



March 2012

Optimizing parameters of the POCLUST algorithm for muon tomography for the detection of nuclear weapons

W. BITTNER, D. MITRA,
and M. HOHLMANN

Florida Institute of Technology, Department of Physics and Space Sciences,
150 West University Blvd, Melbourne, FL 32901

Motivation



Nuclear contraband is smuggled across borders.

Current radiation scanners use gamma and neutron emissions to detect nuclear contraband.

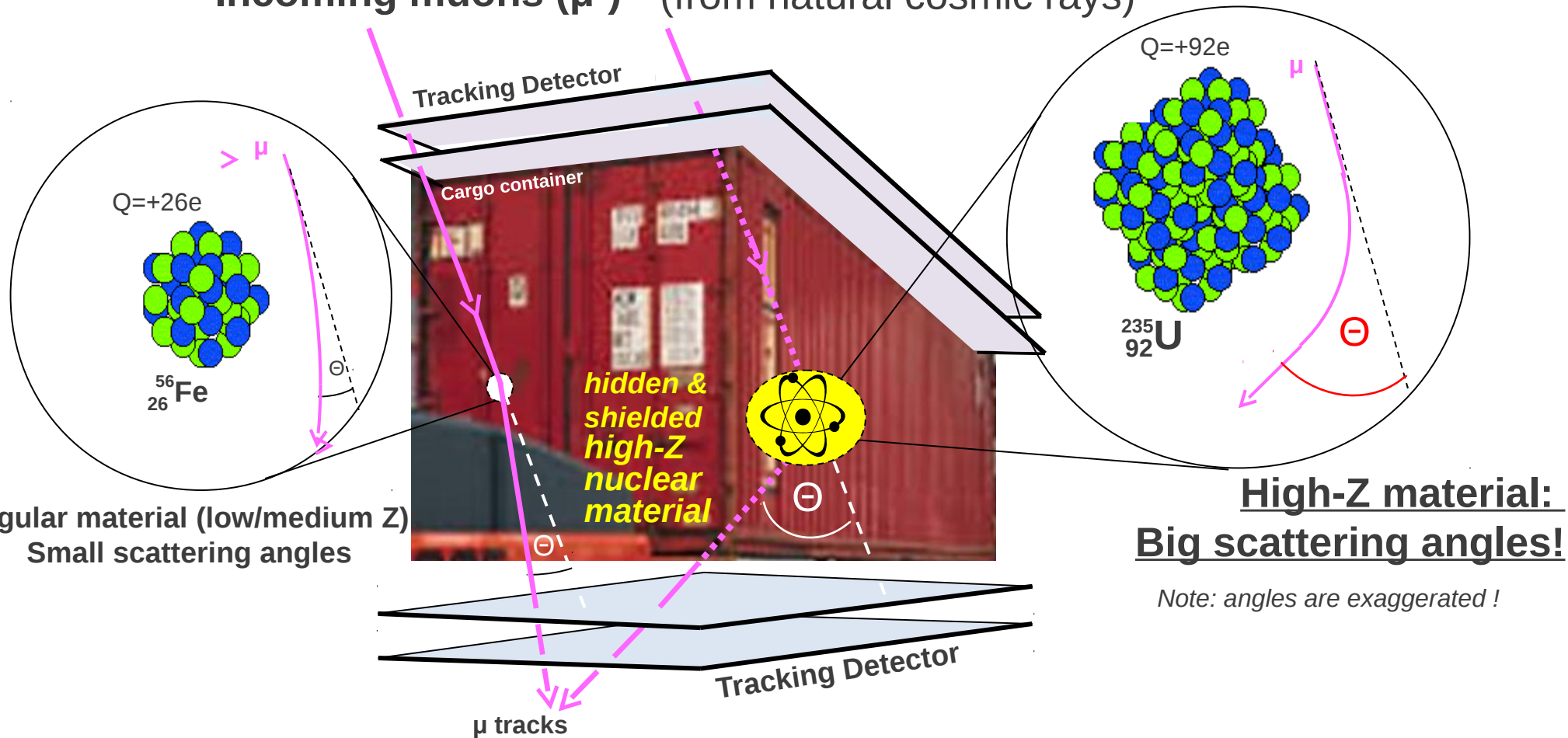
About 800 radiation portal monitors in the U.S.

Only **3.25 mm thick lead shielding** needed to absorb 99% of gammas emitted by ^{235}U .

How can we detect shielded nuclear contraband?

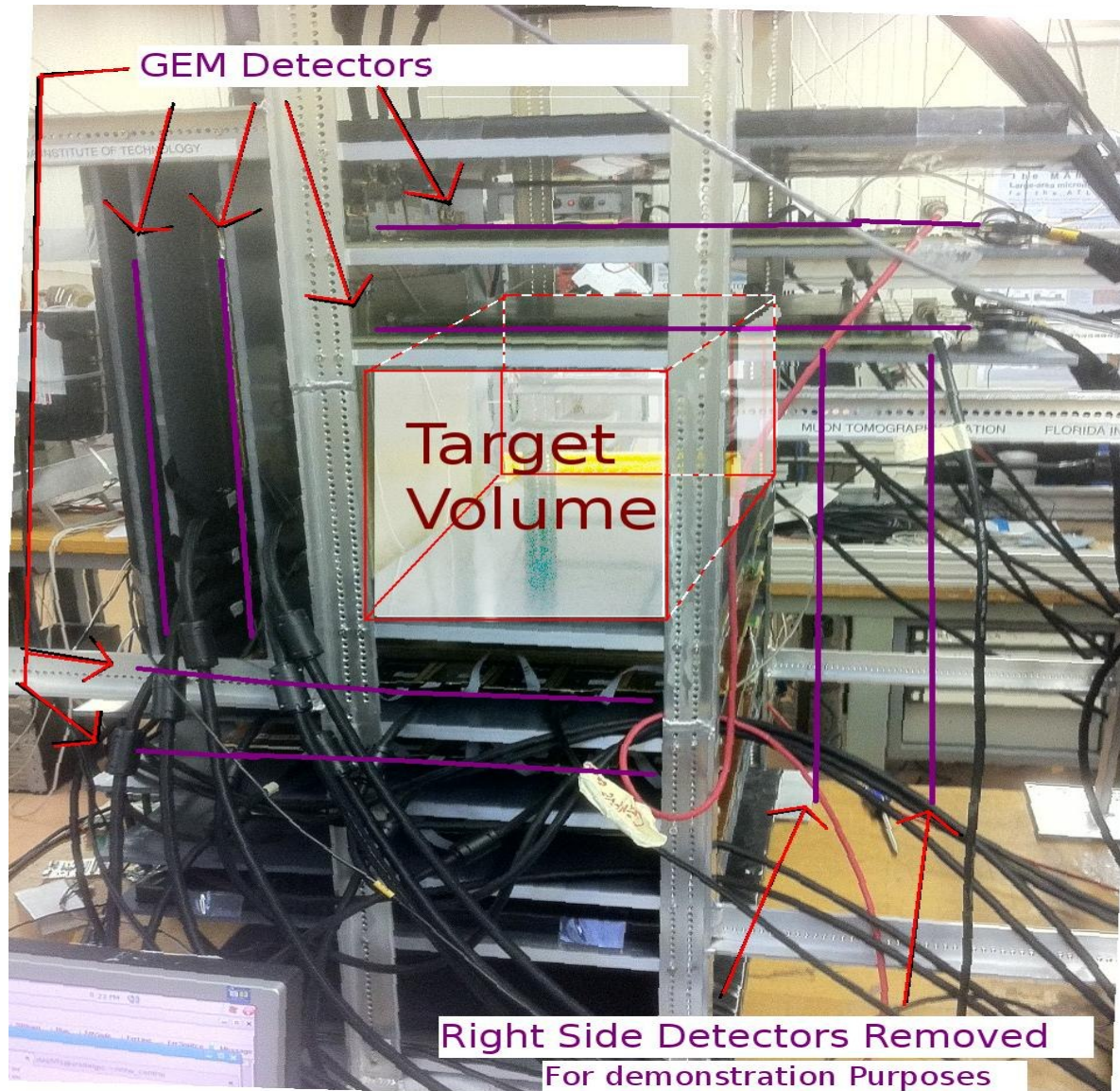
Muon Tomography Concept

Incoming muons (μ^\pm) (from natural cosmic rays)

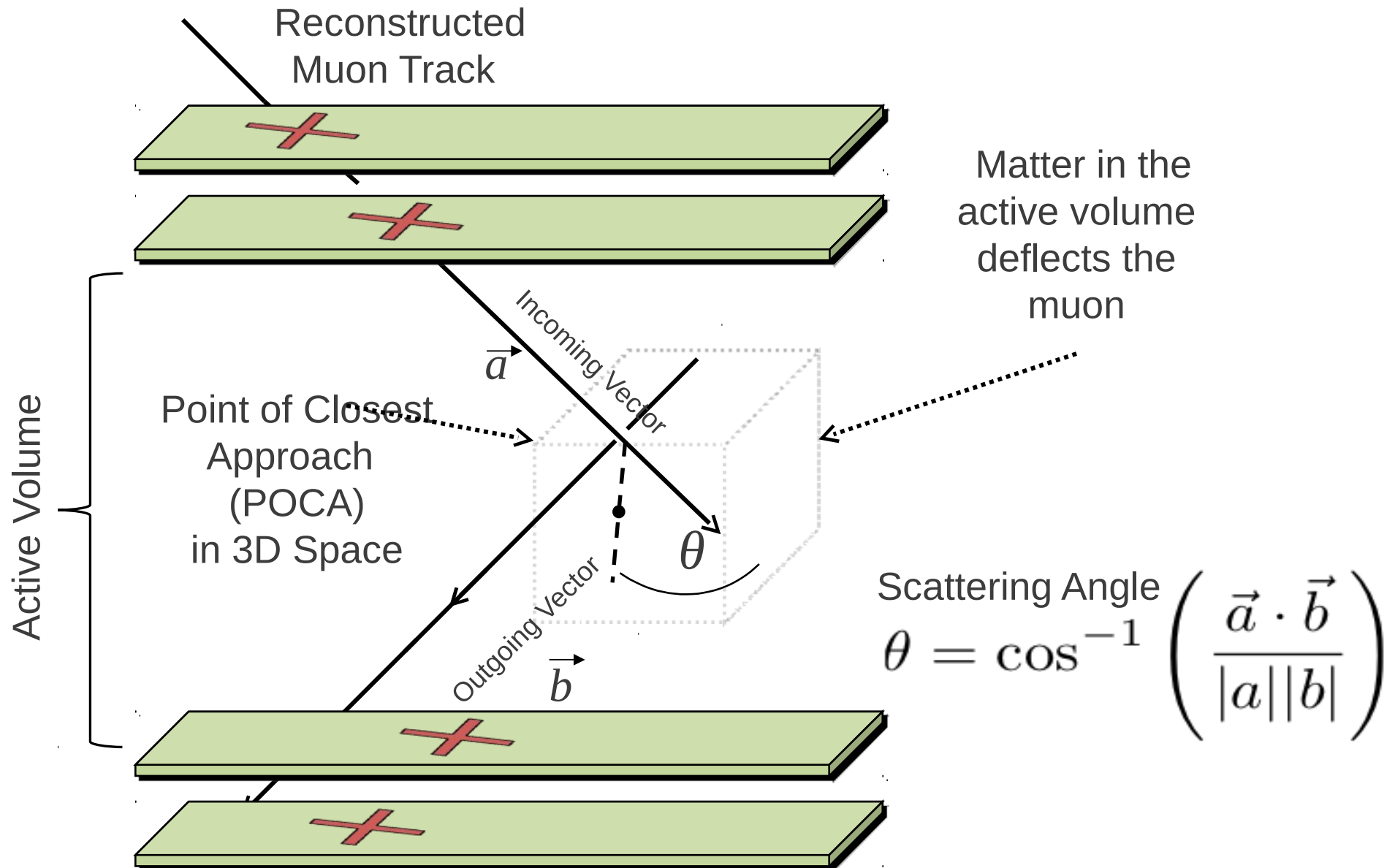


Idea: Use multiple scattering of charged particles in matter to detect high-Z material

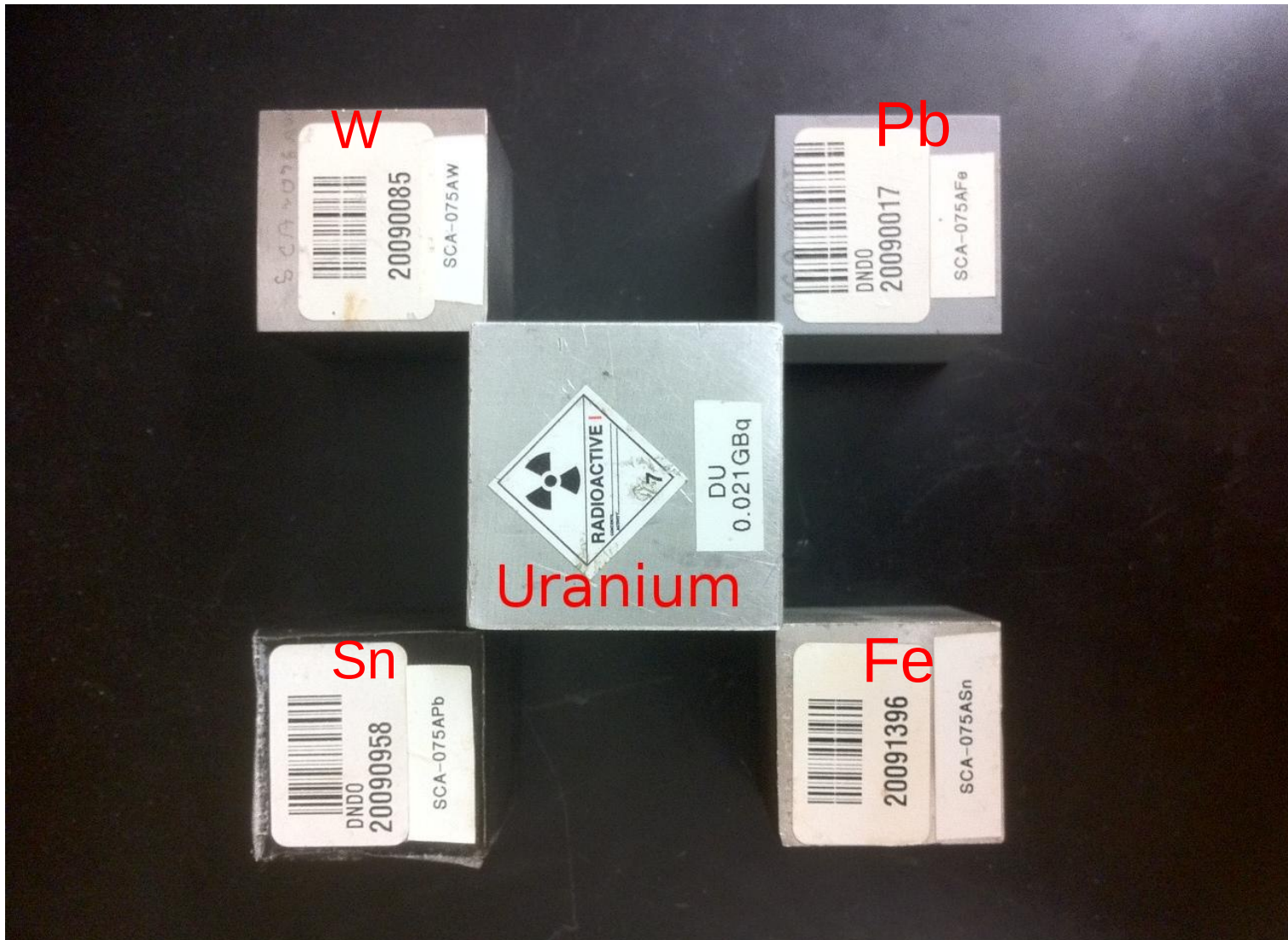
Current GEM Muon tomography station at Florida Tech



Reconstruction Algorithm (POCA)



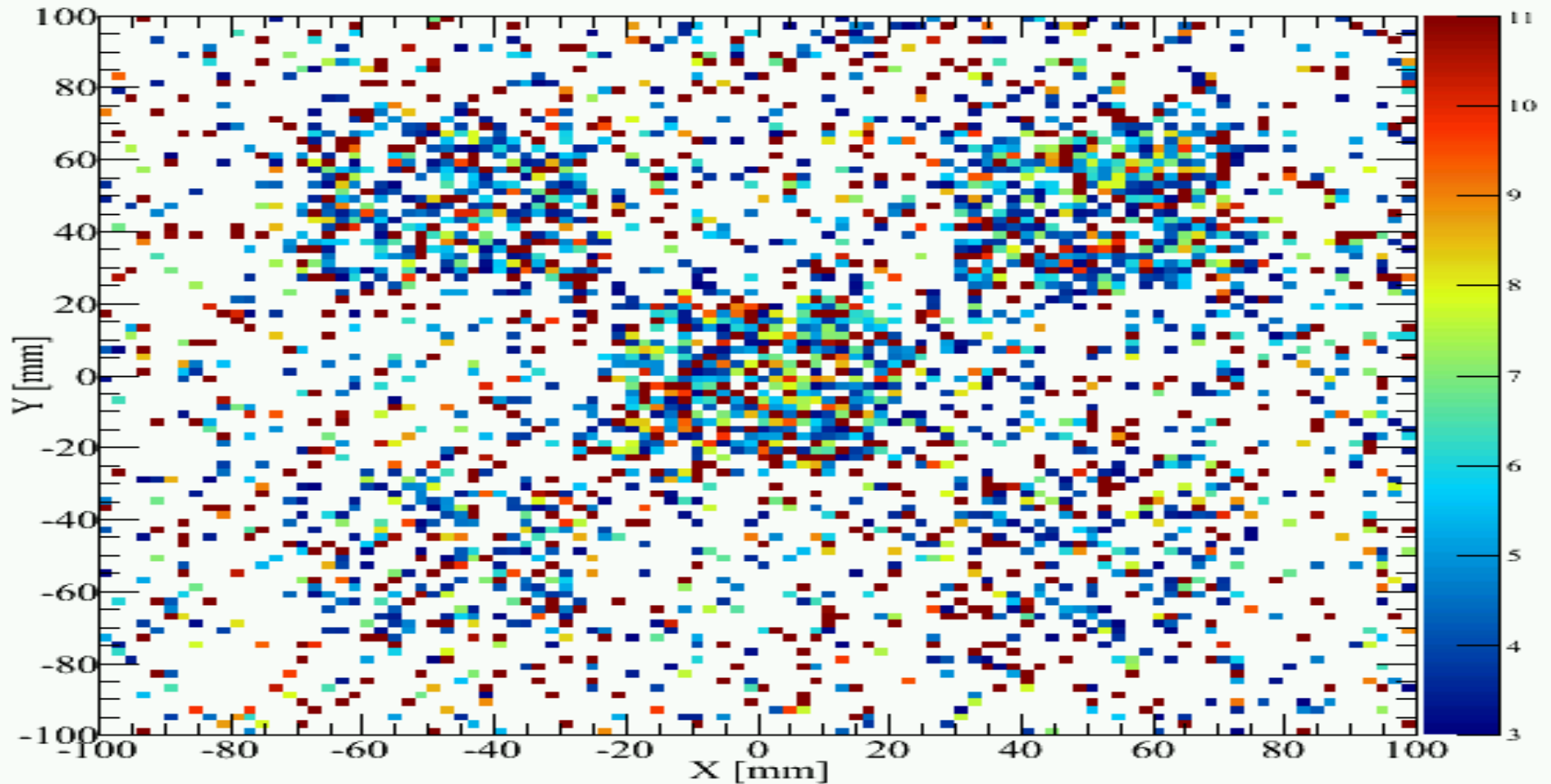
5 Target Scenario with Uranium



Goal: To be able to differentiate the materials in the visualization using the reconstruction methods Of the raw detector hits. Especially to be able to locate, and identify the Uranium!

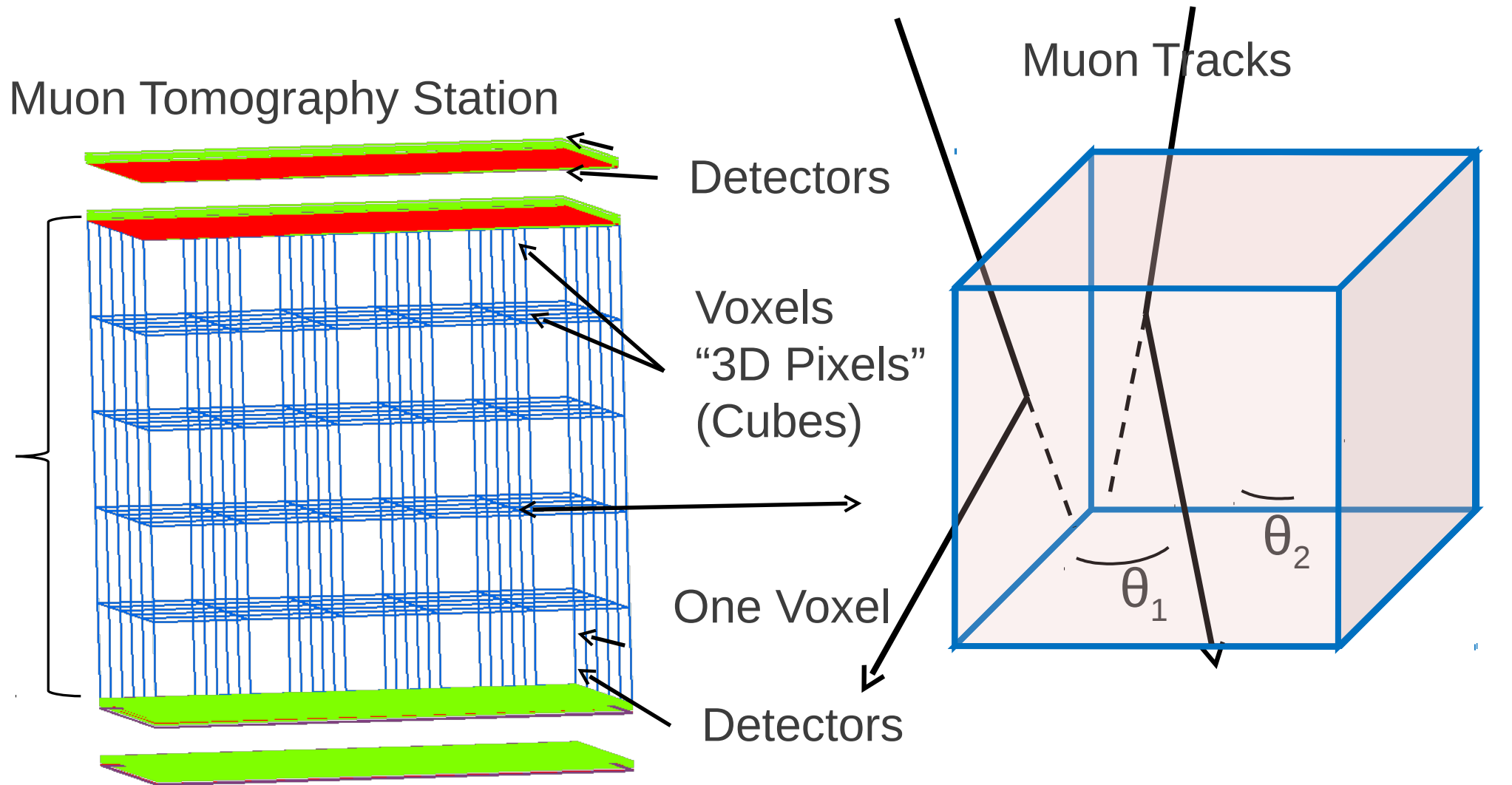
2D Visualization using POCA reconstruction of the 5 target scenario

5target28novAllXYatZ_minus40mm_max 1



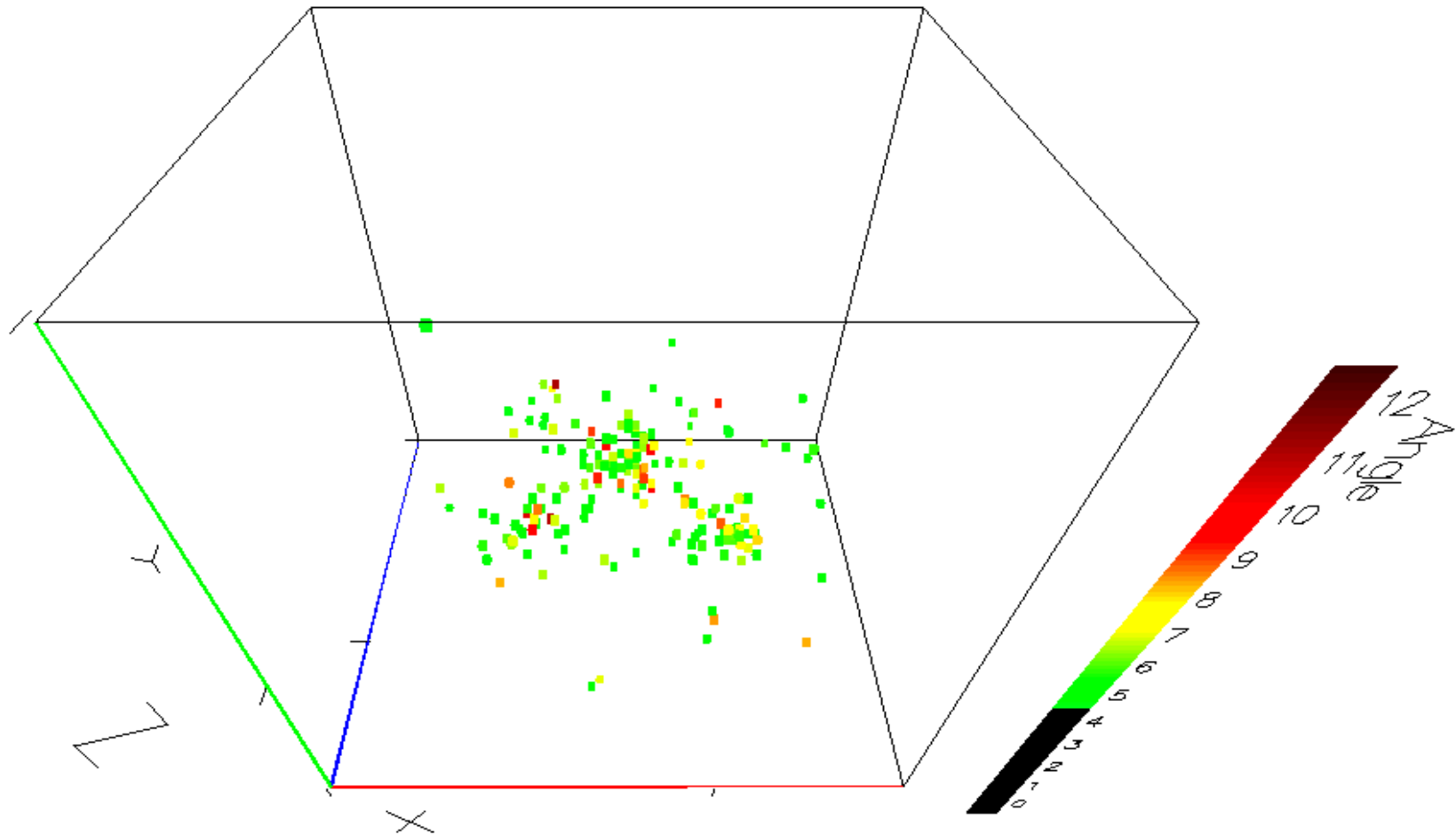
The Uranium (in the middle) produced a much higher density of points
And a much greater mean scattering angle,
Where as the Fe and Sn produced much less of a density of points.

Voxelization of POCA Points



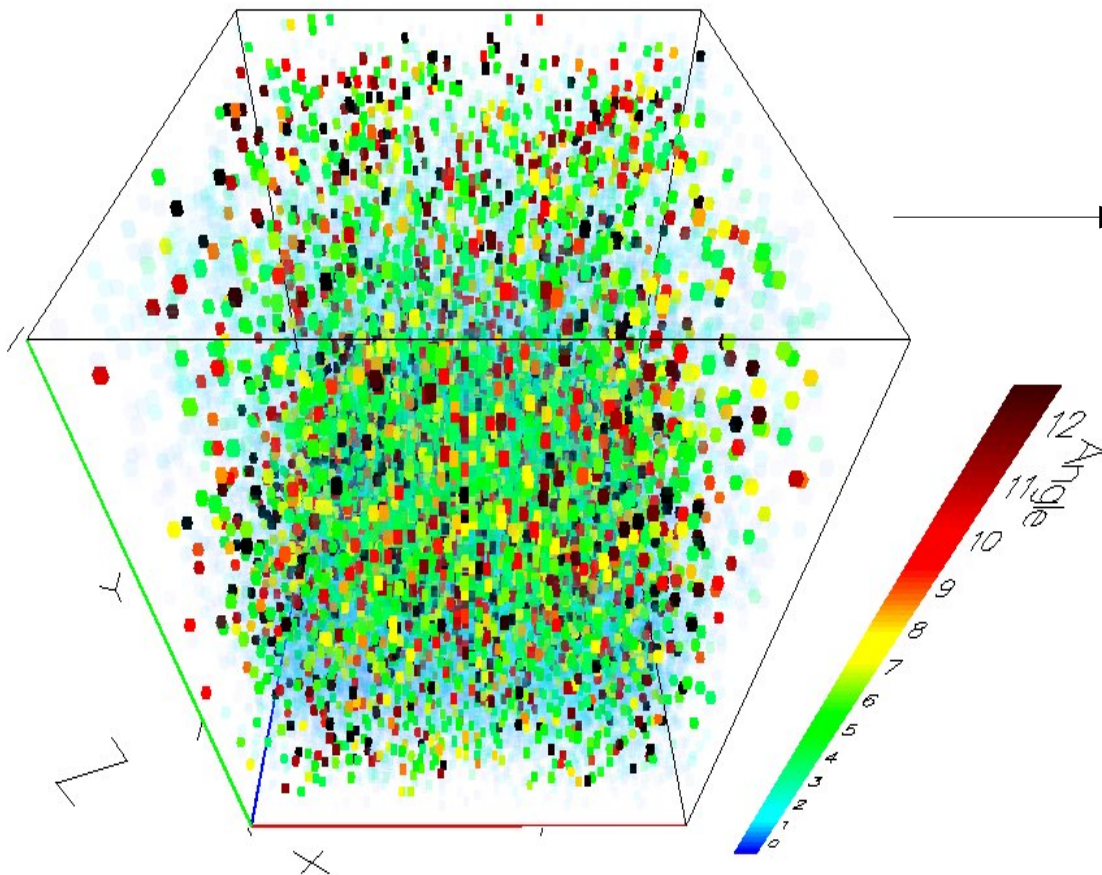
Voxel color indicates
mean scattering angle in voxel
 $\langle \theta \rangle$

3D Display with Voxelization and manual optimization of parameters

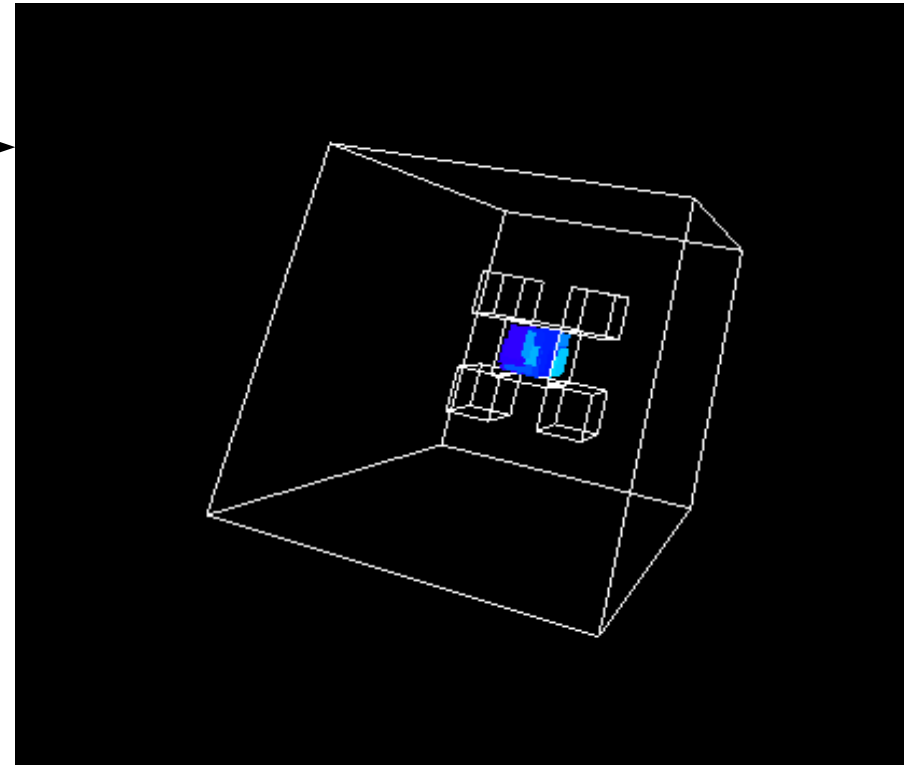


POCLUST Clustering Algorithm: The Future of reconstruction!

Before POCLUST:



After POCLUST



POCLUST can detect, isolate, and reconstruct the imaging of just the Uranium from the noise
Of the real data from the 5 target scenario!

POCLUST: Overview

- POCA Points are read in, unvoxelized
- Simple thresholds applied to remove major noise
- Clustering of the POCA points begin
- Deletion or removal of “sporadic” clusters occurs on intervals
- Merging of Clusters that meet criteria
- When all the points have been processed, output is visualized in OpenGL and compared to original targets in wireframes

Step 1: Noise Removal

- POCA Points outside of the target volume are discarded. POCA can reconstruct points sometimes outside of the volume
- Points $<$ a min deflection angle threshold are discarded
- Point $>$ a max deflection angle threshold are discarded

Step 2: Clustering

- For all POCA points:
 - Closest cluster is located, call it c
 - Point is checked to be “close enough” to cluster to be added
 - Once cluster reaches a mass of (MAX_POINTS_IN_CLUSTER) 100, the distance between clusters metric is changed from Euclidean
 - It is changed to $\text{Dist} = \sqrt{(x_1 - x_2)^2 + \dots + (\text{POCA Angle}^2) / (\text{Cluster Variance})}$
 - These distance metrics have separate header parameters i.e. MAX_L2_NORM_DIST, and MAX_DM_NORM_DIST

Step 3: Removing Sporadic Clusters

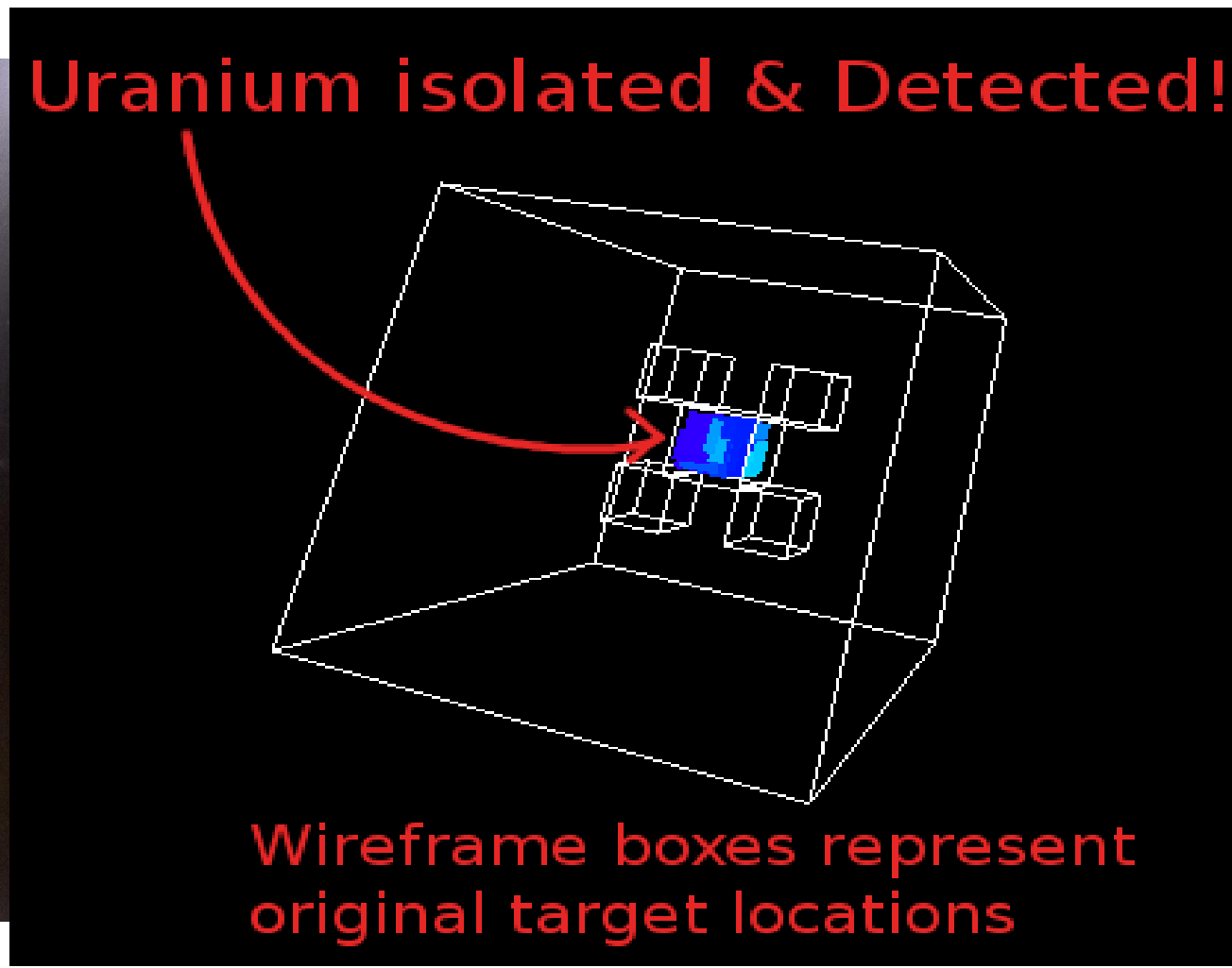
- We define a sporadic cluster as:
 - Percent = The percent of POCA points within that cluster that has an average deflection angle of $<$ the parameter `angleThresh`
 - If The number of points in the cluster is greater than 50, and the Percent is $<$ 4, then the cluster is defined as sporadic
 - Sporadic clusters get deleted immediately, along with the POCA points inside
 - The removing of sporadic clusters is run time elapsed since last run, and runs through all clusters

Step 4: Merging the Clusters

- Two clusters will merge to form one if:
 - They both satisfy “isSimilar()” and “isClose()”
 - Or: They “overlap()” > than a parameter OVERLAP_PARAM
- Two clusters are “isSimilar()” if:
 - $\text{abs}(\text{Percent of Cluster1} - \text{Percent of Cluster 2}) < \text{parameter MinPercent}$
 - AND $\text{abs}(\text{Cluster 1 variance} - \text{Cluster 2 Variance}) < \text{parameter MIN_VARIANCE}$
- Two clusters are “isClose()” if:
 - Distance between two cluster centroids (Euclidean) is < than parameter CENTROID_DISTANCE
- Two cluster are “overlap()” if:
 - The overlap volume / (cluster volume 1 + cluster volume 2) is > parameter OVERLAP_PERCENTAGE

Step 5 – Visualizing Output

Using the Florida Tech HEP Lab Vx4D visualization framework, OpenGL, and Linux, 3D visualizations are created directly from the POCLUST output, with the ability to compare to the original real physical target positions (wire frames).



Current and Future Plans

- Finish the new re-write and clean OOP Framework
- Finish debugging the ability for clusters to grow not just by the increase of cuboid dimension (voxel growth)
- Allow POCA points and clusters to not only merge, but wholly and partially unmerge, with the ability to merge into a more optimal cluster
- Finish the system such that POCA points are never deleted, but are returned to the “Space” when released
- Parameter optimization for complex shielding scenarios using Artificial Intelligence methods to adjust the wide array of parameters.
- Live streaming display of live muon tomography (POCLUST is an online algorithm)
- Compute scattering densities of clusters, and use it to estimate the Z of the cluster