X-ray Simulation Tools

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Conclusions

- Simulations can predict performance of explosive detection systems (EDS)
  - Reduced time to market and development costs
  - May obviate prototype development to predict performance
  - Applicable to x-ray CT, transmission, backscatter, diffraction, and MMW
- Components: Simulated test objects and simulation tools
- Can provide library of test data with known ground truth
- Simulated data can match the values, noise, scatter, artifacts of experimental data
- Tools exist for medical imaging, but challenges for EDS
  - Simulated test objects, Object complexity, Ease of use, Scatter, and Speed
- SBIR project to develop common interface for existing tools
- MMW simulations performed by PNNL and ALERT

Challenges for EDS Simulations

- Many (infinite) materials / objects
- Severe metal, beam hardening, photon-starvation, and streak artifacts
- Artifacts cause object splitting, object merging, errors in estimated size
- Artifacts increase the feature space of threats / non-threats
- In order for simulations to be useful for security, must accurately model the artifacts, nonideal effects

Goals for Simulation Tools

- Model realistic scanner effects
  - Validated
- Easy to use
  - Expert User and Technician User*
- Flexible scanner configuration
  - Flexibility to model a specific scanner very precisely*
- Speed
  - "1000 bags per week"*

*DHS SBIR User Survey

Goals for Simulated Objects

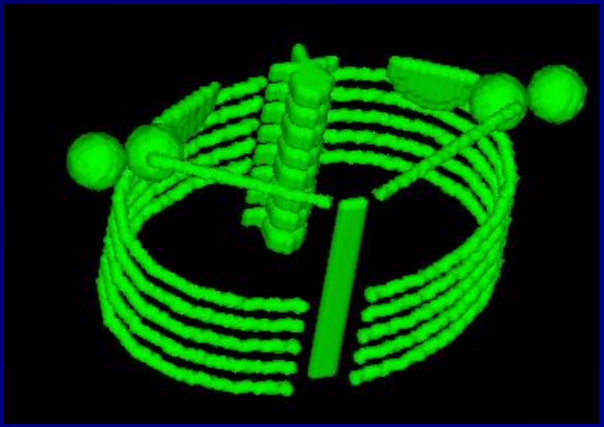
- Model objects with realistic complexity
- Easily model numerous bag configurations
  – Place a threat object in numerous configurations with varying clutter*
- Compatible with CAD outputs and other standard formats
- Define ‘standard’ phantoms that can be used to compare algorithms / systems

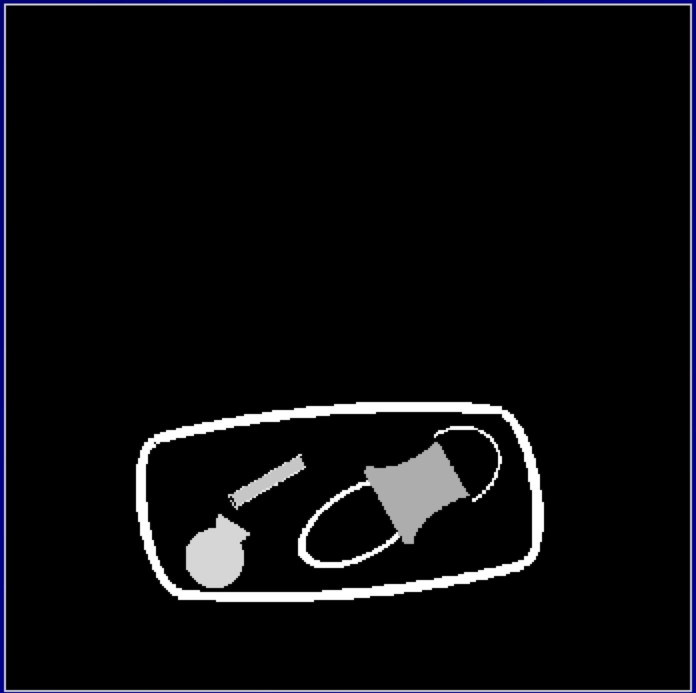
*DHS SBIR User Survey

Simulated Objects: Current Status

Objects: Primitive Shapes

- Combinations of primitive shapes
- Specified in text file
- Challenging to define complex objects

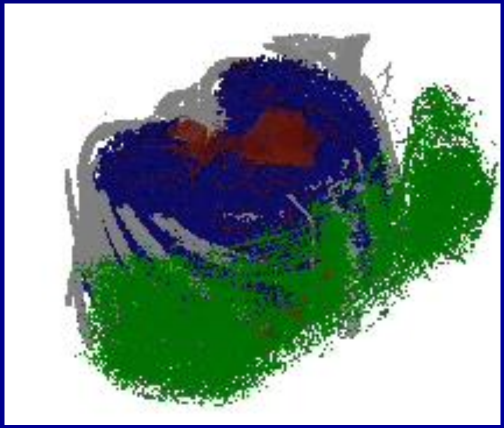




Courtesy of Seemeen Karimi

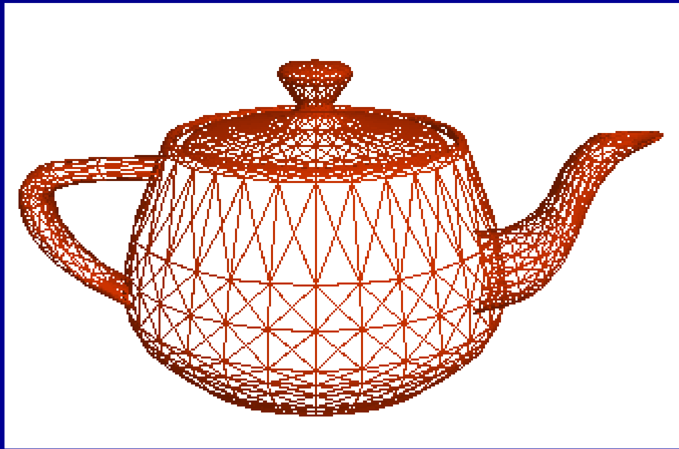
Voxelized Models

- Represent complex objects by cartesian grid of voxels. Each voxel has one μ value
- Ray-tracing algorithms available
- Model heterogenous texture
- Convert an experimental image set into a software phantom
- Require large memory
- Partial volume limitations



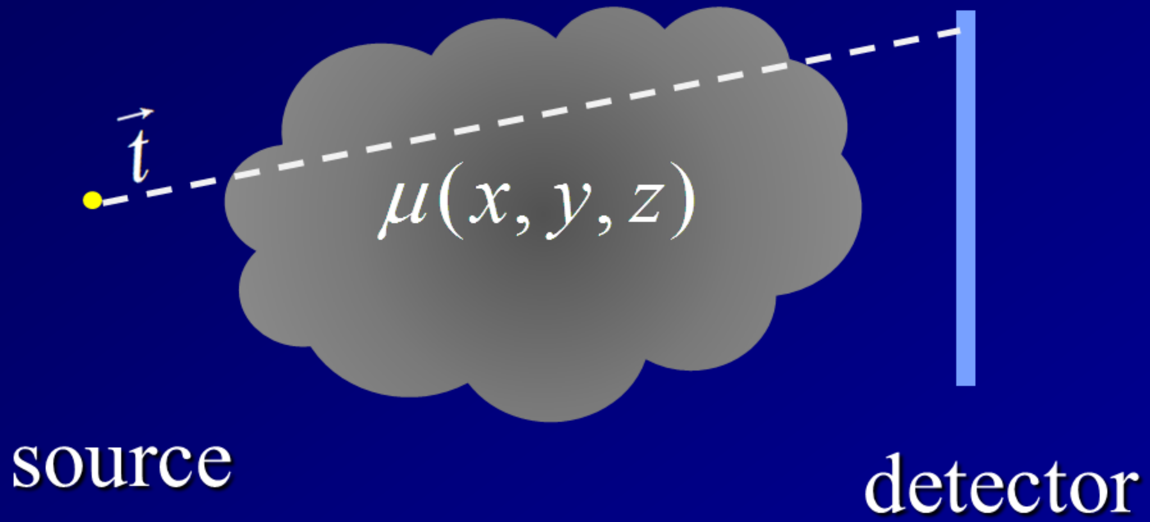
Polygonal Mesh Objects

- Defines the object surfaces through mesh points
- Standard CAD output (e.g. .stl)
- Numerous object models available in public domain (e.g., Google sketch up 3D warehouse)
- Ray tracing algorithms available



Simulation tools: Current Status

Simple Simulation



$$\bar{N} = \int N_o(E) e^{\left(-\int \mu(x,y,z) d\vec{t}\right)} dE$$

How to calculate line integrals through objects?

Calculating Line Integrals

- Analytical calculation through combinations of primitive shapes
  - e.g., CATsim, g3d, CTsim,
- Ray tracing through voxelized objects
- Ray tracing through mesh objects

Nonideal Effects Can be Modeled

- Poisson noise
- Source aperture
- Detector aperture
- Detector crosstalk
- Afterglow
- HVPS drifts
- Geometric errors
- Electronic noise
- Sampling during rotation

Scatter Effects

- Generally requires Monte Carlo simulations
  - GEANT4, PENELOPE, MCNP, etc.
  - Used for backscatter simulations
- Computationally expensive
- Typically a combination of deterministic ray tracing and Monte Carlo simulations

ALERT Task Order 3: Simulation Task

- Validated that simulated data replicates experimental data
  - Large library of data acquired on Imatron scanner as part of DHS ALERT Task Order 3
- Developed common set of numerical phantom definitions and simulated data
- Leveraged concepts and tools in the medical imaging field to develop simulation tools for future projects

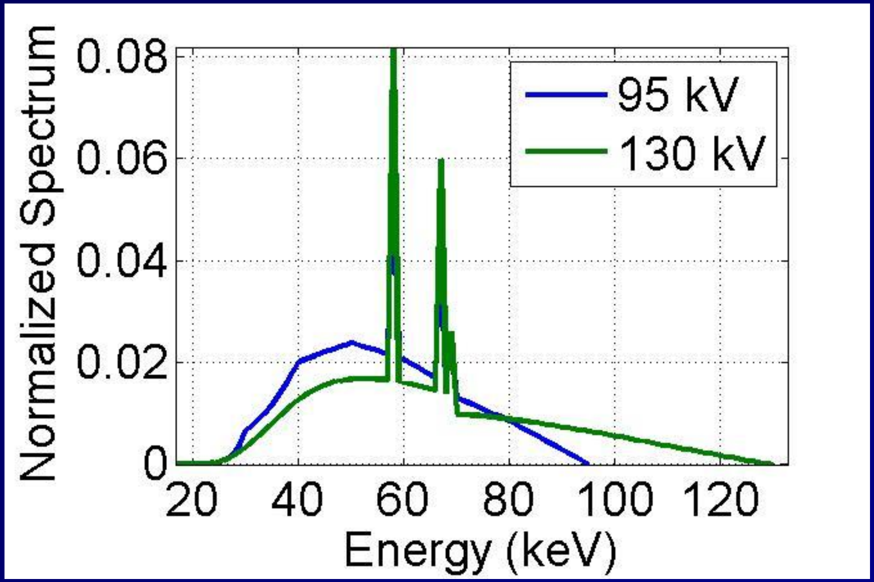
Task Order 3 Methods

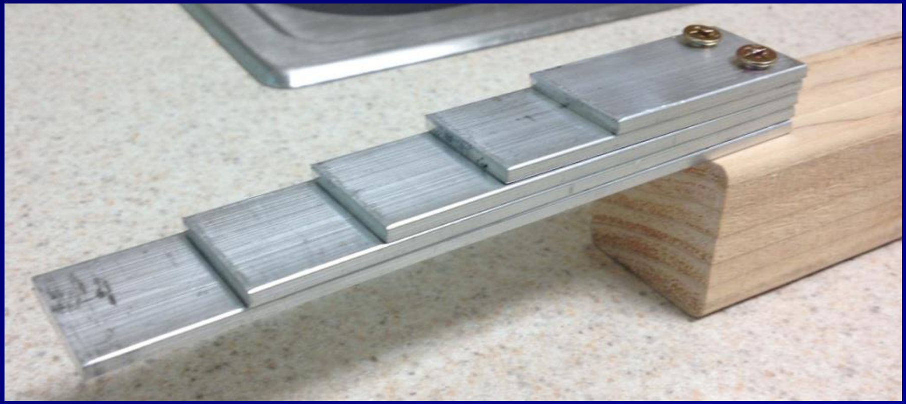
- Raytracing software analytically calculated intersection of rays with primitive shapes
  - Cylinders, ellipses, boxes, cones
  - Models focal spot and detector aperture
- Monte Carlo simulations estimated scatter signal
- Matlab scripts combined ray-tracing, scatter, photon noise, and electronic noise.

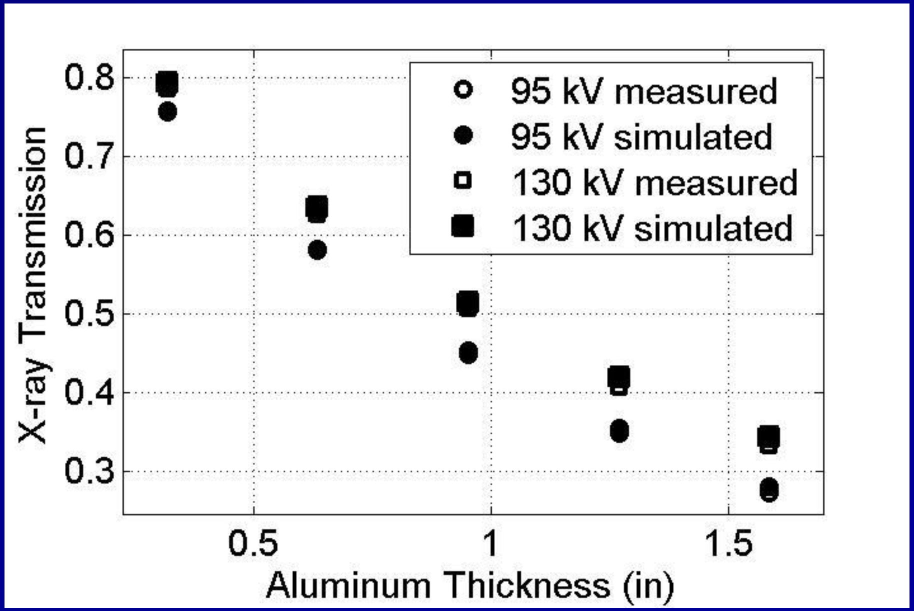
Validation

- Match the Imatron spectra
- Match the Imatron fluence
- Match the Imatron geometry
- Match the reconstructed HU mean and standard deviation
- Match the scatter level and artifacts

X-ray Spectra

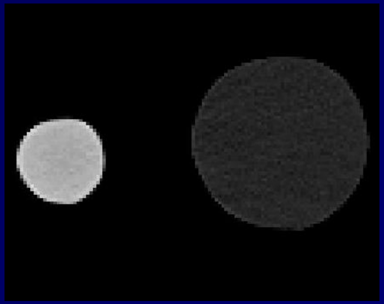


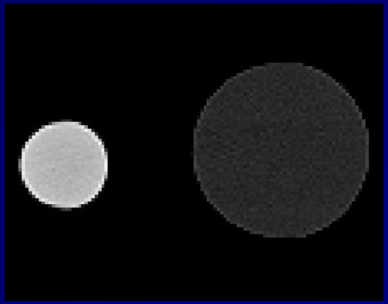


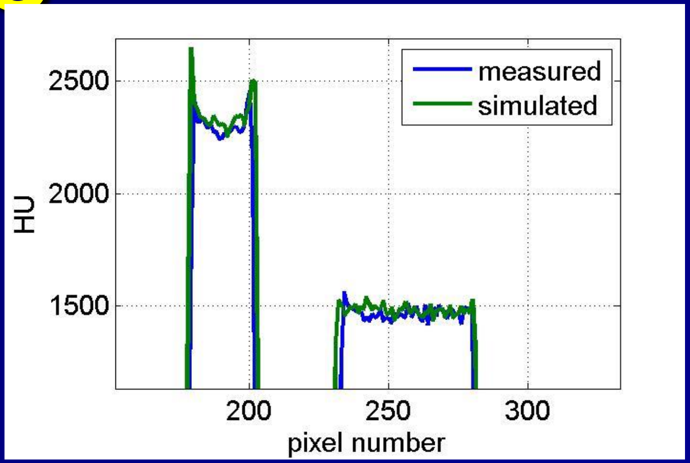


Graphite and Magnesium

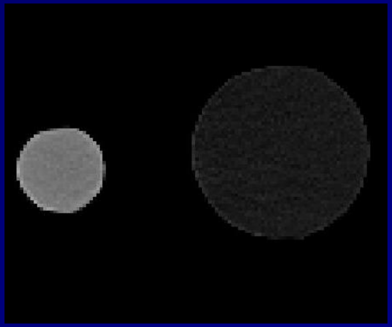
95 kV

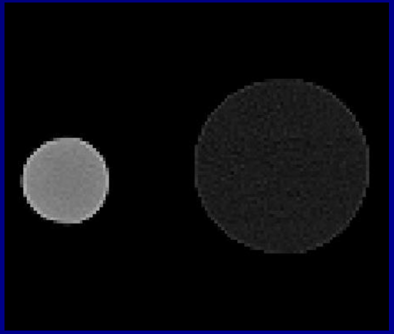


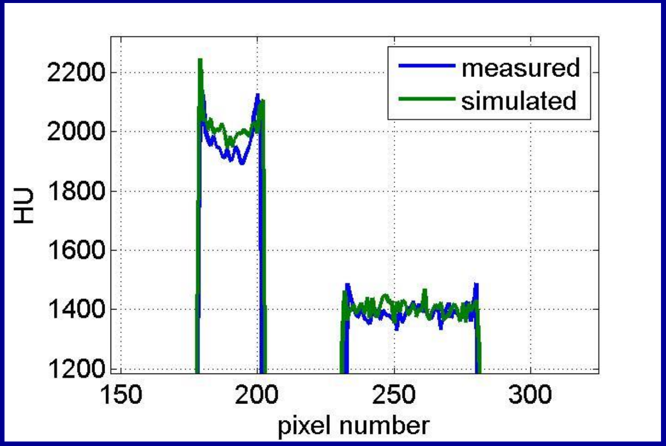




130 kV



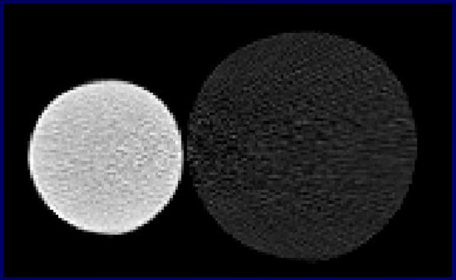


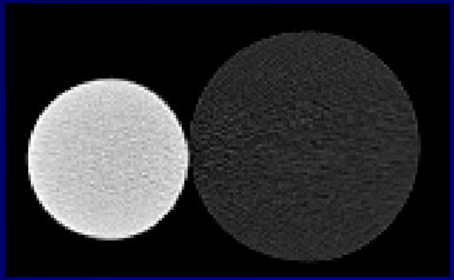


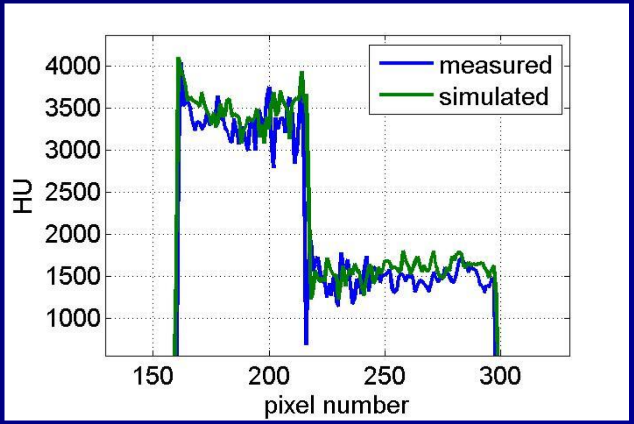
Measured | **Simulated** | **Horizontal Profile**

Graphite and Aluminum

95 kV







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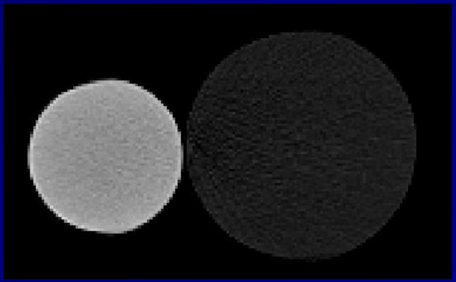
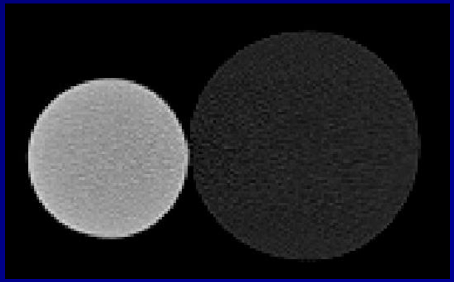
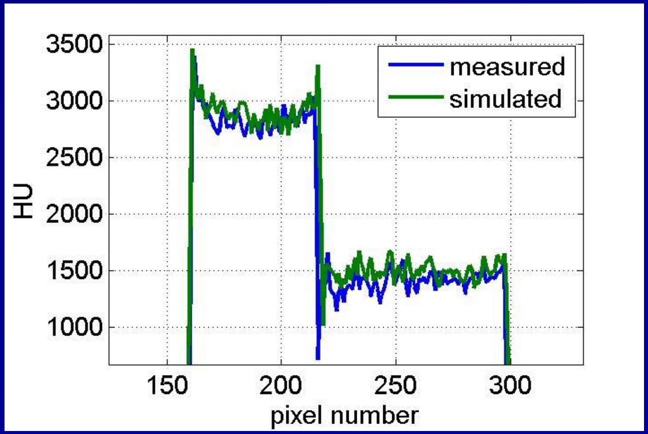
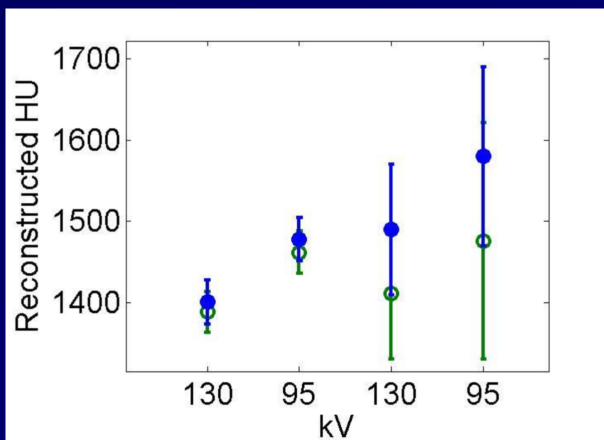




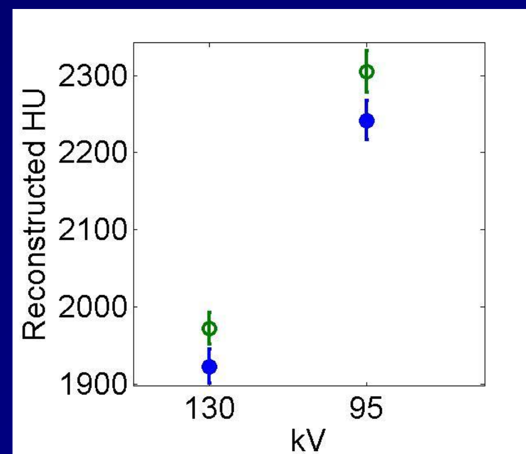


Measured **Simulated** **Horizontal Profile**

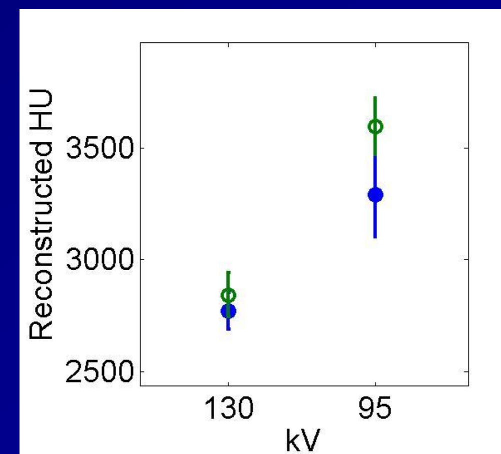
Reconstructed HU Values



Graphite



Magnesium

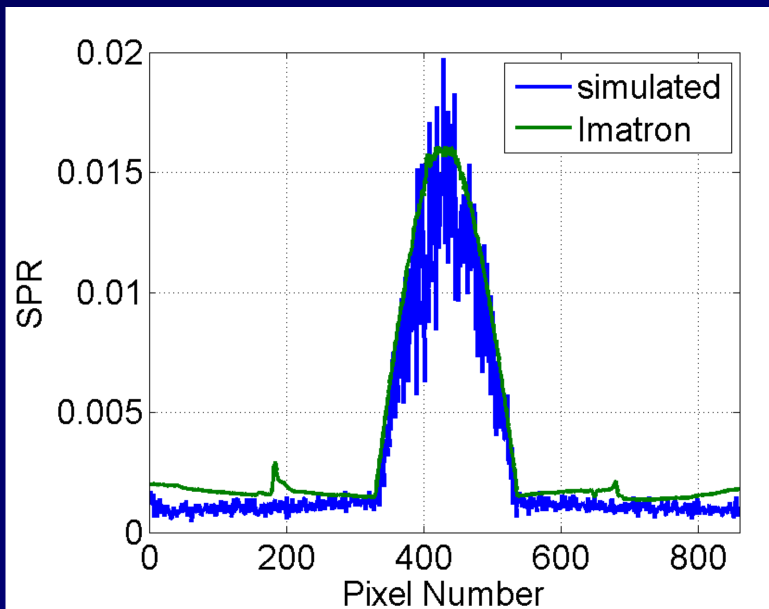


Aluminum

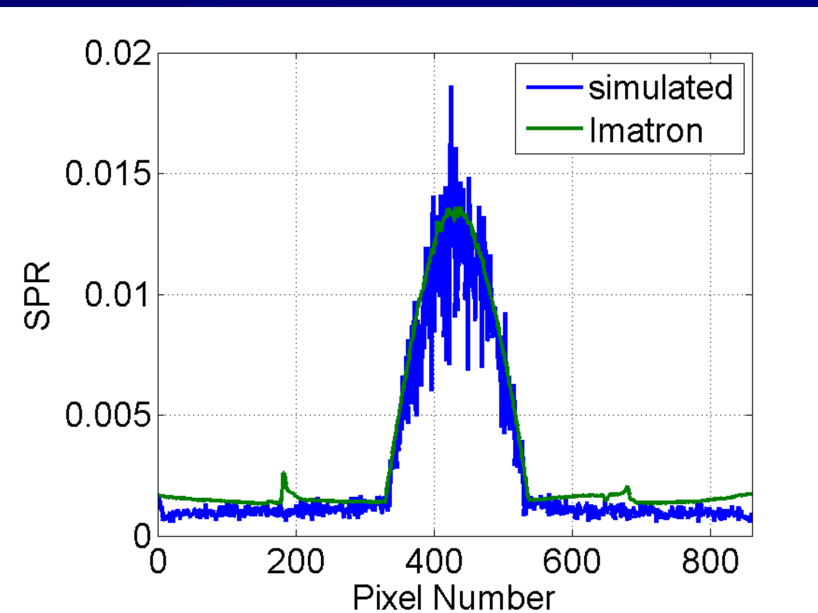
- ● Experiments
- ○ Simulations

Good agreement between mean and std values

Scatter-to-primary ratio



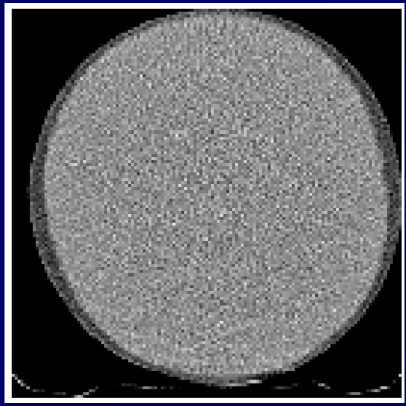
95 kV

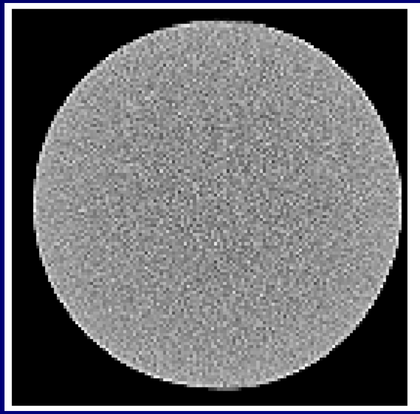


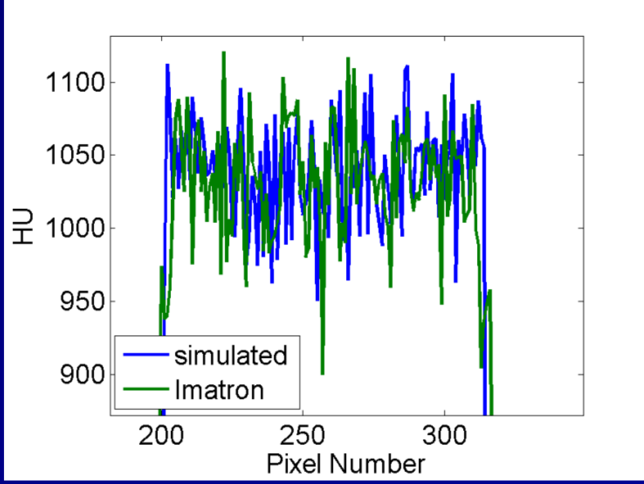
130 kV

Images Reconstructed With Scatter

95 kV







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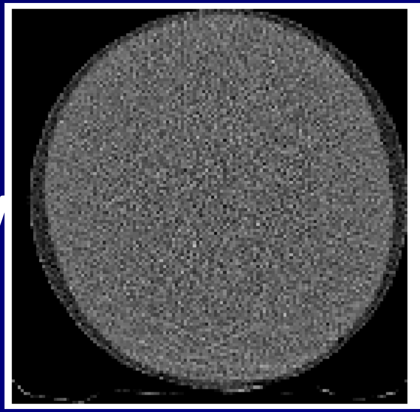
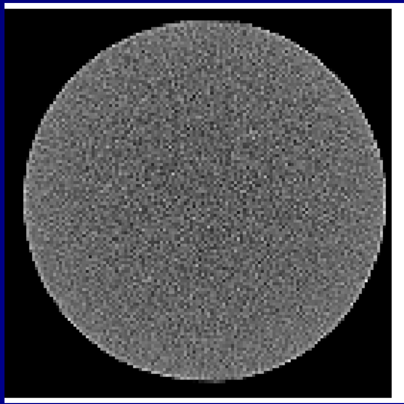
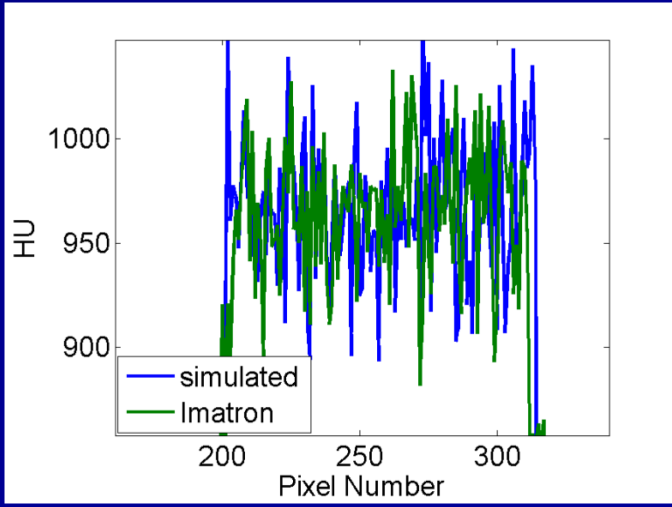


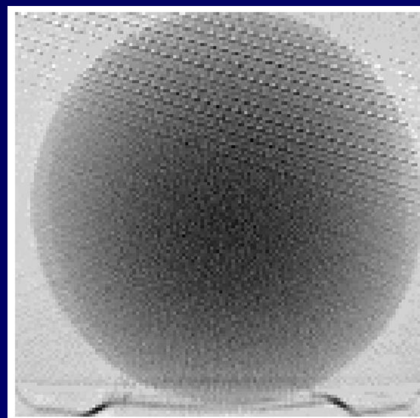


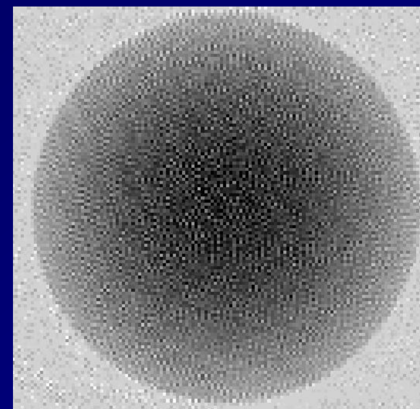


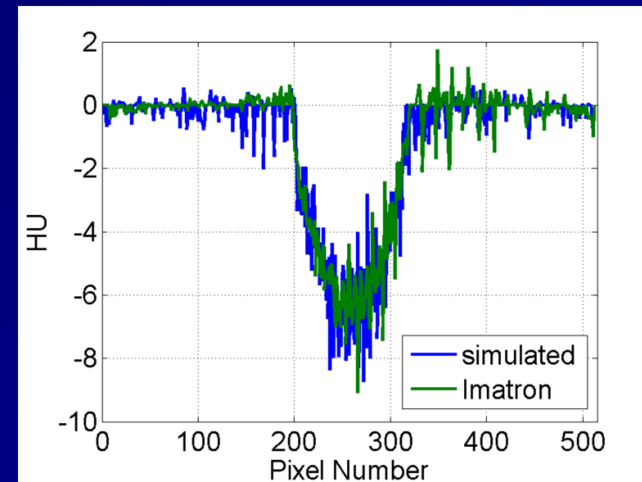
Imatron Simulated Horizontal Profile

Scatter Artifact

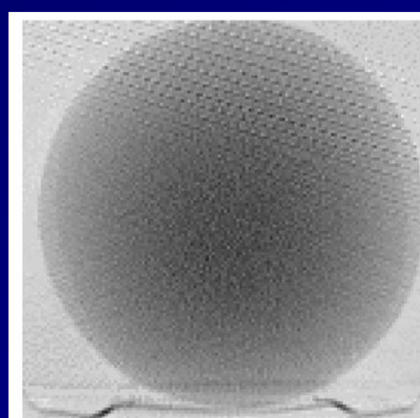
95 kV

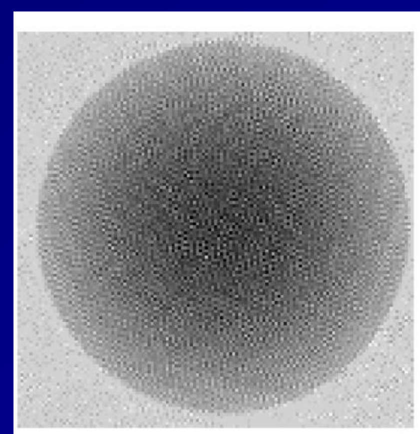


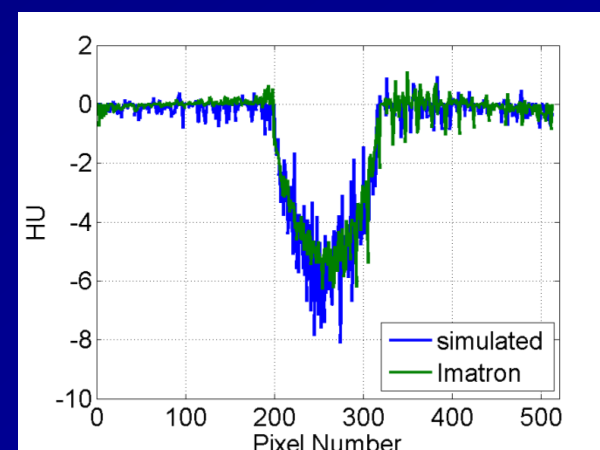




130 kV





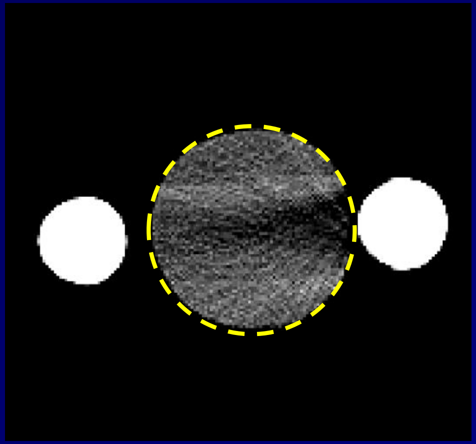


Imatron

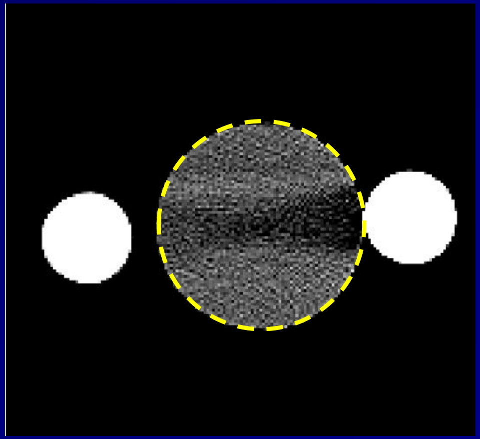
Simulated

Horizontal Profile

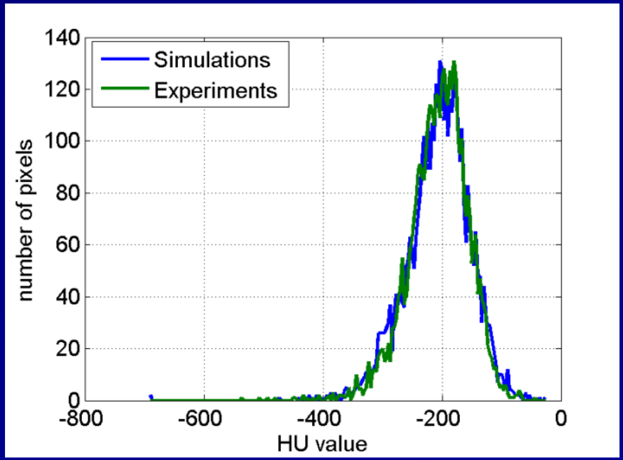
Streak Artifacts



Imatron



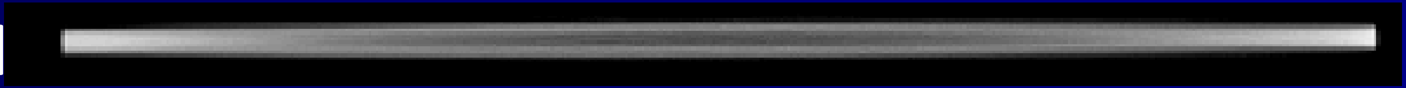
Simulated



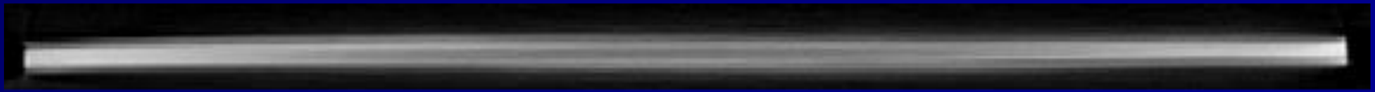
HU Histogram

PVC Sheet Object

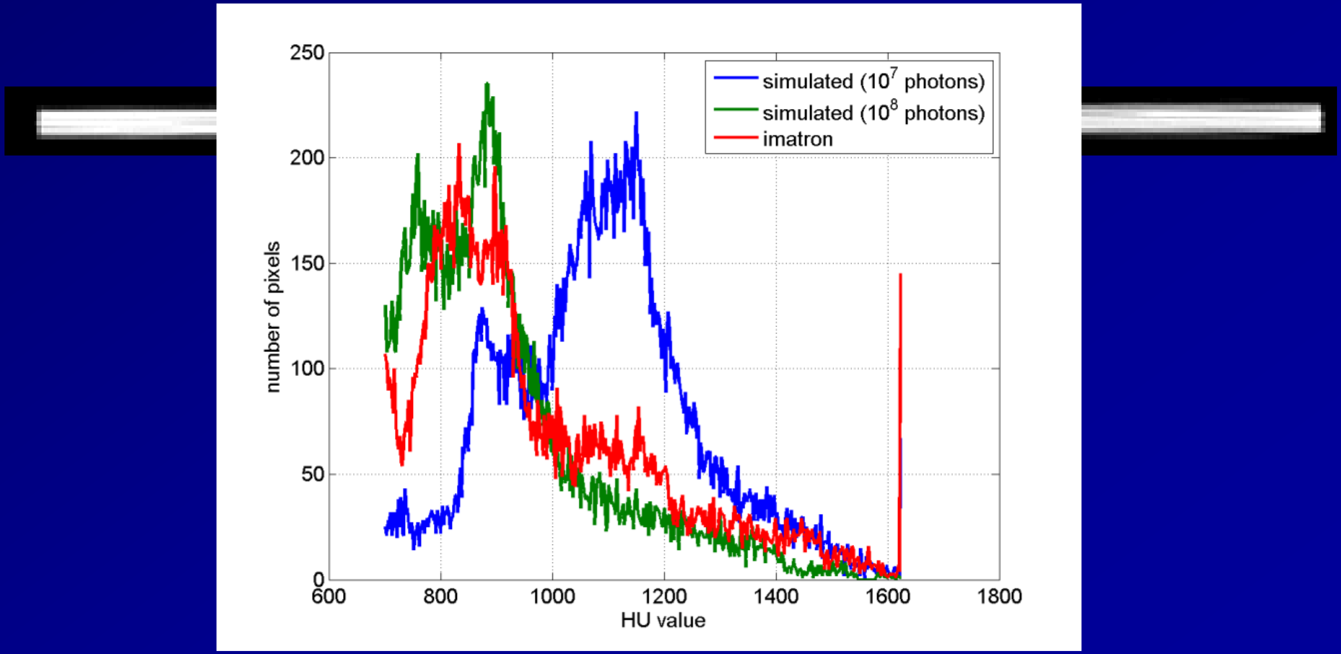
Simulated



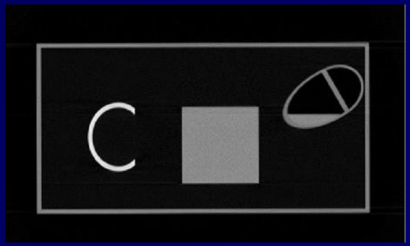
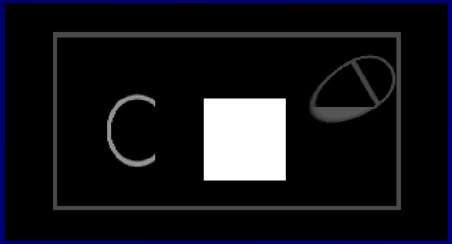
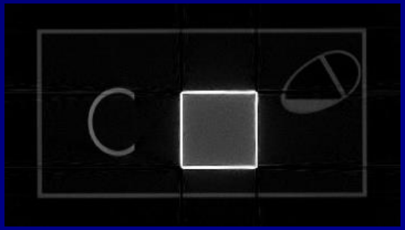
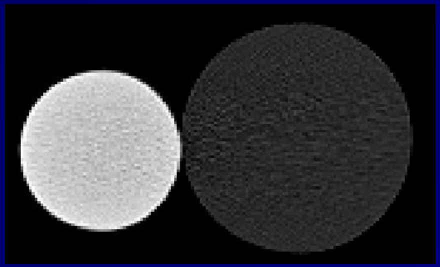
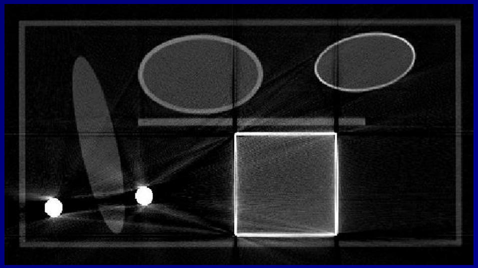
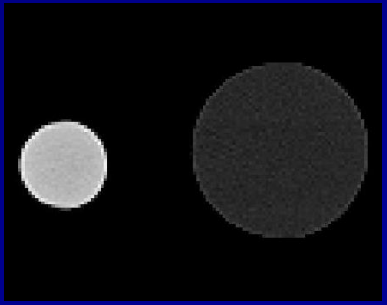
Imatron



Simulated without scatter

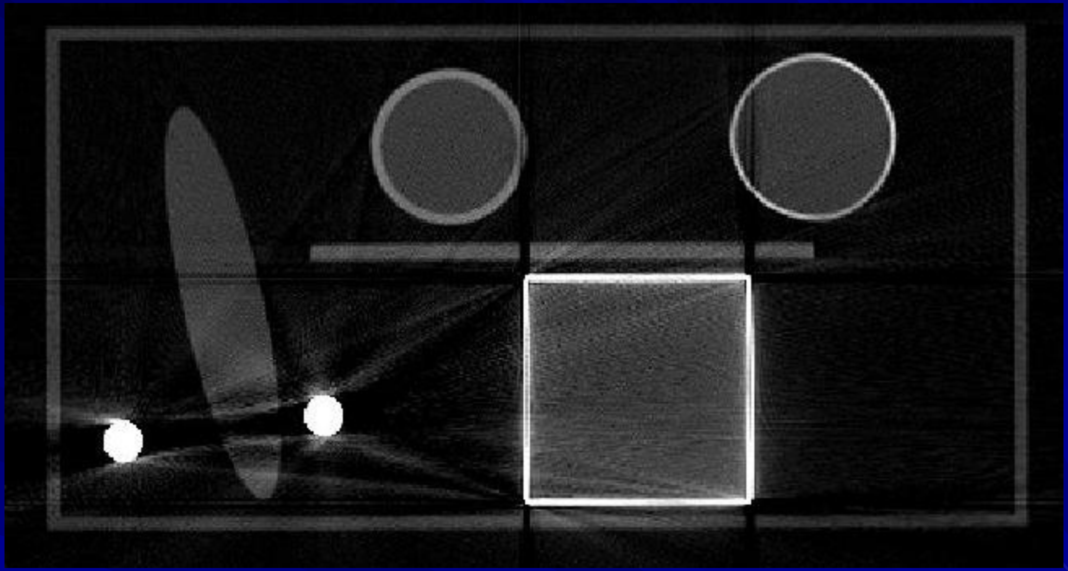


Suitcase Phantoms and Data


Phantom 'Standard'

- Water objects in four configurations / containers
- Rubber sheet object
- Metal artifacts



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Phantom
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{ [ Box: x=0 y=0 z=0  dx= 38 dy= 19 dz=27 ] formula=C8H8 rho=0.1 }


// Text Block
{ [ Box: x=2 y=-2 z=5.5 dx=9 dy=9 dz=12 a_x(0.707,0,0.707)
a_y(0,1,0) ] formula=Al rho=2.699 }
```

Task Order 3: Lessons Learned

- Defining complex objects with primitive shapes is difficult, limited, and time consuming
- Primitive shape definition varies across software packages
  - Forbild, g3d, GEANT all use different definitions
- Scatter must be modeled to have realistic streak/shading artifacts
- Good simulations require detailed information from scanner vendor

DHS SBIR: X-ray Simulation Platform for Explosive Detection Equipment

- Surveyed potential users
  - – 17 responses from 10 companies, 2 national labs
  - – 88% already use simulations, but stated potential for improved tool
  - – Highly ranked user needs for improved tool
    - Graphical User Interface
    - Scatter Modeling
    - Flexibility
    - Speed

TRIPLE RING technologies

DHS SBIR: X-ray Simulation Platform for Explosive Detection Equipment

Proposed Solution: Particle / Ray Interaction Simulation Manager (PRISM)

- Unified user-interface wrapper for existing simulation tools
- Interface for specifying and visualizing simulation
- Open-source architecture that can be linked to numerous existing simulation tools.
- Input from CAD programs
- Accompanied with digital luggage library

TRIPLE RING technologies

DHS SBIR: X-ray Simulation Platform for Explosive Detection Equipment

Phase 2:

- Develop PRISM architecture
- Develop translation layer to interface PRISM to GEANT4
- Develop methods to reduce run time (GPU, variance reduction)
- Develop luggage library
- Validate tool against experiments
- Validate that tool meets user requirements

Parallel efforts for MMW at PNNL and ALERT

Ray Tracing Simulation Tool for Portal-Based Millimeter-Wave Security Systems using the NVIDIA OptiX Ray Tracing Engine

Kathryn Williams

ALERT Center of Excellence

Northeastern University, Boston, MA

Algorithm Development for Security Applications

October 23, 2013

Components to Model

- Transmitter
  - Electromagnetic wavefronts simulated by propagating a collection of rays
- Human Body
  - Triangular mesh
- Ray-Body Intersection
- Receiver Arc Array
  - Field of rays aggregated at discretized receiver

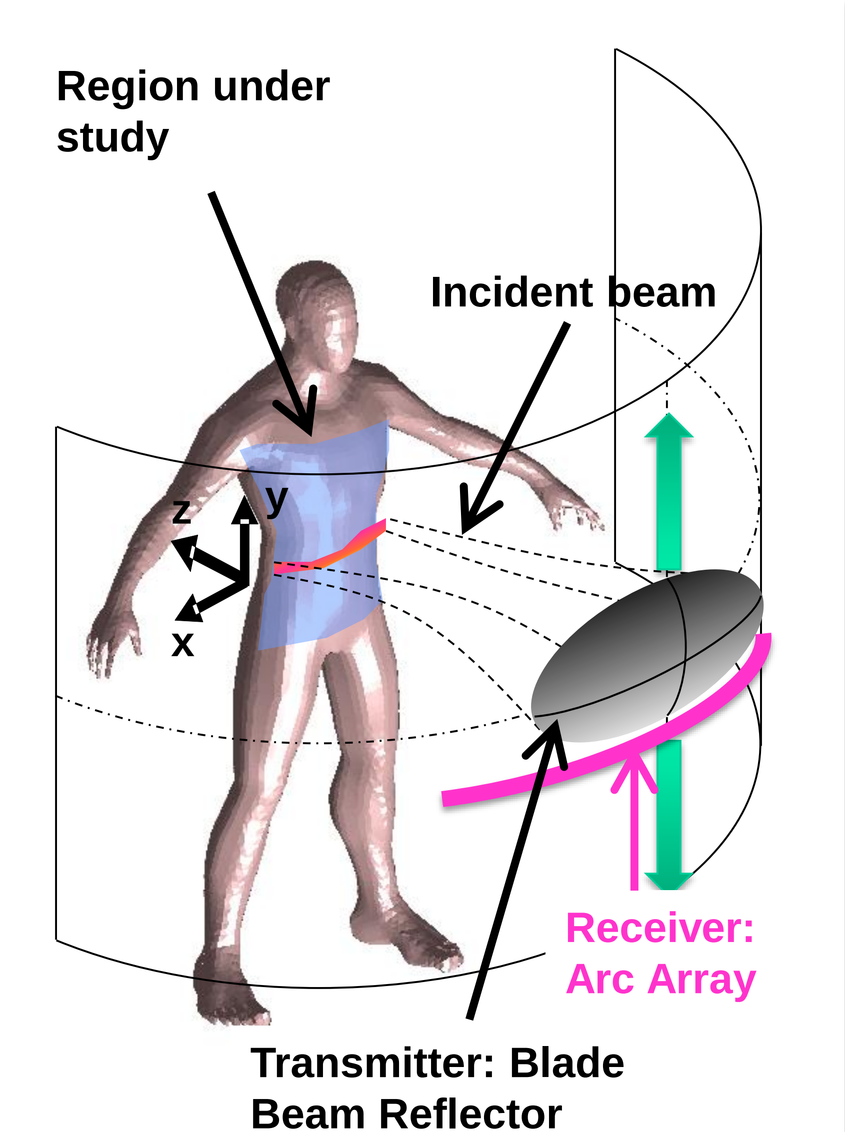

Image courtesy of Yuri Alvarez

Conclusions

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  - Reduced time to market and development costs
  - May obviate prototype development to predict performance
  - Applicable to x-ray CT, transmission, backscatter, diffraction, and MMW
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- Simulated data can match the values, noise, scatter, artifacts of experimental data
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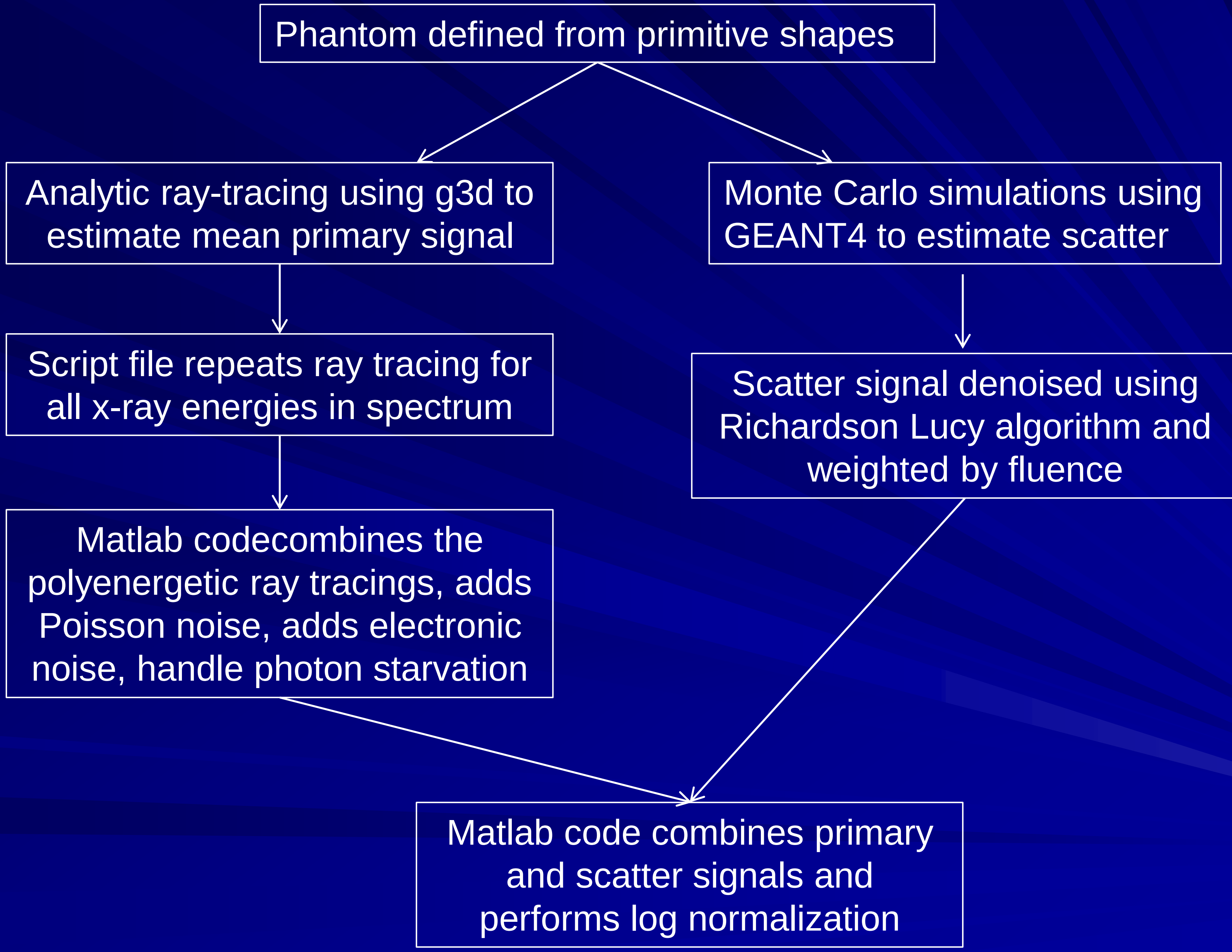
- SBIR project to develop common interface for existing tools
- MMW simulations performed by PNNL and ALERT

EXTRA SLIDES

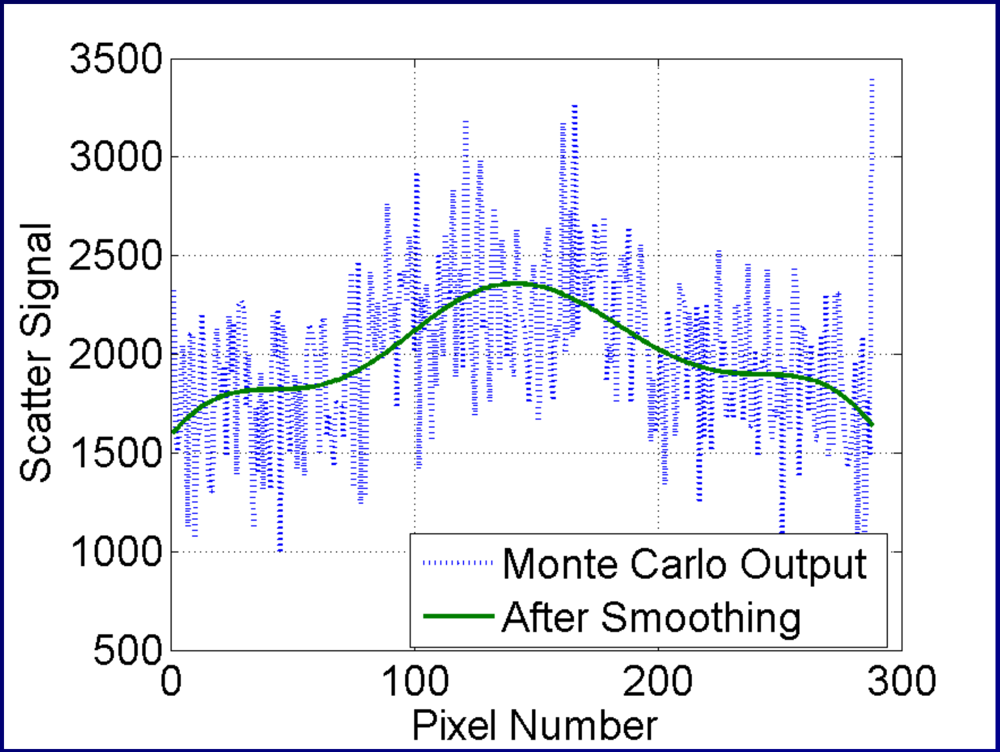


Phantom defined from primitive shapes
Analytic ray-tracing using g3d to estimate mean primary signal
Monte Carlo simulations using GEANT4 to estimate scatter
Script file repeats ray tracing for all x-ray energies in spectrum
Scatter signal denoised using Richardson Lucy algorithm and weighted by fluence
Matlab codecombines the polyenergetic ray tracings, adds Poisson noise, adds electronic noise, handle photon starvation
Matlab code combines primary and scatter signals and performs log normalization

Scatter Validation

- Combined simulated ray tracing and Monte Carlo images of the water_2000ml phantom
- Compared simulated reconstructed images (including scatter) to Imatron images reconstructed without scatter correction
- Compared the scatter artifact (image_with_scatter – scatter_corrected_image) for both simulated and Imatron data

Smoothing of Monte Carlo Output



*The amount of smoothing is adjustable

After smoothing, the scatter signal is scaled to adjust for differences in fluence in the MC simulations compared to ray-tracing. Poisson noise is added to the scaled scatter signal , which is then added to the ray tracing generated primary signal