AN INVESTIGATION OF PROMPT GAMMA ACTIVATION ANALYSIS AND COMPTON IMAGING

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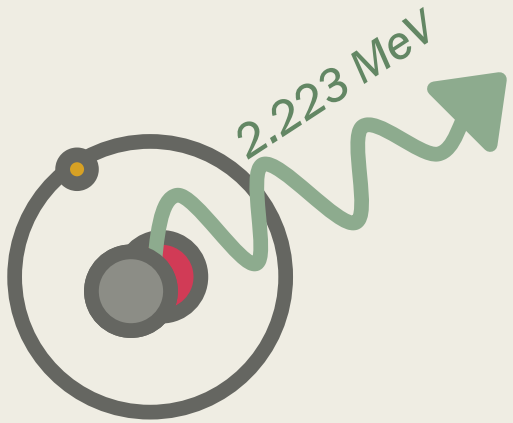
Overview

- Prompt Gamma Activation Analysis
  - *What is Prompt Gamma Activation?*
  - *Composition Analysis*
  - *3D Filament Composition*
- Compton Imaging
  - *Compton Scattering and Compton Camera*
  - *Geant4 Simulation*
  - *Image Reconstruction*

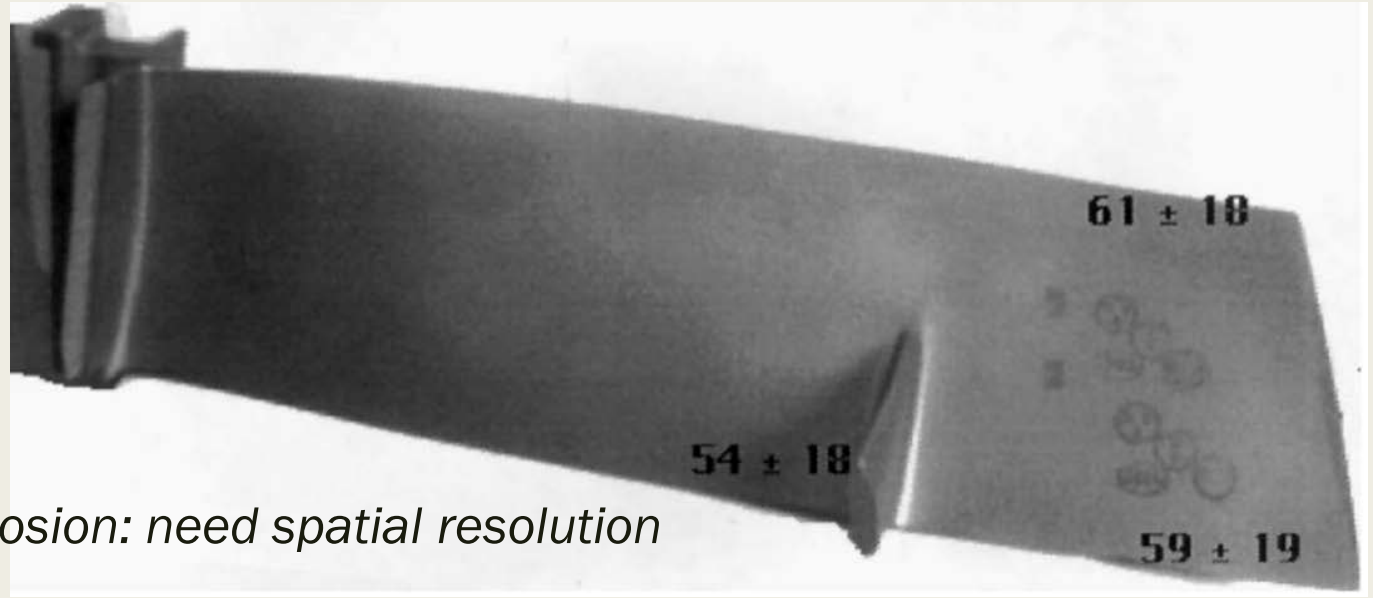
Prompt Gamma Activation

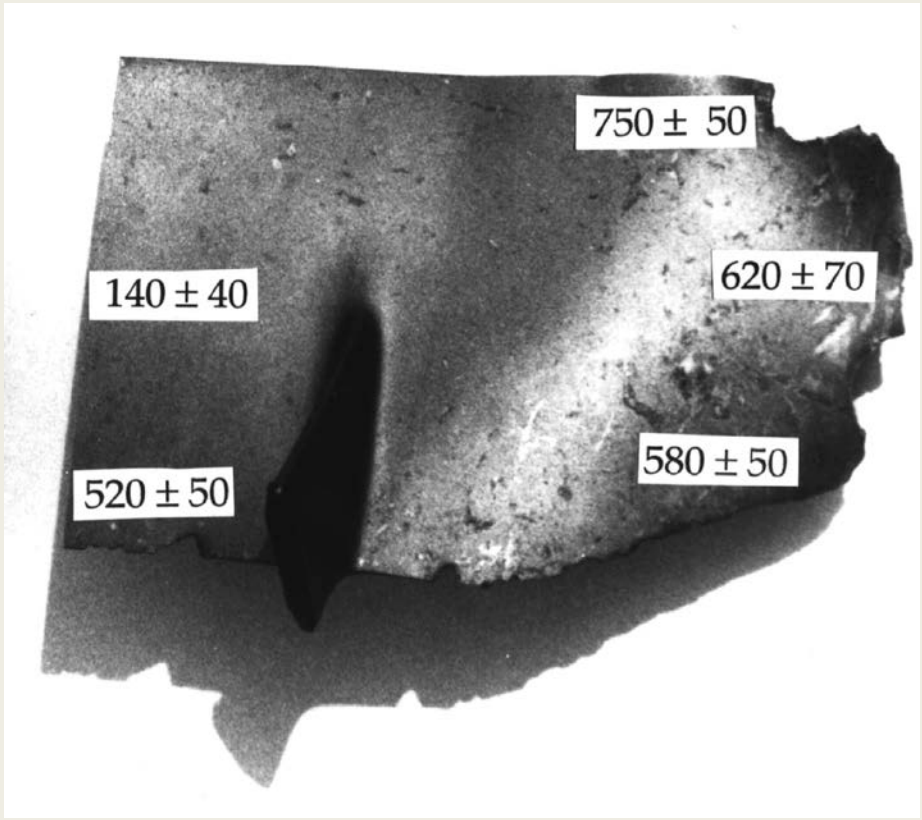
- Incident neutrons: pass through, scatter, or capture
- Capture events excite elemental nucleus
- Characteristic gammas emitted at de-excitation.
- Emission spectra characterize sample



Motivation

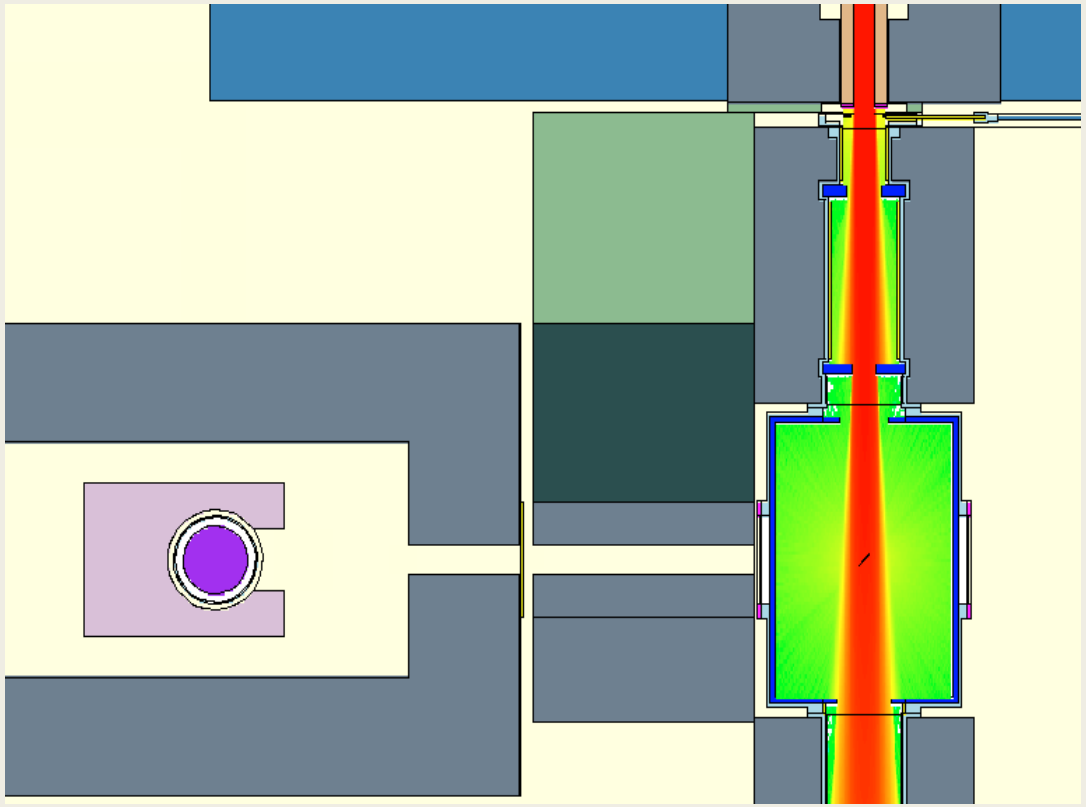
- PGAA and Compton Imaging
  - *Bulk Composition Analysis*
  - *Non-destructive technique*
  - *Potential to detect impurities and corrosion: need spatial resolution*





PGAA Beam Line

- Located on NG-D
- Polychromatic beam: average at 6 Å; Flux: 5E9 n/cm^2-s



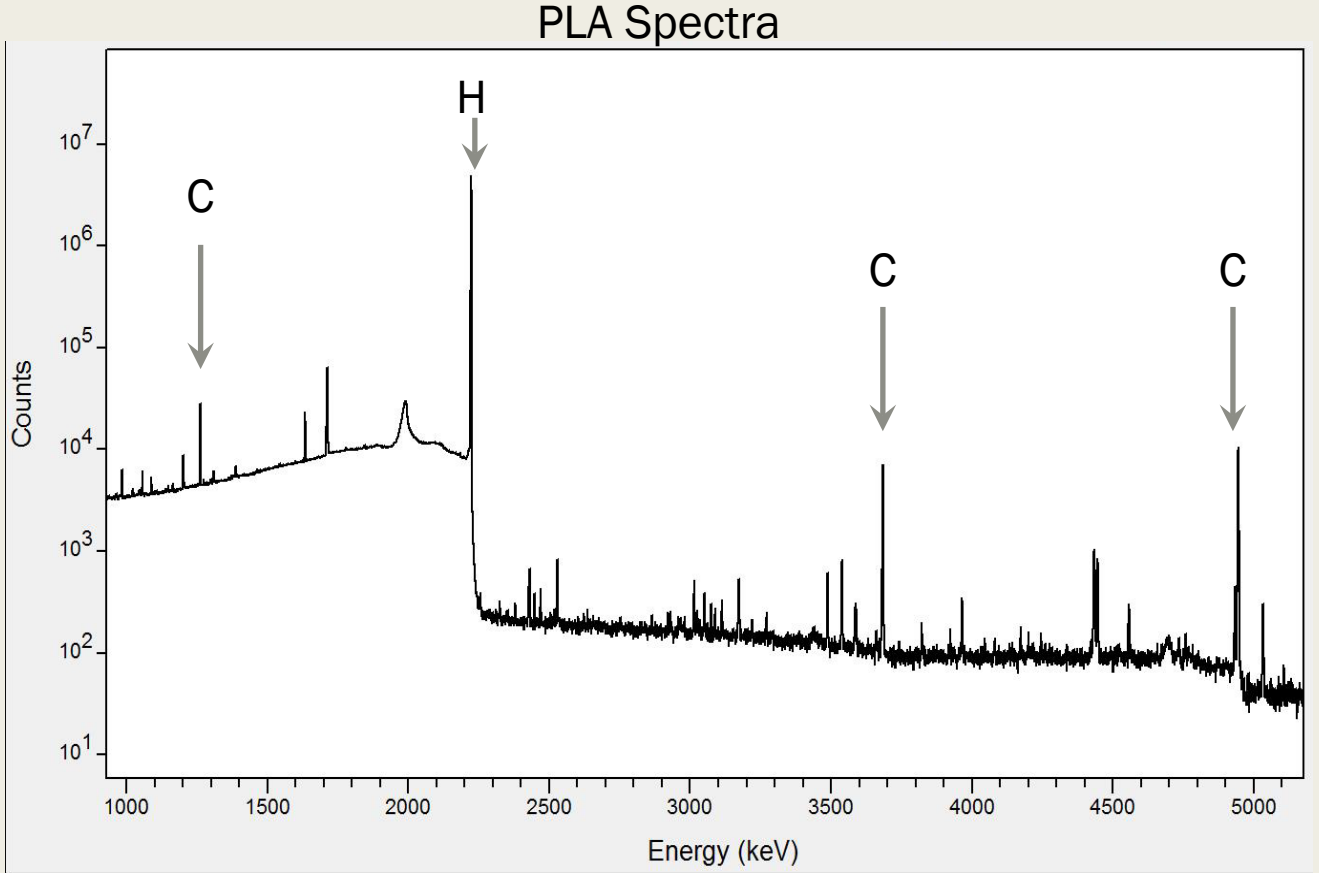
Credit: Danyal Turkoglu

Prompt Gamma Activation Analysis

- Compare spectral intensities
- Calculate mass ratios

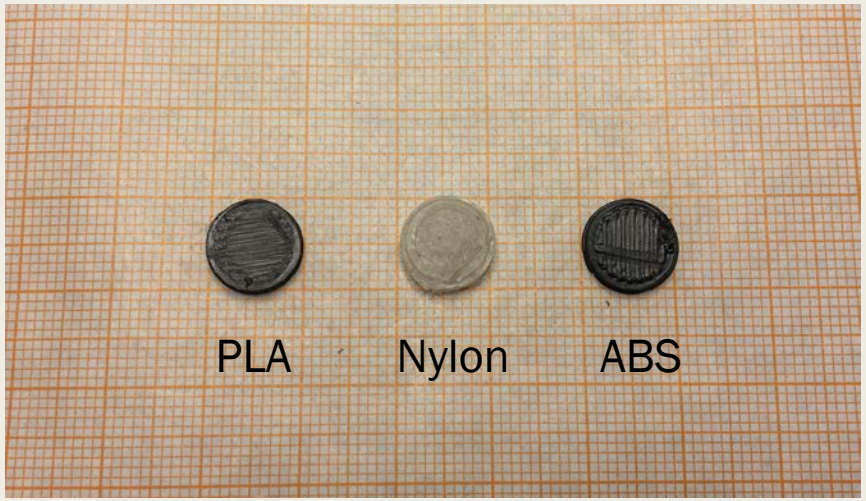
$$\frac{m_H}{m_X} = \frac{A_H/\varepsilon_H}{A_X/\varepsilon_X}\frac{\sigma_{\gamma,X}/M_X}{\sigma_{\gamma,H}/M_H}$$

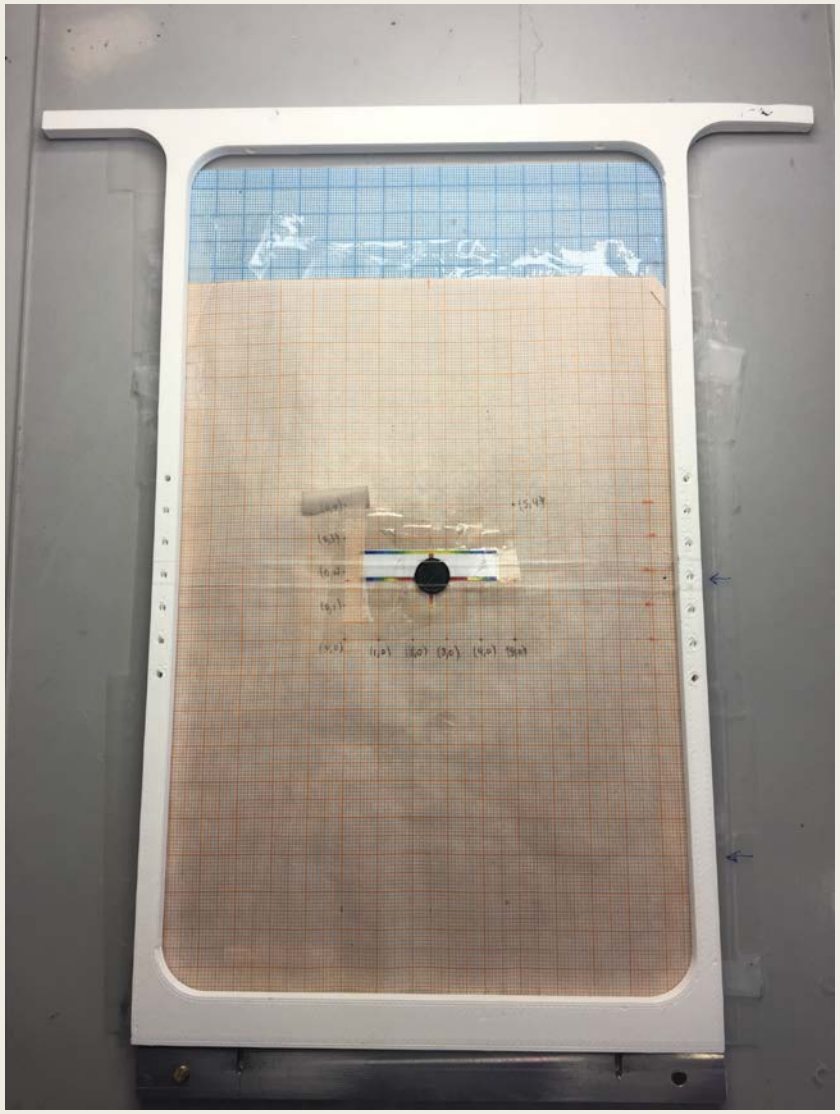
- A_X is the net peak area, ε_X is the detector efficiency at the peak energy, $\sigma_{\gamma,X}$ is the gamma production cross section, and M_X is the atomic mass.



3D Printing Filament Analysis

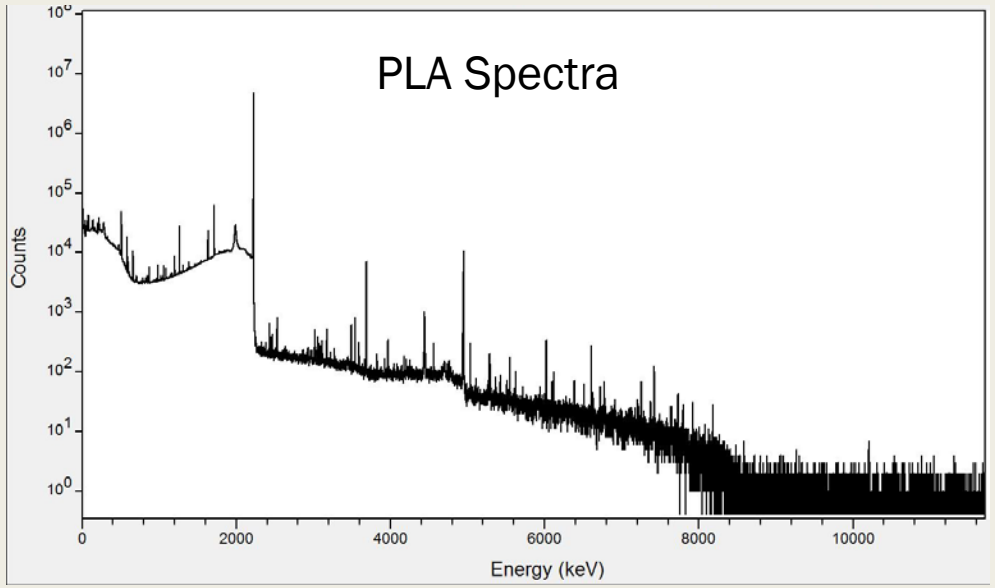
- Three common filaments were examined: PLA, ABS, and Nylon
- Four disks for each plastic:
  - *2cm diameter*
  - *0.5mm-2mm thickness in 0.5mm increments*

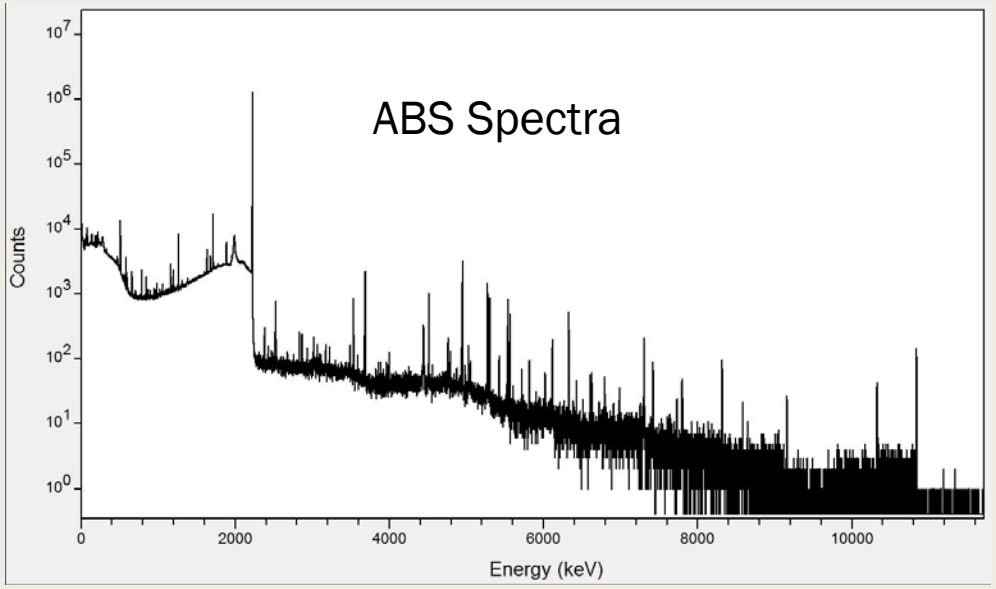


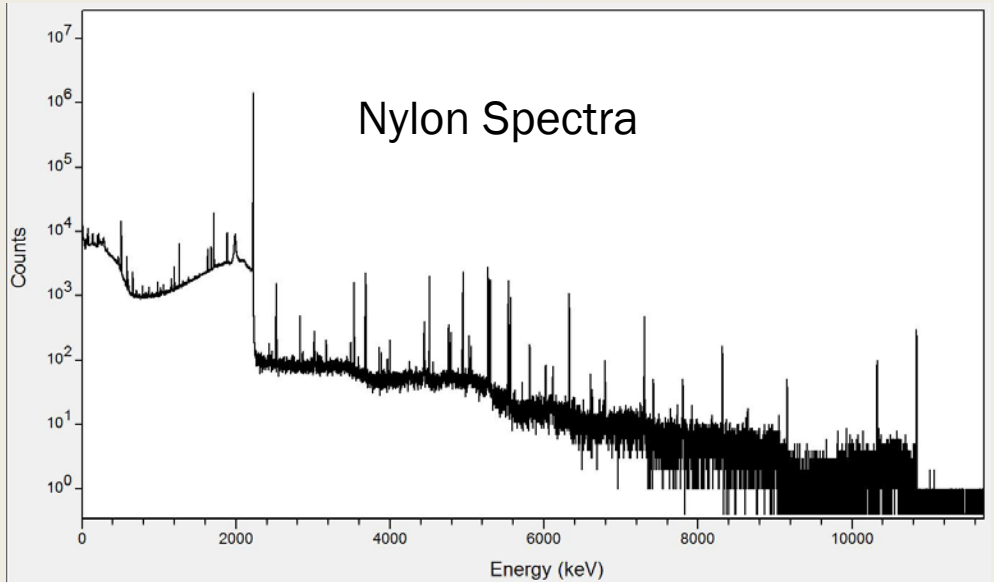


Filament Properties

- PLA
  - *Bioplastic:* $C_3H_4O_2$
- Nylon
  - *Overall class of polymers with different stoichiometry*
- ABS (Acrylonitrile Butadiene Styrene)
  - *Three part composition:* $(C_8H_8)_x(C_4H_6)_y(C_3H_3N)_z$



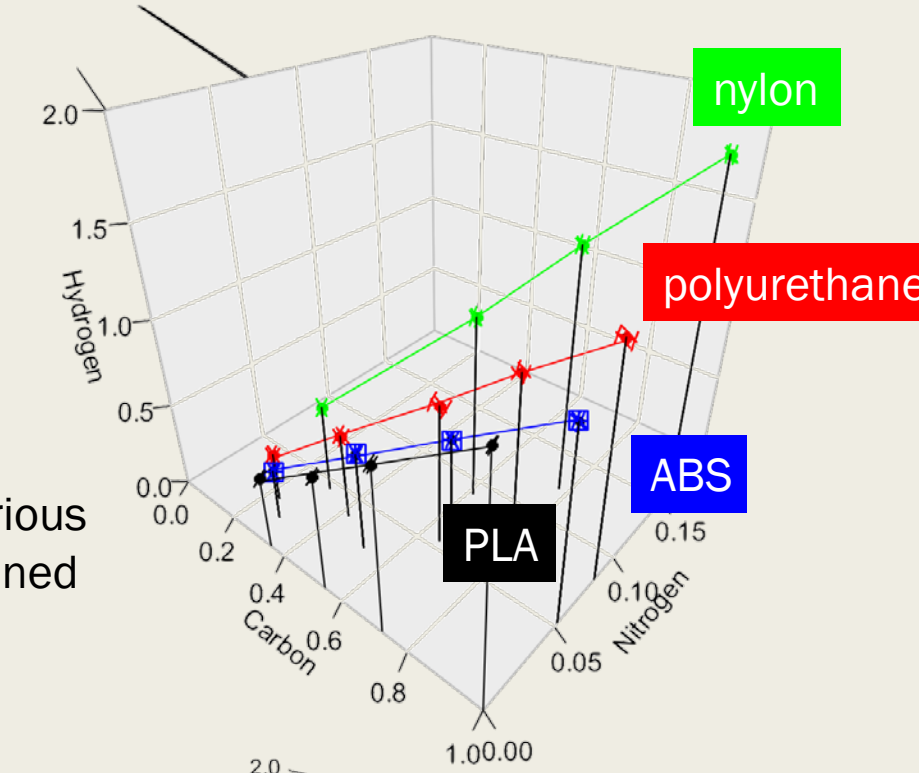


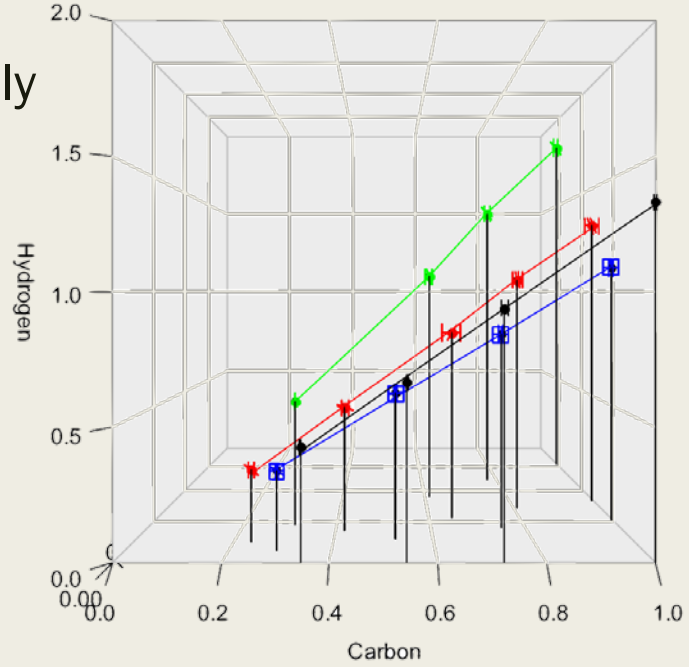


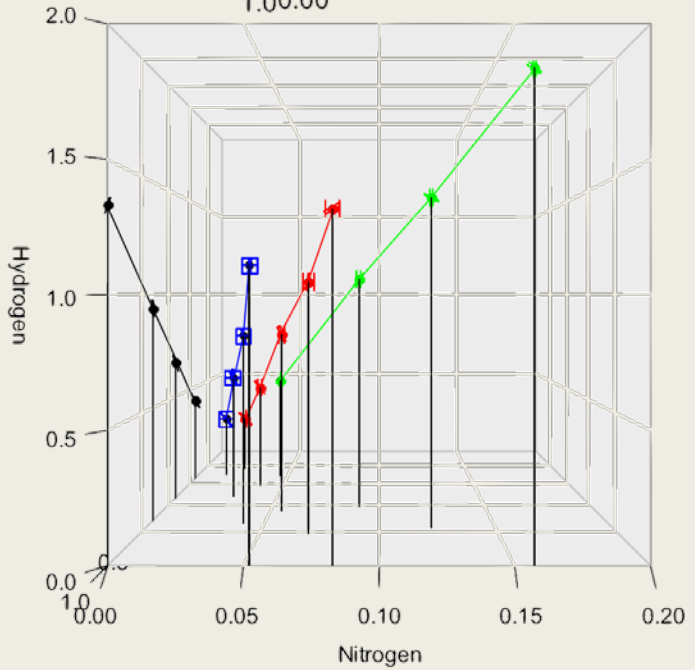
Comparison

- Prompt gamma yield: Depth Dependent; Atom ratio: constant
- Linear behavior with increased thickness: No self-shielding effects
- Slope: Stoichiometric ratios
- ABS: x:y:z=> 2:2:3
- Nylon: Blended Filament; primarily nylon 6,6

Atom Ratios of Various Materials Determined From PGAA







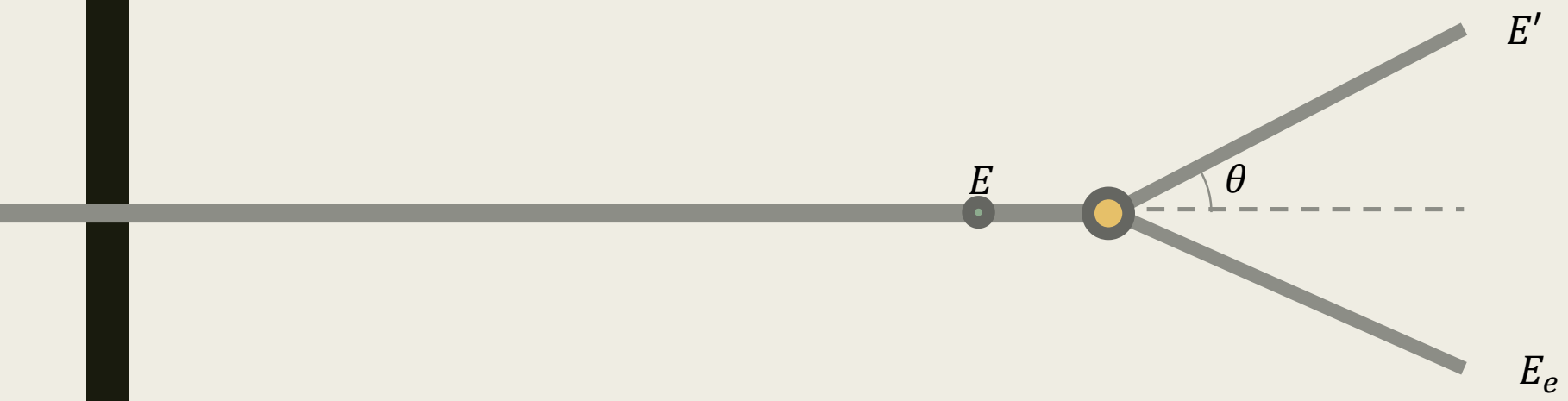
PGAA and Compton Imaging

- Current PGAA
  - *Bulk analysis only*
  - *Limited spatial resolution*
- Proposed For PGAA
  - *Use Prompt Gammas to image sample*
  - *Utilize Compton imaging techniques*
  - *Give spatial resolution*

Compton Scattering

- Intermediate-High Energy Regime
- Photon scatters off electron
- Angle determined by

$$\frac{1}{E'} - \frac{1}{E} = \frac{1-\cos(\theta)}{m_e c^2}$$

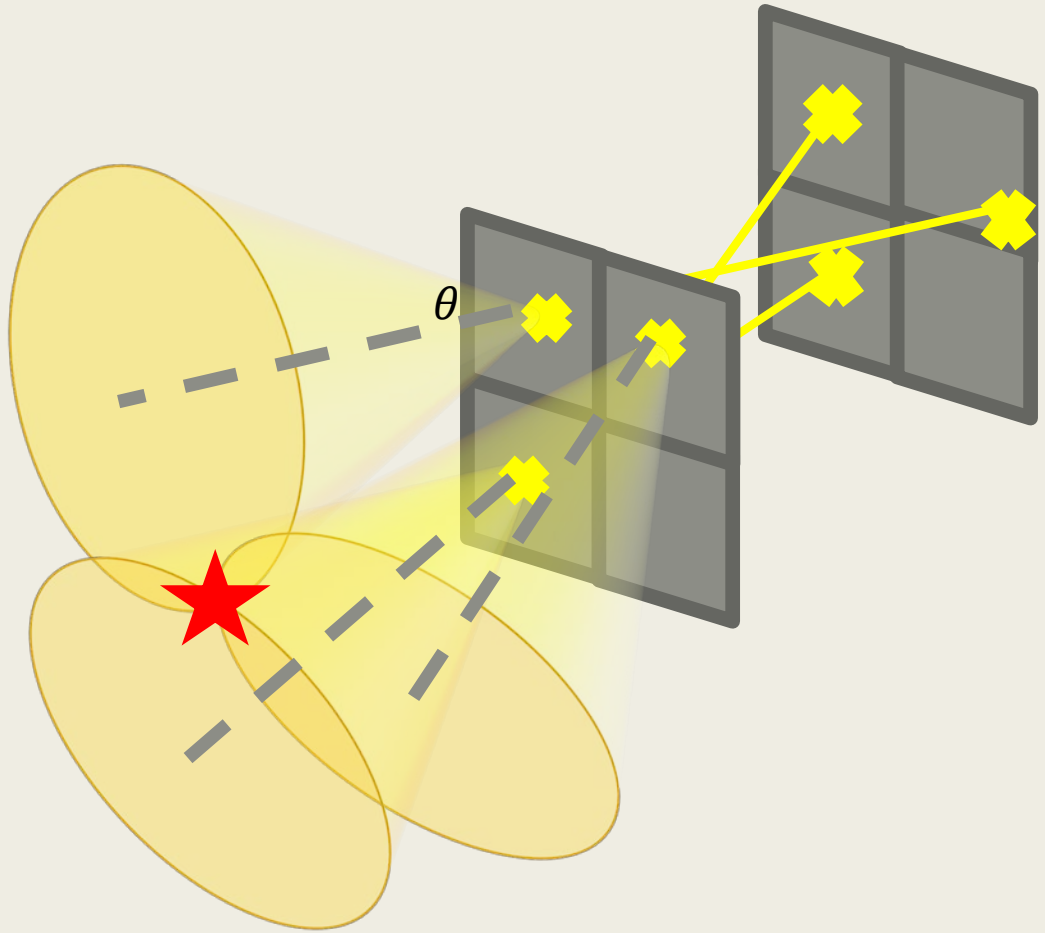


Compton Camera

- Multistage pixelated detector
  - *Scatters in first stage*
  - *Absorbed in second stage*
  - *Pixilation gives positional data*
- Generates Compton cones
  - *Energy deposited gives angle*

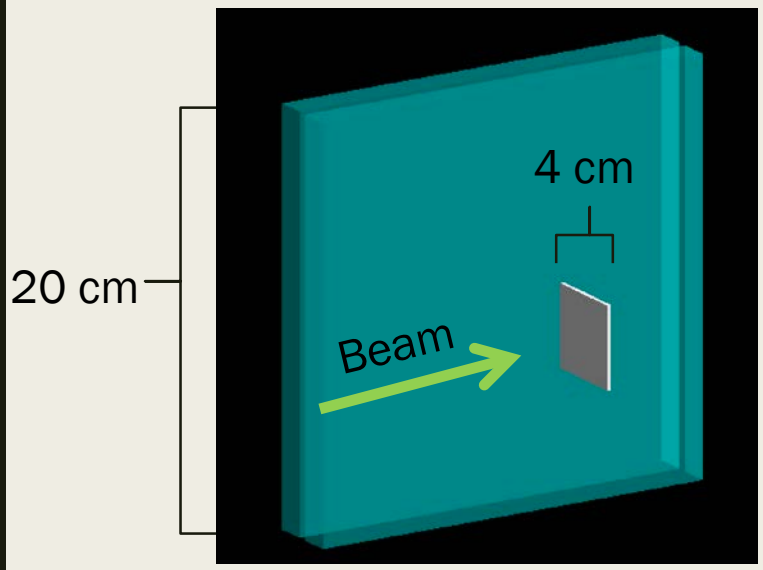
$$\frac{1}{E'} - \frac{1}{E} = \frac{1 - \cos(\theta)}{m_e c^2}$$

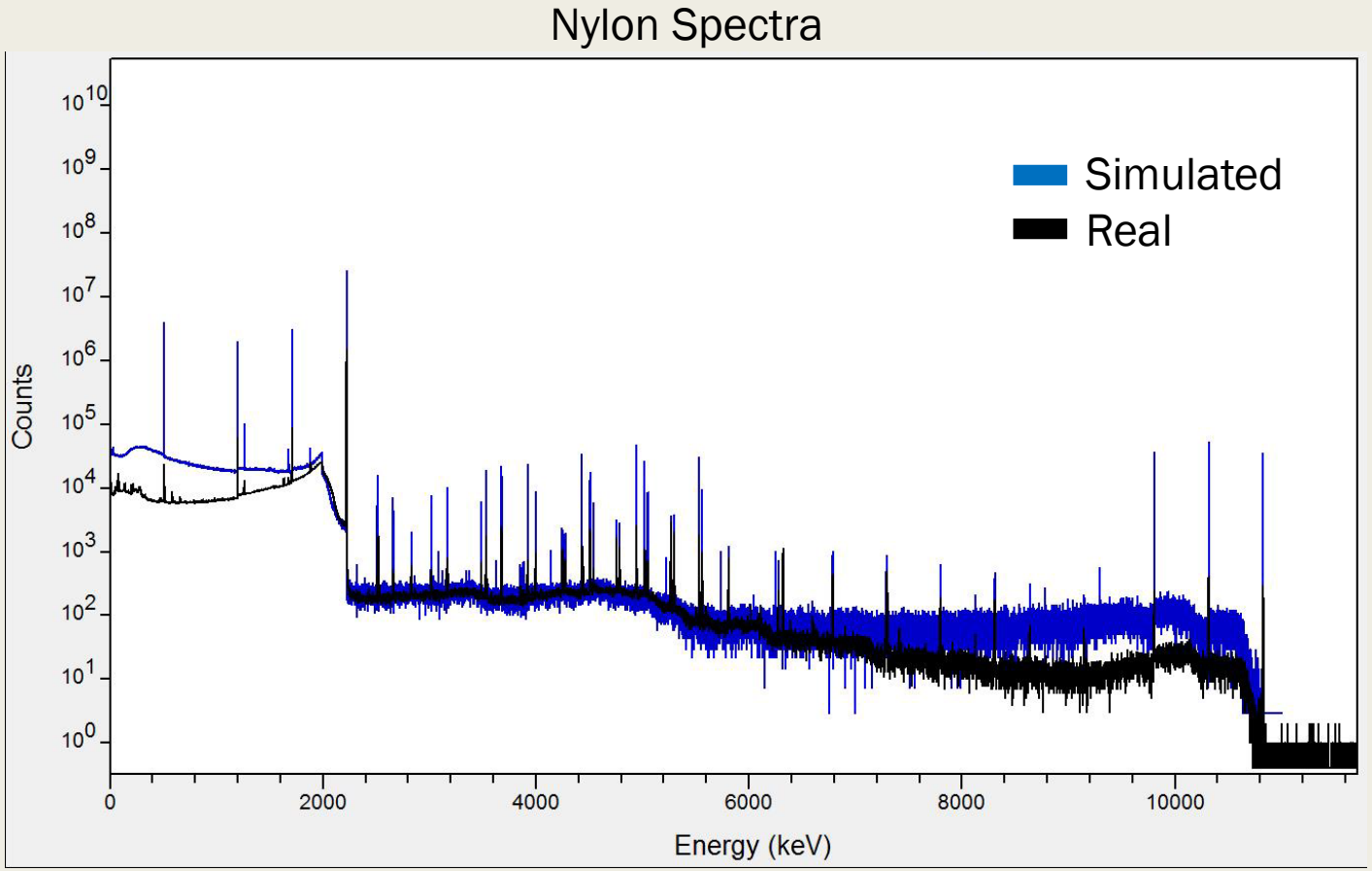
  - *Positional data gives placement and orientation*
- Volumetric reconstruction from single scan



Simulation

- Geant4: Monte-Carlo simulation for radiation transport
- Models 5 meV neutron beam interacting with sample
- Detectors output spectra and Compton events



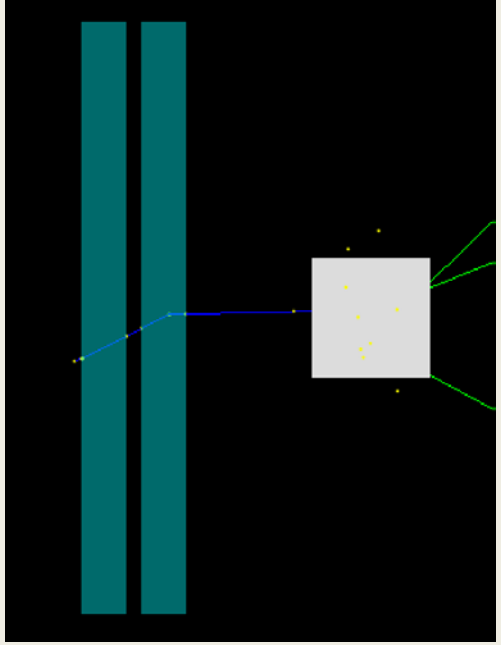


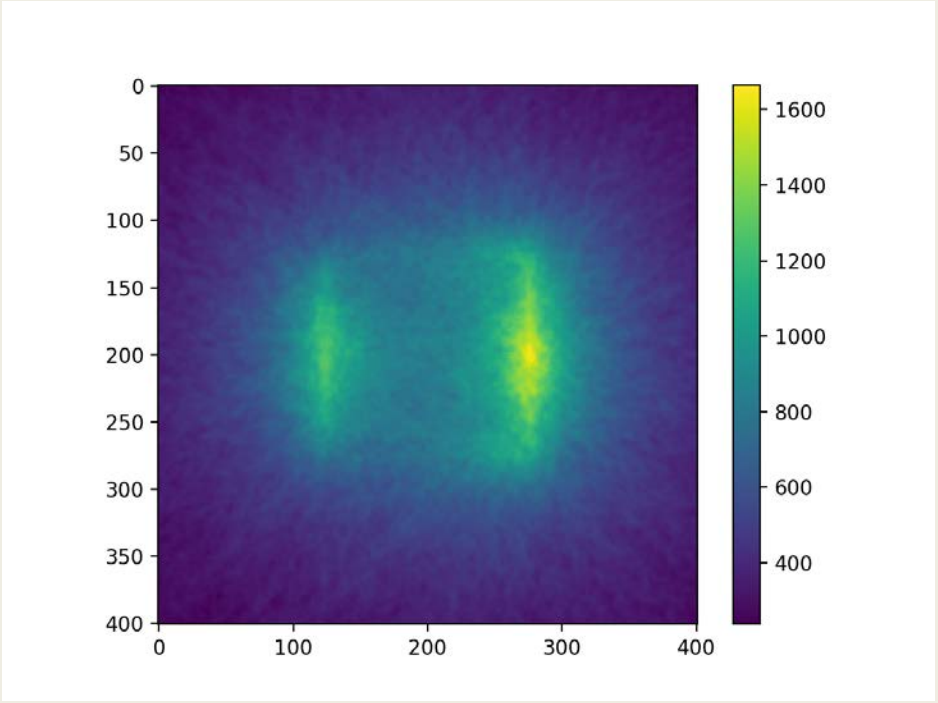
Geant4 Information

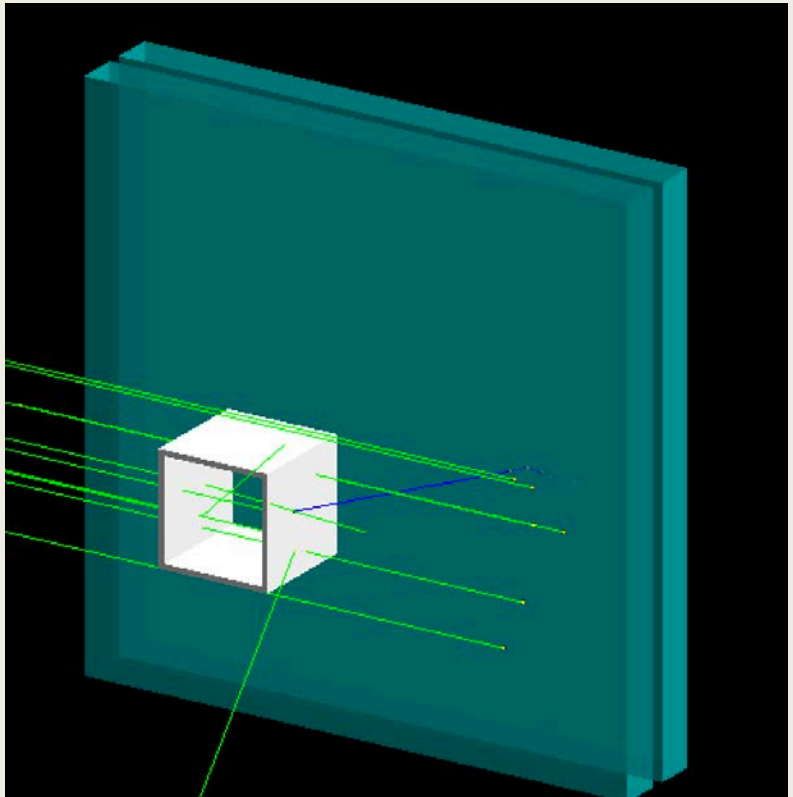
```
Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0     16.6    -7.87     -100   2.5e-09        0        0         0       World initStep
    1     16.6    -7.87      -20   2.5e-09        0       80        80      Sample Transportation
    2     16.6    -7.87    -19.8  4.89e-10 2.01e-09    0.222      80.2      Sample hadElastic
    3     16.1    -8.22    -19.5         0        0    0.706      80.9      Sample nCapture
    :----- List of 2ndaries - #SpawnInStep=  2(Rest= 0,Along= 0,Post= 2), #SpawnTotal=  2 --------------
    :      16.1     -8.22     -19.5      2.22              gamma
    :      16.1     -8.22     -19.5   0.00132           deuteron
    :---------------------------------------------------------- EndOf2ndaries Info --------------

************************************************************************************************
* G4Track Information:   Particle = deuteron,   Track ID = 3,   Parent ID = 1
************************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0     16.1    -8.22    -19.5   0.00132        0        0         0      Sample initStep
    1     16.1    -8.22    -19.5         0  0.00132 0.000243  0.000243      Sample hIoni

************************************************************************************************
* G4Track Information:   Particle = gamma,   Track ID = 2,   Parent ID = 1
************************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0     16.1    -8.22    -19.5      2.22        0        0         0      Sample initStep
    1     17.2    -7.52      -18      2.22        0     1.98      1.98       World Transportation
    2     62.5     20.8     40.9      2.22        0     79.5      81.5   Detector1 Transportation
    3     71.8     26.6       53      1.87        0     16.3      97.8   Detector1 compt
    :----- List of 2ndaries - #SpawnInStep=  1(Rest= 0,Along= 0,Post= 1), #SpawnTotal=  1 --------------
    :      71.8      26.6        53     0.353                 e-
    :---------------------------------------------------------- EndOf2ndaries Info --------------
```

Event Tracking

- Geant4: Tracks particle events sequentially
- Events track parent and daughter particles
- Simulate ~1E10 Events, 3 hrs
- High event counts allow for image reconstruction



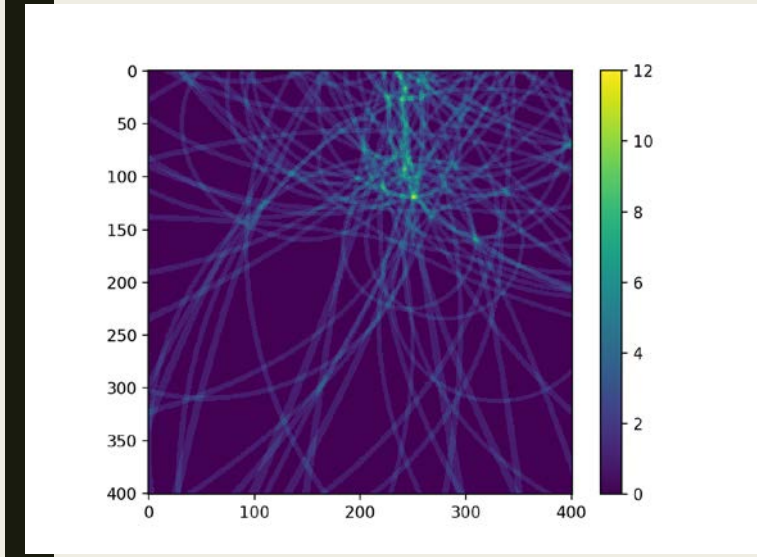




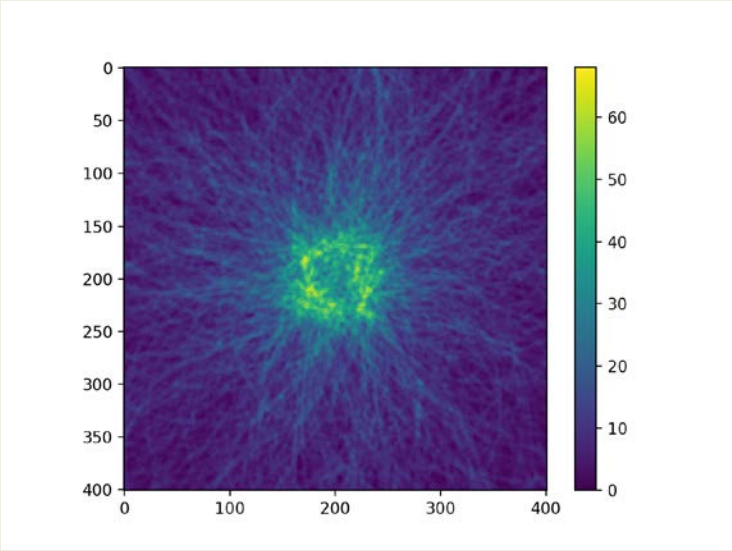
Back Projection Reconstruction

- Cones projected onto plane through sample
- Conic sections plotted
- Heat map generated

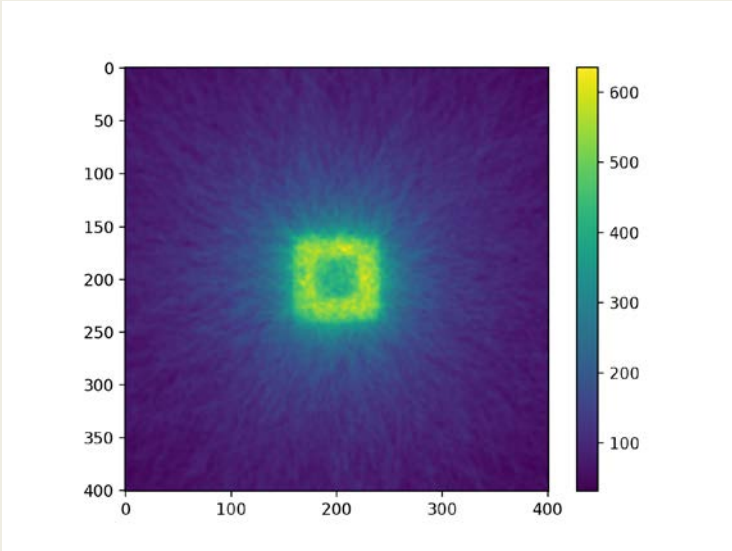
100 Cones



1000 Cones



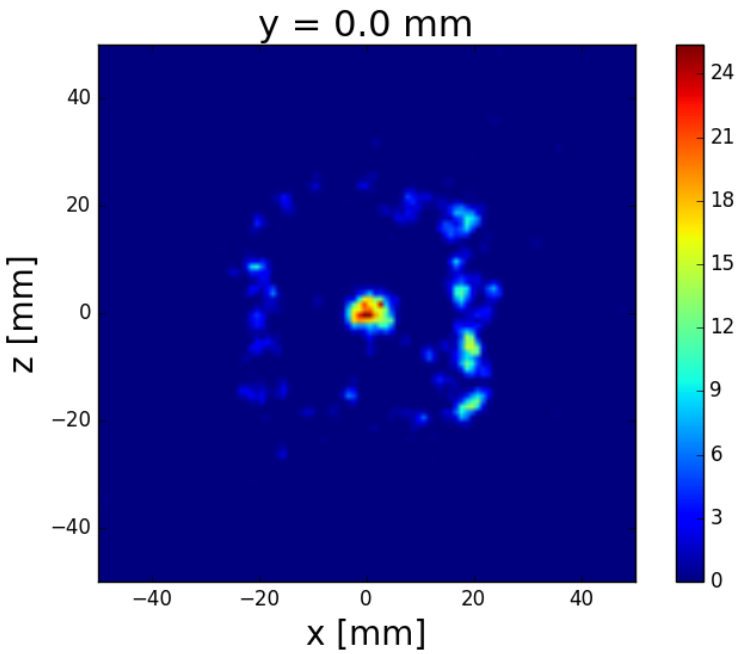
10000 Cones



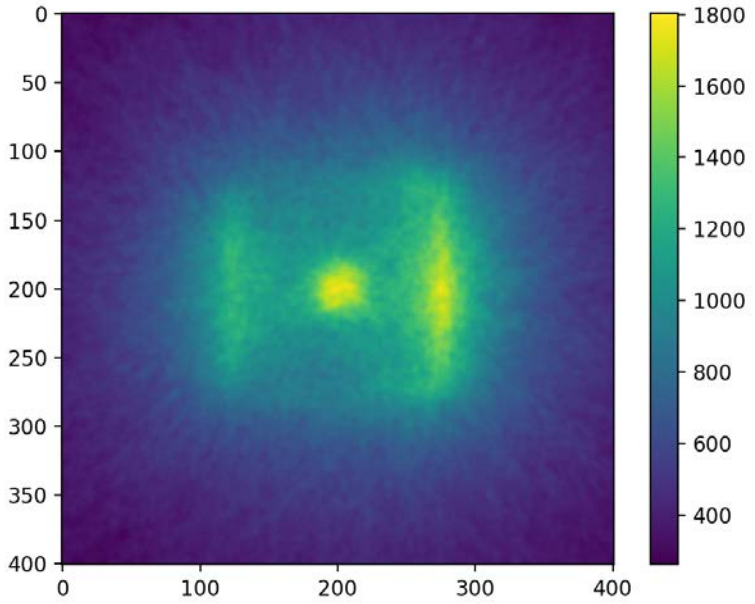
Statistical Reconstruction

- Alternative Reconstruction Method
- UMD School Of Medicine
- Computationally Faster
  - *4 min vs 3 hrs*
- Smoother

Statistical Reconstruction



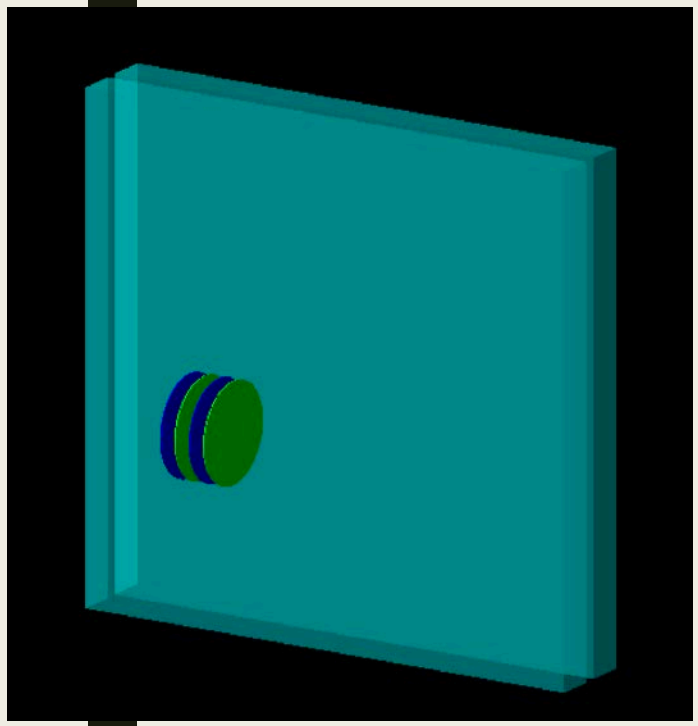
Back Projection



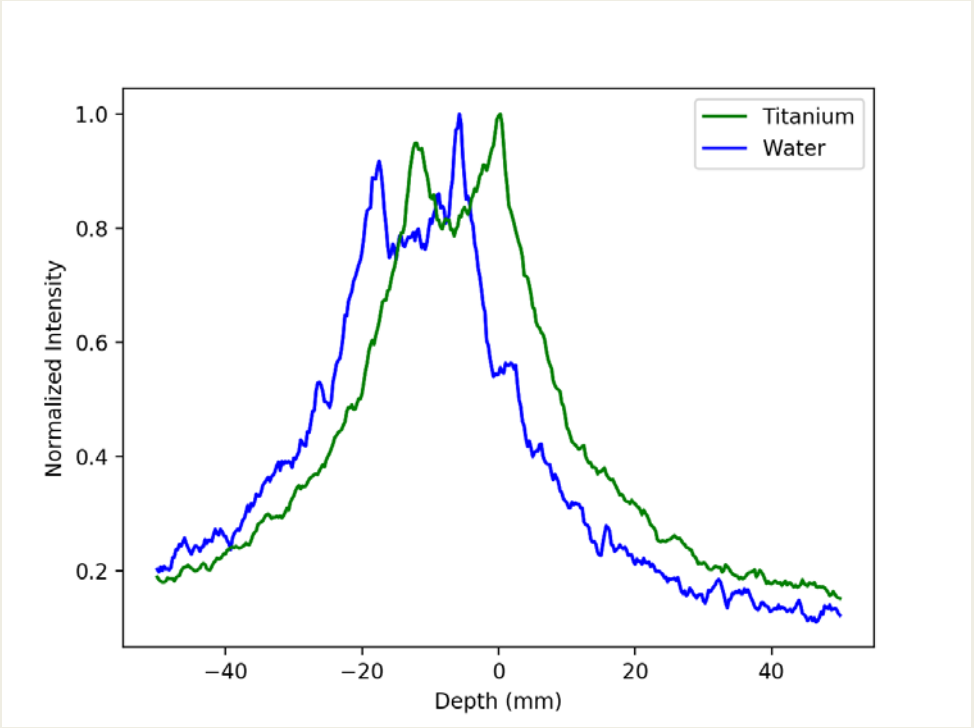
Credit: Jerimy Polf

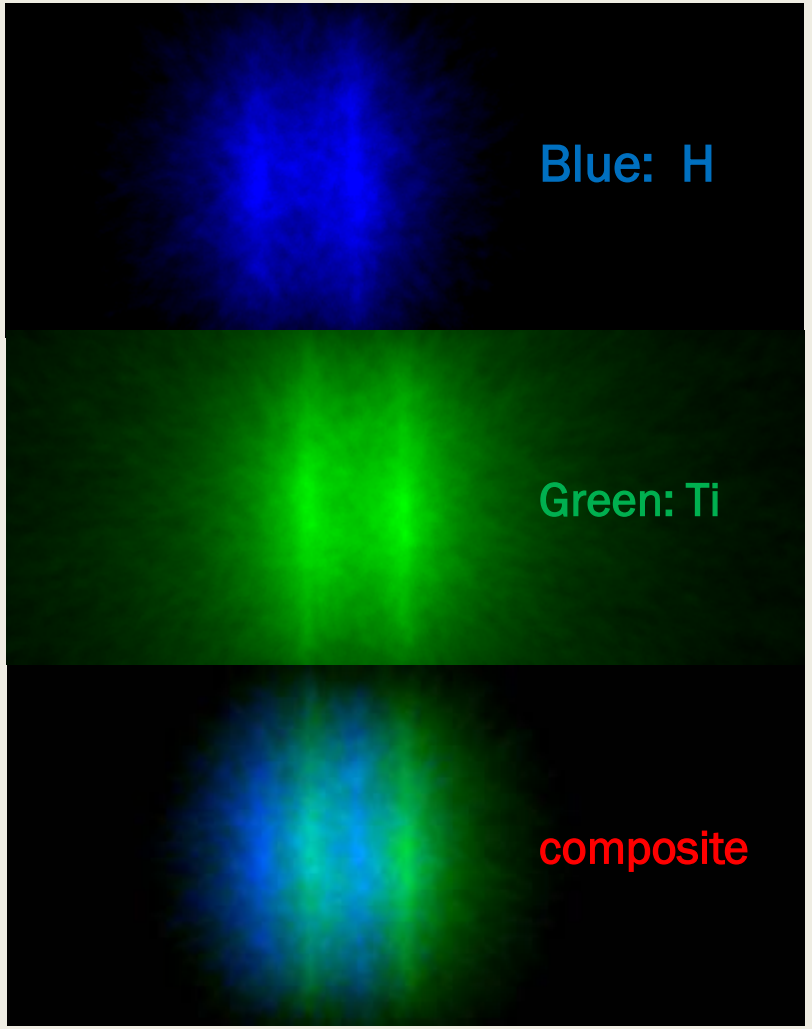
Simulation

- Material Filtering: Water vs Titanium
- Spatial Resolution and Composition



Disks: 0.5 mm depth
2.0 cm radius





Statistical Reconstruction

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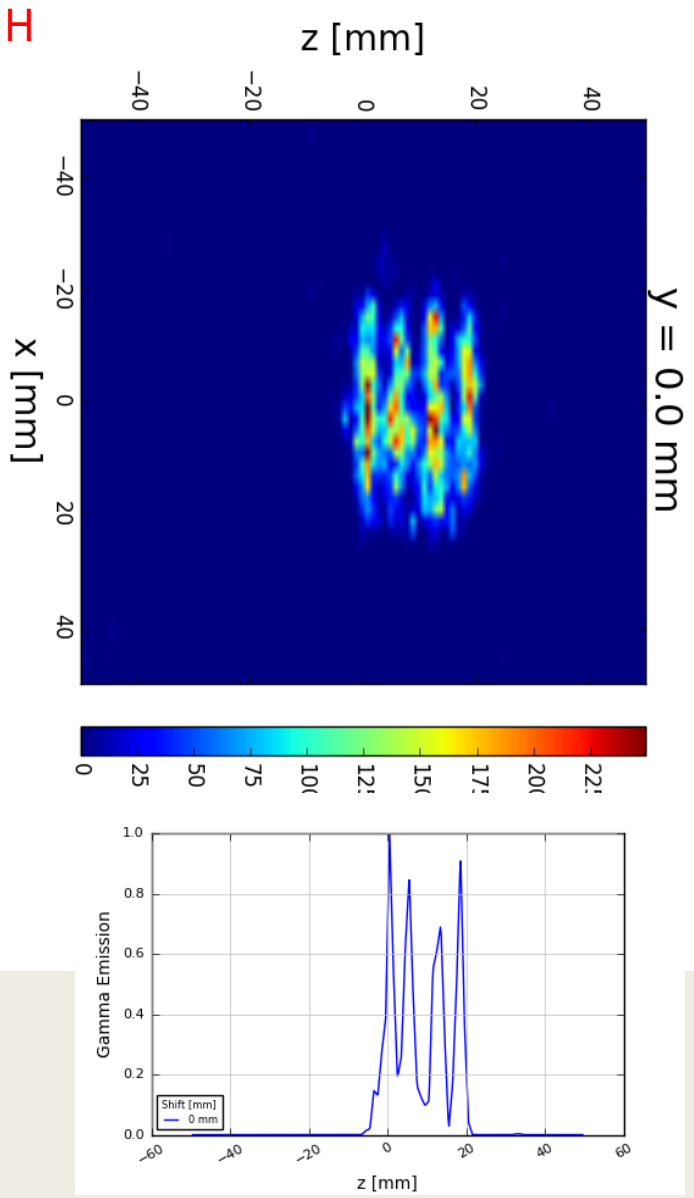

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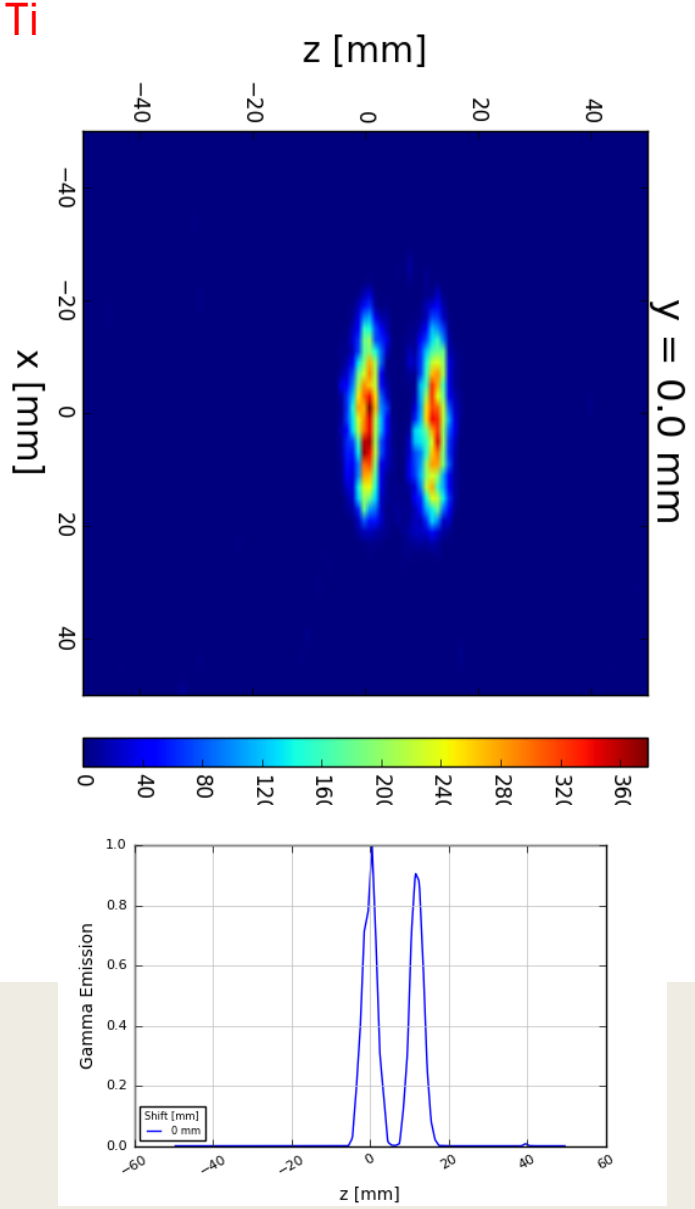
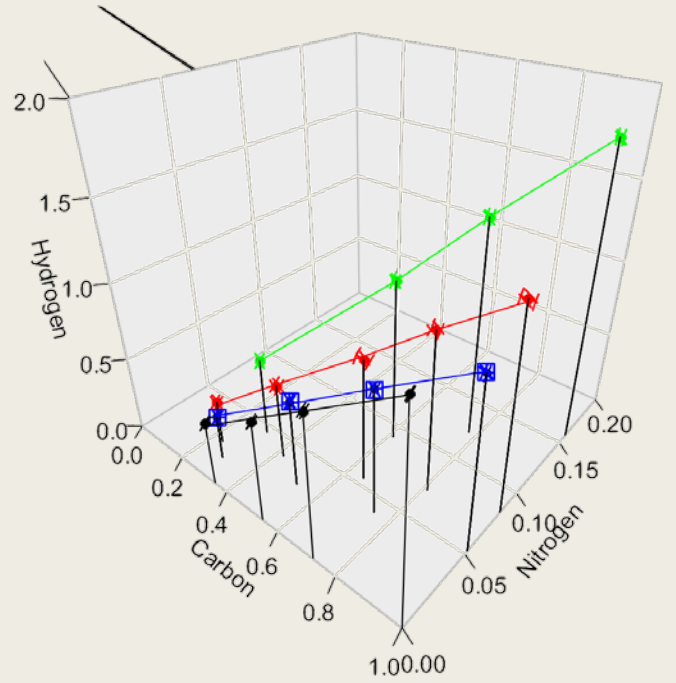
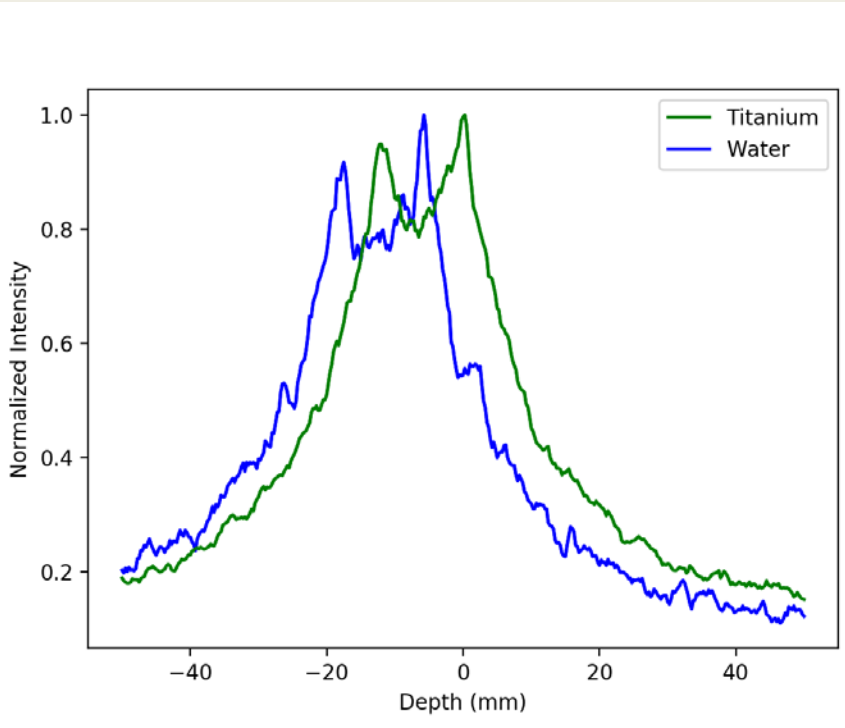


Conclusion

- PGAA
  - *Nondestructive*
  - *Accurately determine chemical composition*
- Compton Imaging
  - *Spatial Resolve Prompt Gamma emission*
  - *Distinguish based on element*
- Together
  - *Complimentary techniques*
  - *Composition and position*





Special Thanks

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- Jeremy Polf and Haijian Chen, UMD Proton Therapy Center
- SURF Directors