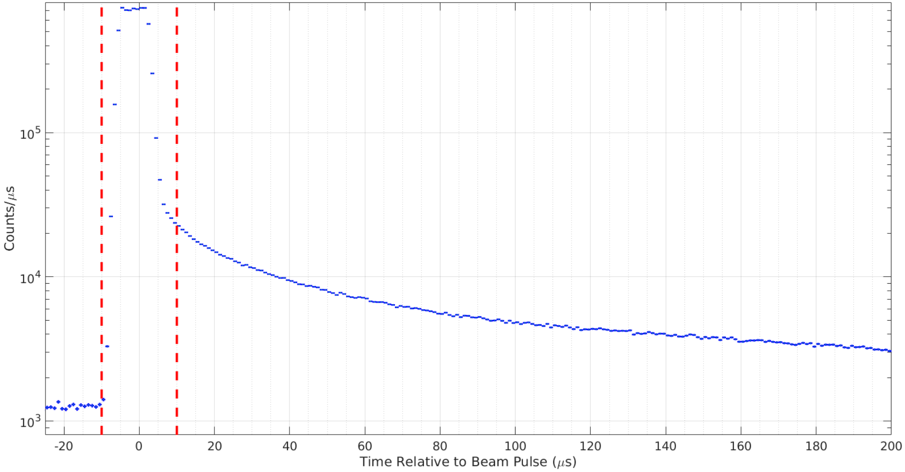
Energy Dependence of Transmission

Scan Data Analysis

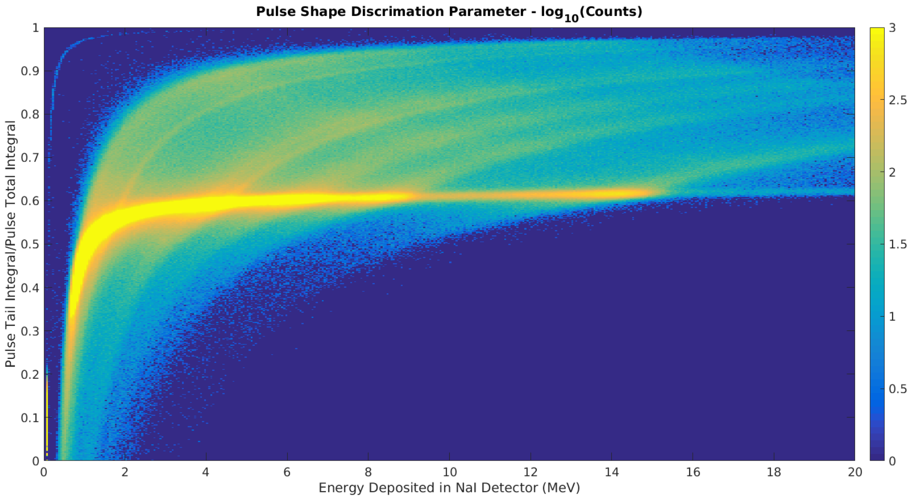
Extracting images from the scan data proceeds as follows:

1. Collect raw NaI spectra as a function of scan time/position
2. Accept only events within a 20 μs window of each beam pulse
3. Correct for time varying beam current using data from a charge integrator
4. Use pulse shape discrimination to compute pile-up fraction, use to rescale spectra
5. Compute ratio of the spectrum at each scan time to the spectrum with open beam
6. Use relative transmission of γ-rays as a function of energy to estimate areal density and effective Z

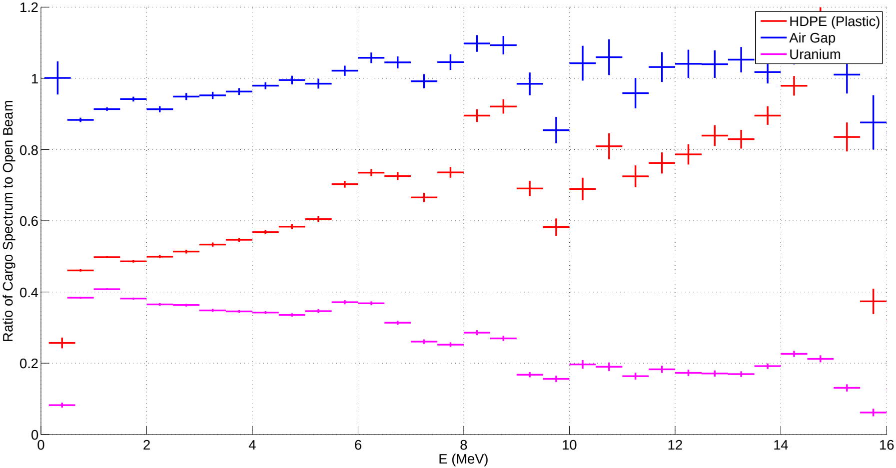
Beam Pulse Timing Cut



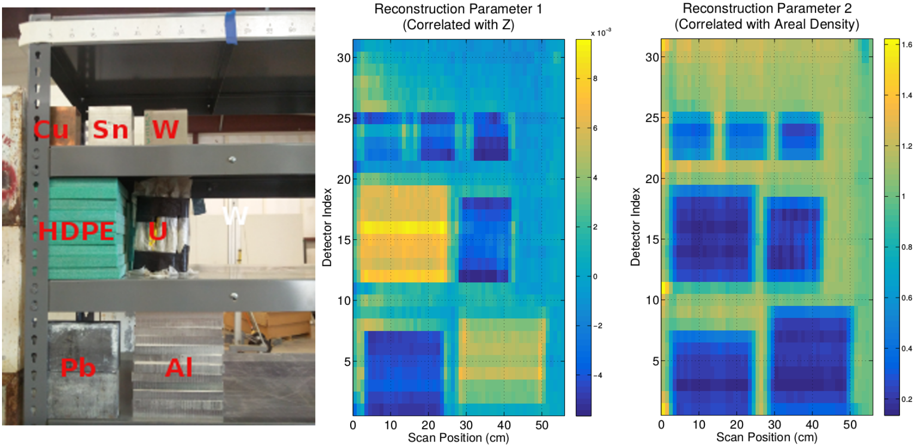
Pile-Up Correction



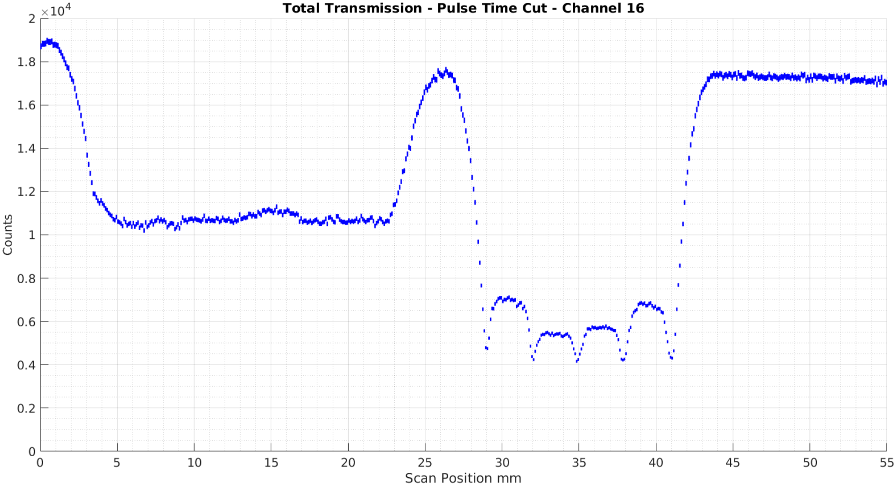
Spectral Ratios to Open Air



Preliminary 2D Images



Position Resolution



Future Efforts

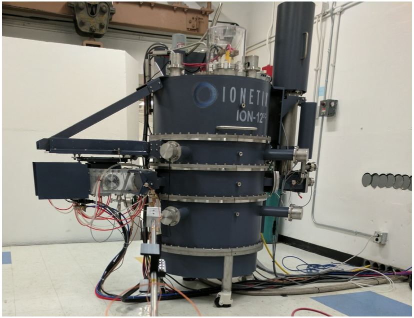
- Experimental Efforts:
  - University of Massachusetts Lowell 5.5 MV Van de Graaff generator
  - MIT 12.5 MeV superconducting proton cyclotron
  - Plans for tomography-style imaging using the MMGR beam
  - ARI program systems integration (see other various talks)
- Analysis Efforts:
  - Completion of the Bates scan data analysis (including mining neutron and afterglow info)
  - Integration with MIT-CSAIL algorithms group for design and analysis of future experiments

Future Experimental Effort - UML Van de Graaff

- 5 MV Van der Graaff accelerator
- DC current (eliminating pile-up effects and allowing much higher currents)
- Possibility of enabling $\sim$ns scale pulsing
- Higher energy d^+ beam expected to increase γ yields
- Possible to run other positive ions (p, α, d^+), explore other reactions for MMGR

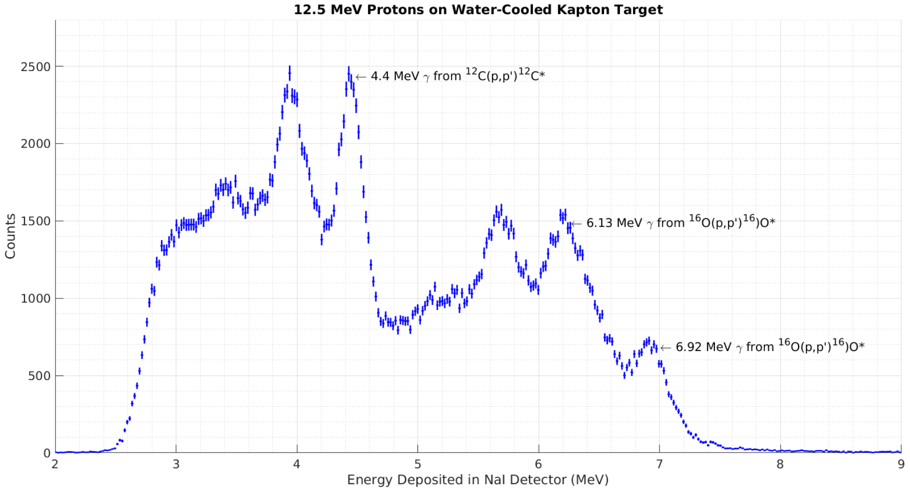
First Transmission Measurements at UML

Future Experimental Effort - MIT *p* Cyclotron



- Ionetix ION-12^{SC} superconducting cyclotron recently commissioned at MIT-NSE
- Compact (14 m^2 footprint), commercially-produced 12.5 MeV proton cyclotron
- Originally designed for N-13 ammonia generation with water targets, but can accommodate other targets
- Various (p,p′) reactions may be exploited to produce monoenergetic gammas

First Monoenergetics from the Cyclotron



Summary

- First "scan-style" images from the NaI produced, much learned for future implementations
- Work ongoing to develop new sources (MIT cyclotron), as well as fine-tune the ^{11}B(d,nγ)^{12}C based experiments
- Collaboration with MIT-CSAIL to apply advanced algorithmic work to problems such as detector placement, image reconstruction, etc.
- See other talks (Lanza, Harms, Jovanovic, Nattress, and Rose) for other elements of this project