

Realistic simulations of baggage

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So What? Who Cares?

- 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, MMW
- Previous work demonstrated that simulated data can match the values, noise, scatter, artifacts of experimental CT data
- SBIR project is developing PRISM software for easy-to-use interface to existing simulation tools
- Two components to EDS simulations:
 - Accurate physics modeling → Solved
 - Modeling numerous, complex suitcases → Open problem
- Computer animation tools can solve problem of modeling numerous, complex suitcases configurations
- May be able to use simulated bag set to obviate qualification testing
- May be able to simulate explosives that are dangerous to synthesize and handle



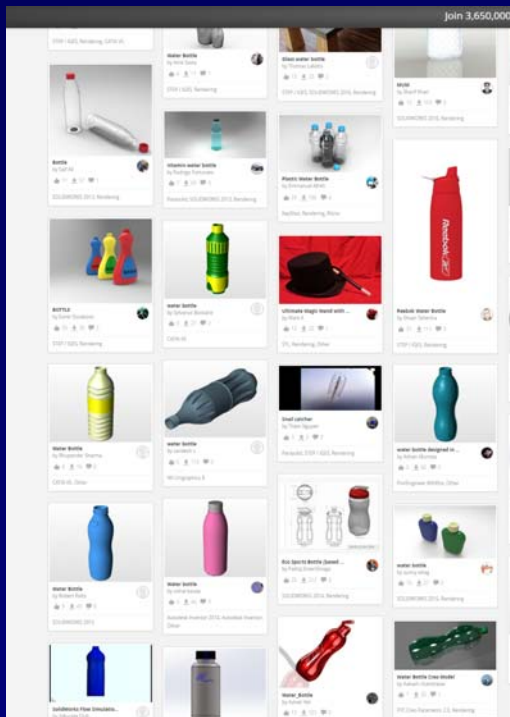
Why now?

- Access to experimental test data is limited
- Validated simulation tools exist
- Computing power is readily available
- Challenge: Modeling realistic suitcases with threats in numerous configurations
 - Concealment, clutter
- Manual modeling of suitcase configurations is labor intensive
- Deterministic packing algorithm is challenging
- Software tools from the computer graphics industry can be used to simulate numerous suitcase configurations

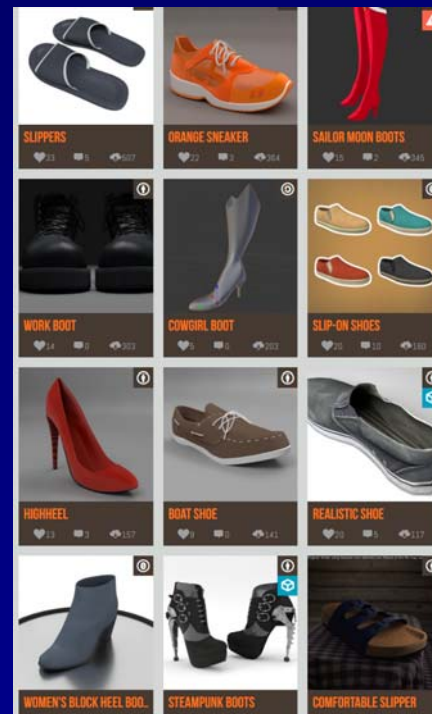
Suitcase Packing Animation Overview

- Define mesh file objects to be packed
- Simulate dynamics of dropping objects into suitcase
 - Rigid body, elastic deformations, collisions
- Complex objects that are composites of multiple STL files can be assigned to move together
- Output STL object configurations after packing for use in EDS simulations
- Example animation software packages: Blender, Unity

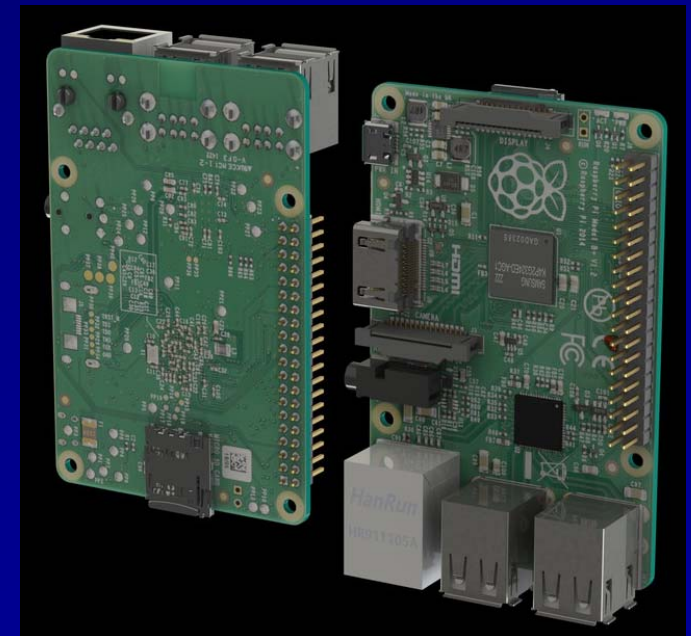
Mesh Object Models



GrabCAD results for a search of 'water bottle'



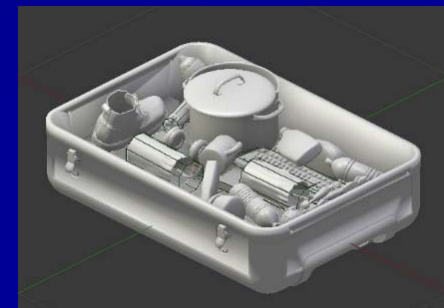
Blendswap results for a search of 'shoe'



CAD model of Raspberry Pi board available on GrabCad

Pilot study: Packing Animation Workflow

- Select suitcase container from predefined library
- Randomly pick from a library of objects
- Seed objects above suitcase with at random locations and orientations
- Assign mass to each object
- Run Blender animation engine (rigid body)
- Remove objects that fall outside of the suitcase
- Export STL files for each object at end of animation

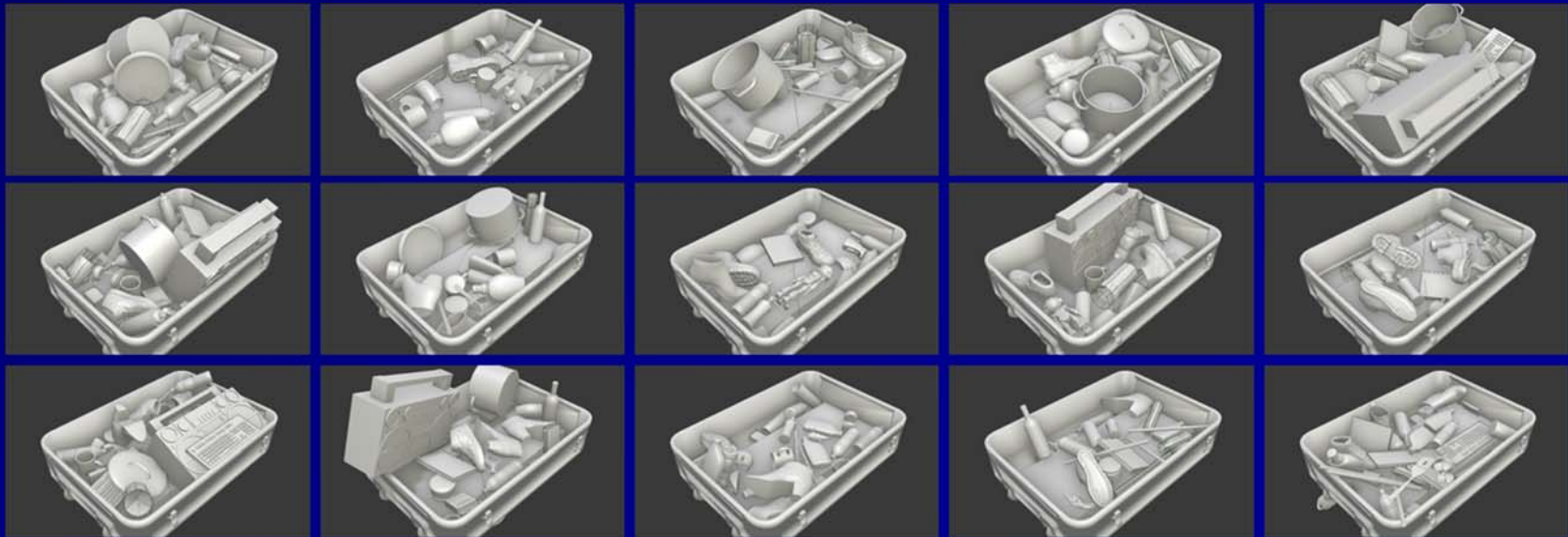


Suitcase Packing Animation



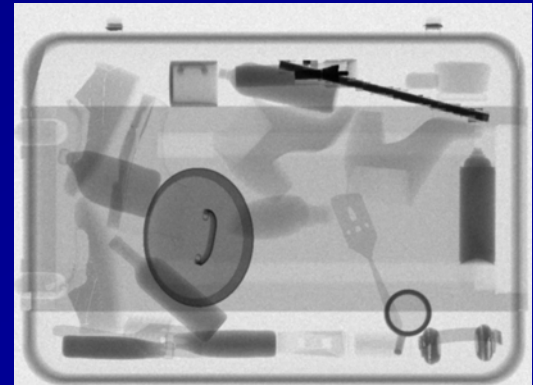
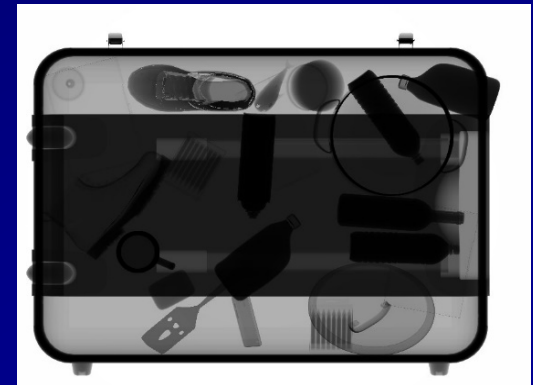
Pilot Study of Suitcase Packing Animation

- Developed python script to automate suitcase packing workflow in Blender
- Generated 15 suitcase models
 - 40 seconds per suitcase using 4 CPUs



PRISM x-ray simulation software

- Collection of STL files output by suitcase packing can be input to EDS simulation software
- Particle / Ray Interaction Simulation Manager (PRISM)
- Funded by DHS SBIR
- Unified user-interface wrapper for existing X-ray simulation tools
- Models ray tracing, scatter, detector effects



Next Steps for Packing Animation

- Model elastic objects that can fill voids between other objects (clothing, foam)
- Drop objects into suitcase individually using automated approach similar to humans
- Close suitcase
- Resolve issues that can occur when moving complex composite objects

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Acknowledgments

Triple Ring Technologies

Tobias Funk

Daniel Badali

Marquette University Visualization Lab (MARVL)

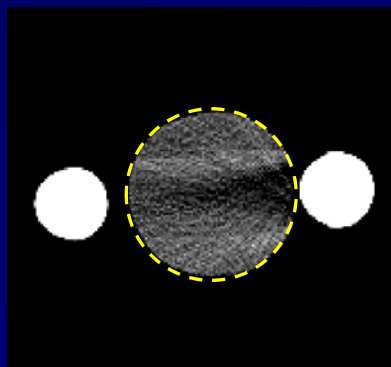
Chris Larkee

John LaDisa

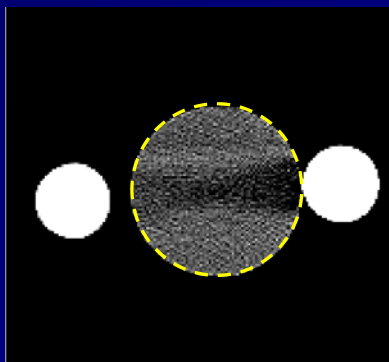
DHS SBIR D15PC00024, “X-Ray Simulation Platform for Explosive Detection Equipment”

EXTRA SLIDES

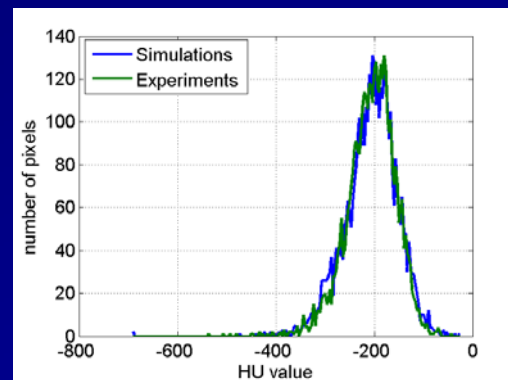
Streak Artifacts



Imatron



Simulated



HU Histogram

PVC Sheet Object

Simulated



Imatron



Simulated
without
scatter



PVC Sheet Object

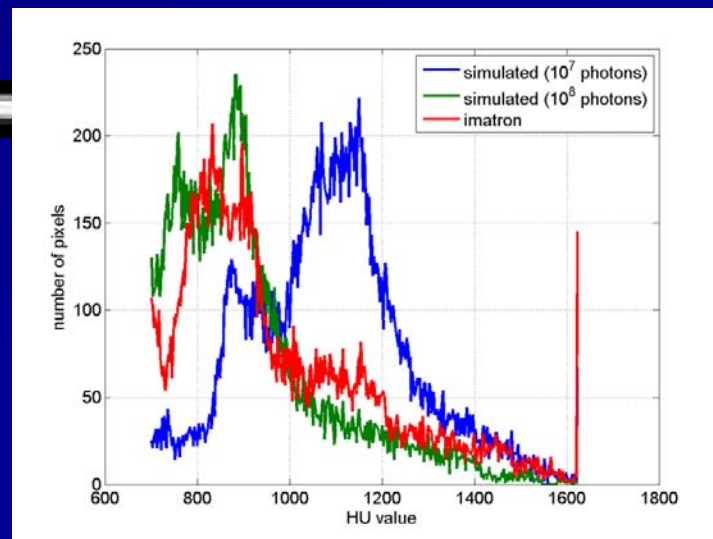
Simulated



Imatron



Simulated
without
scatter



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

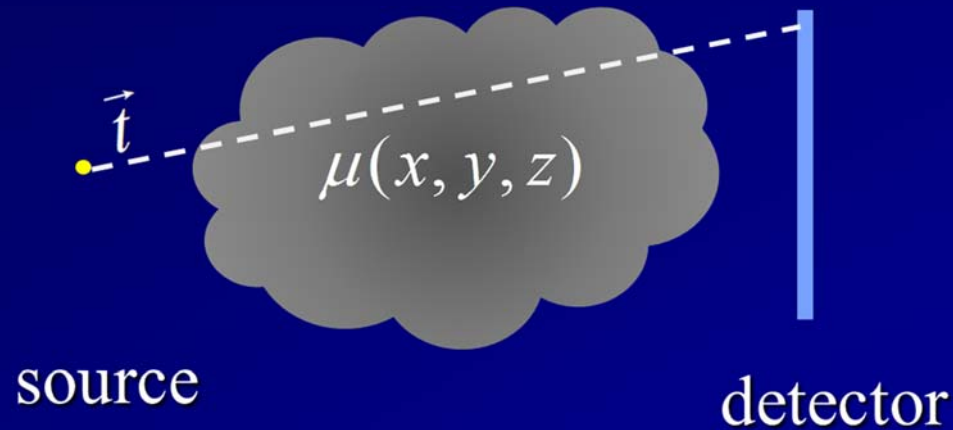
Goals for Simulation Tools

- 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

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

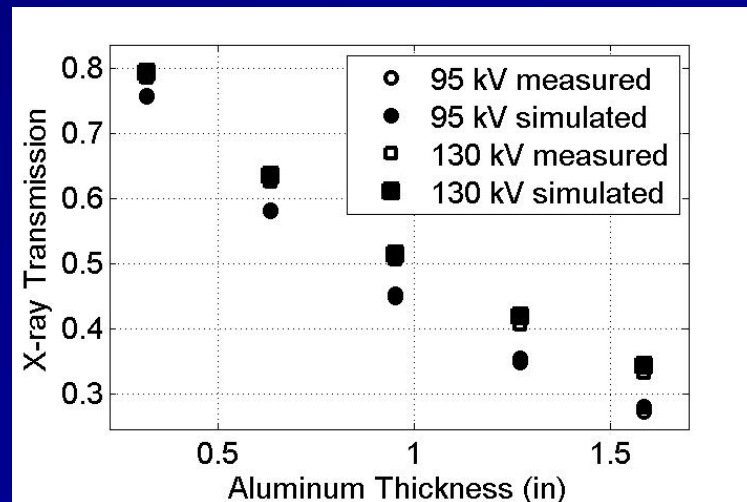
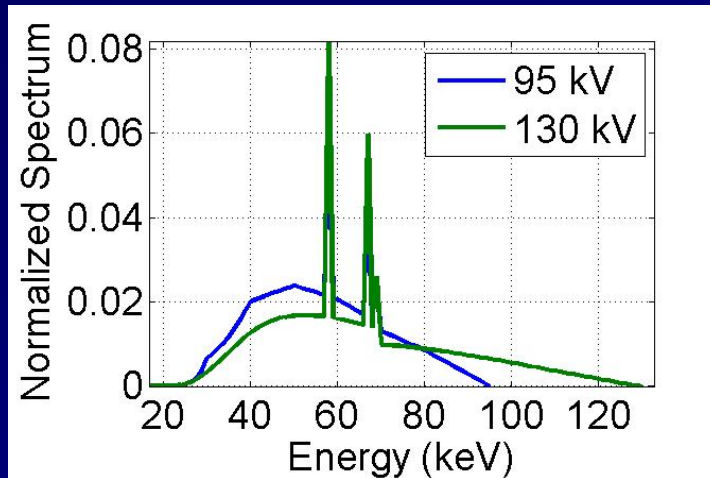
Task Order 3 Methods

- 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

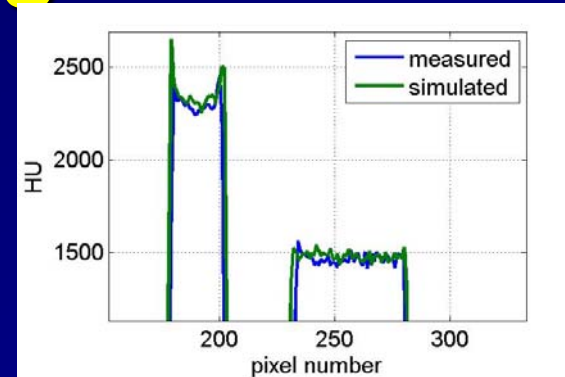
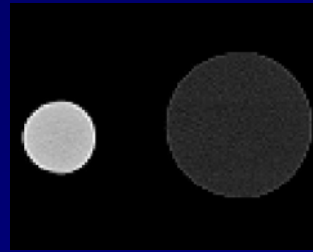
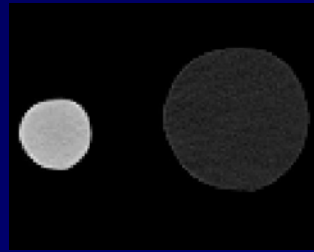
- Match the Imatron spectra
- Match the Imatron fluence
- Match the Imatron geometry
- Match the reconstructed HU mean and standard deviation
- Match the scatter level and artifacts

X-ray Spectra

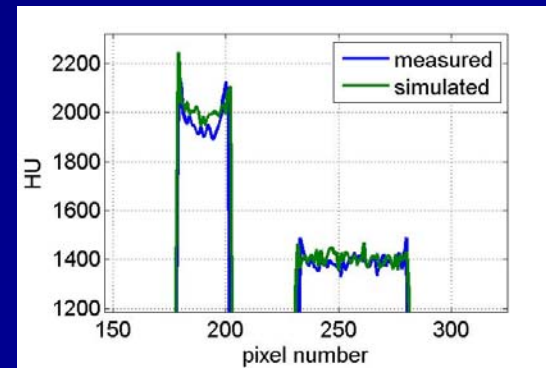
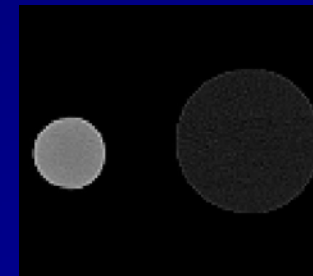
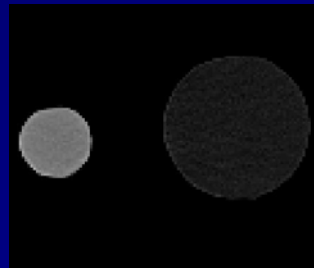


Graphite and Magnesium

95 kV



130 kV



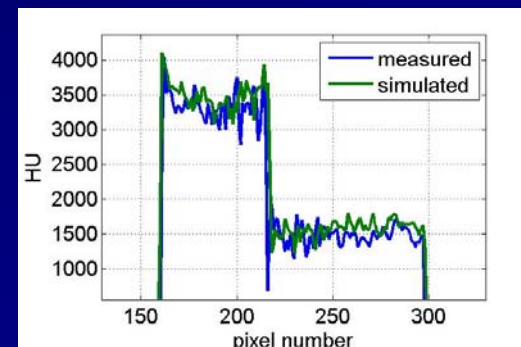
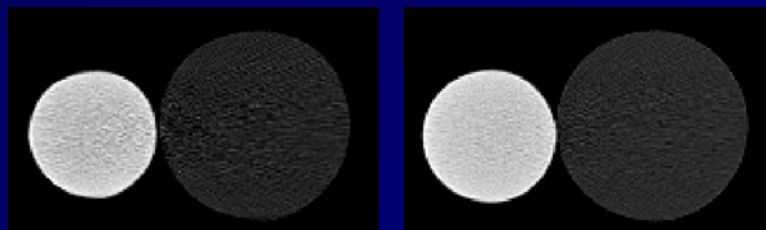
Measured

Simulated

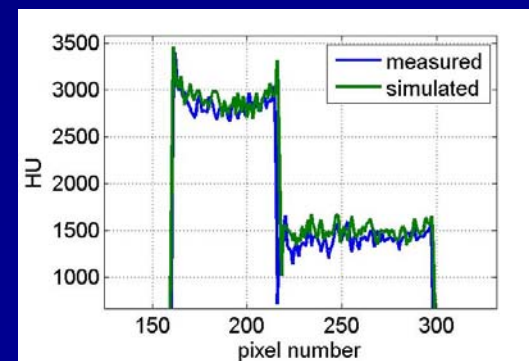
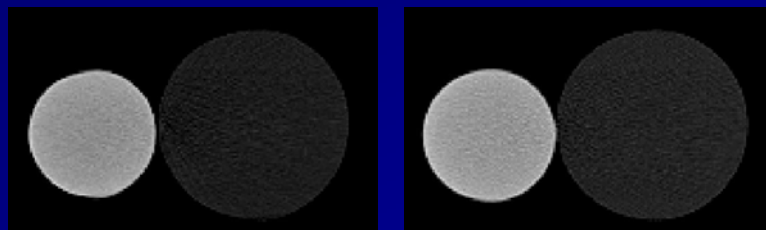
Horizontal Profile

Graphite and Aluminum

95 kV



130 kV

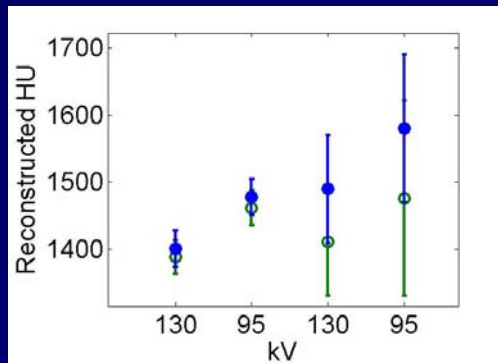


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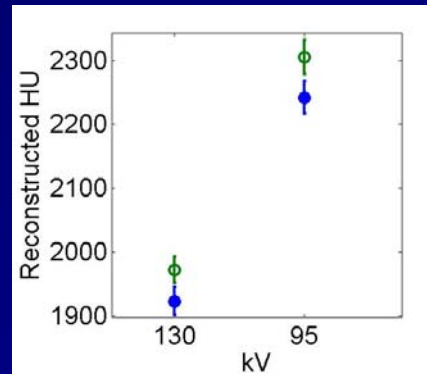
Simulated

Horizontal Profile

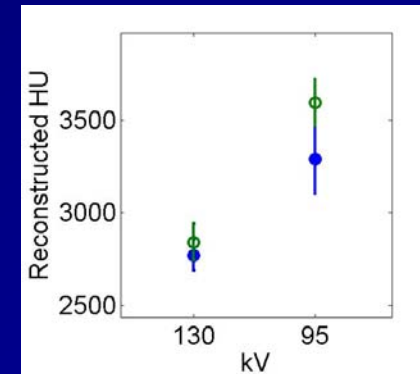
Reconstructed HU Values



Graphite



Magnesium

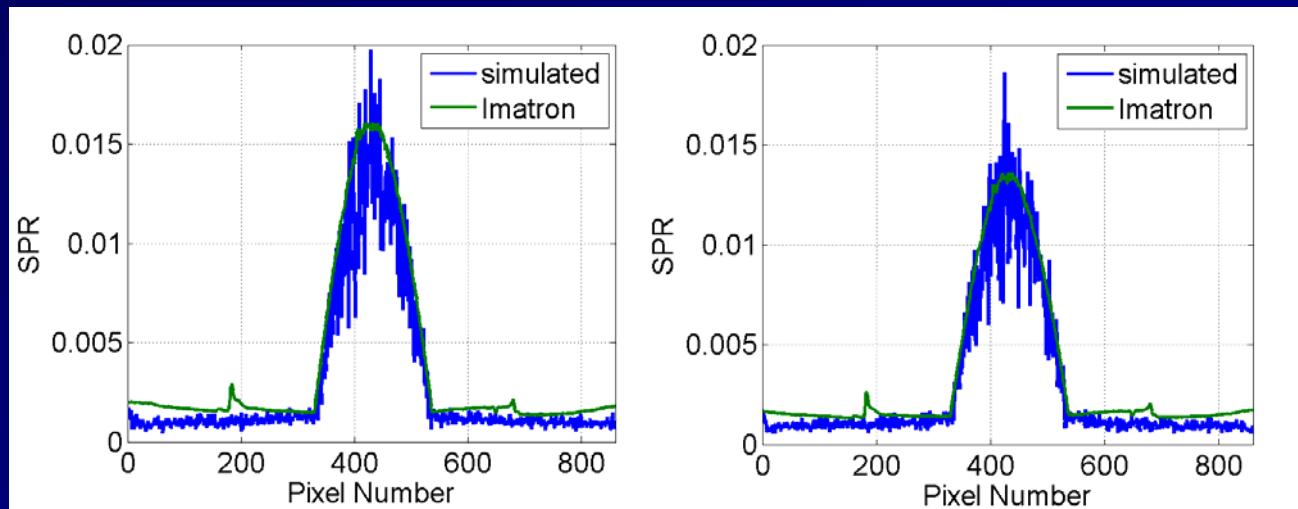


Aluminum

Good agreement between mean and std values

- Experiments
- Simulations

Scatter-to-primary ratio

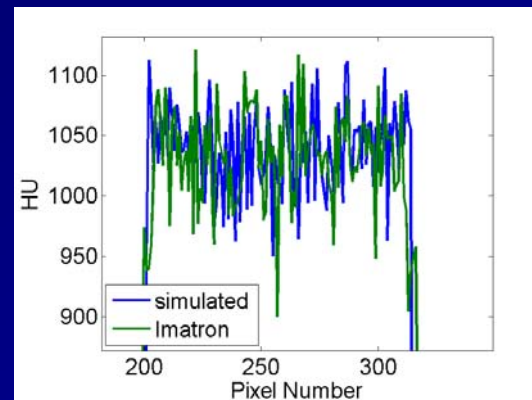
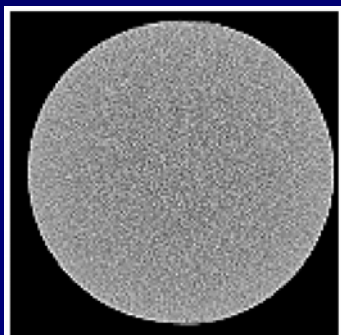
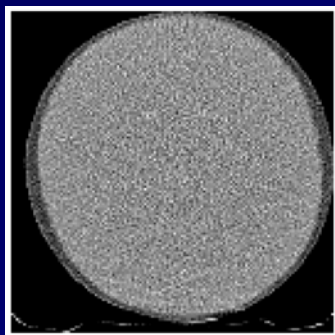


95 kV

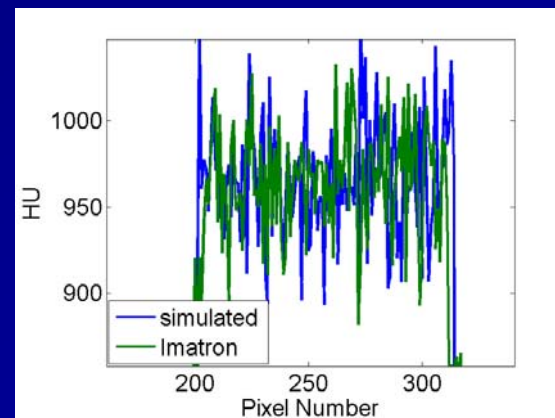
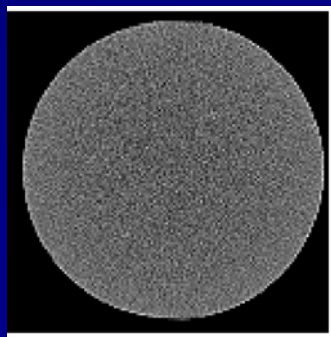
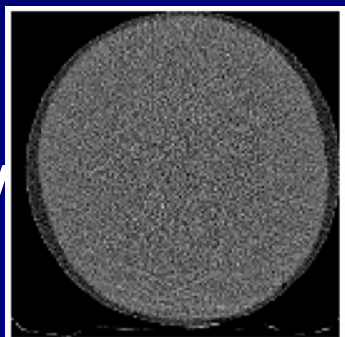
130 kV

Images Reconstructed With Scatter

95 kV



130 kV



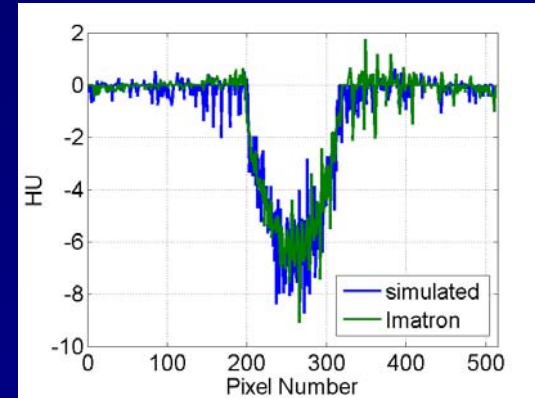
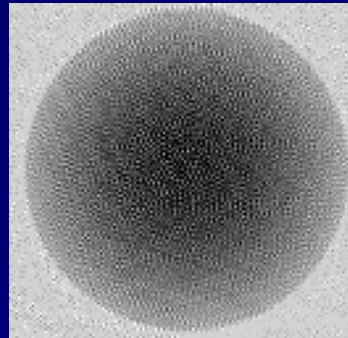
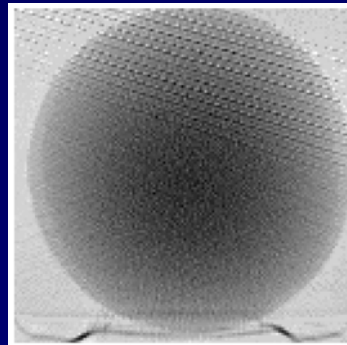
Imatron

Simulated

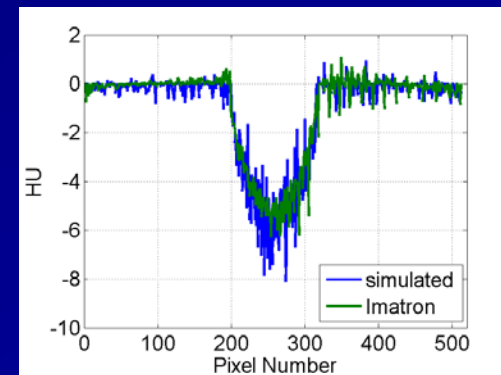
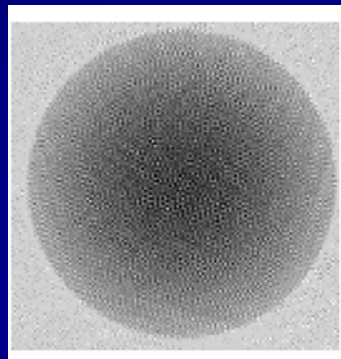
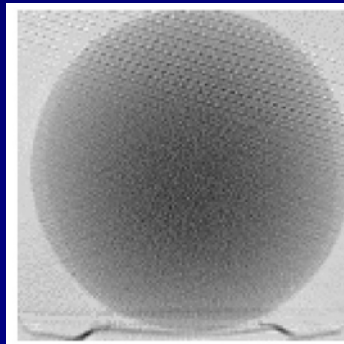
Horizontal Profile

Scatter Artifact

95 kV



130 kV



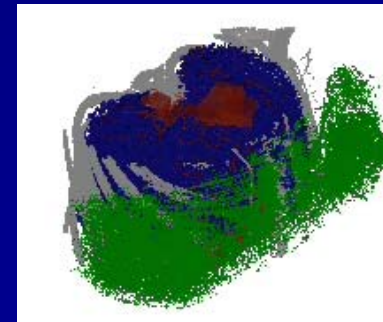
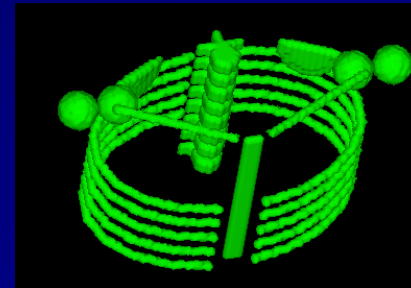
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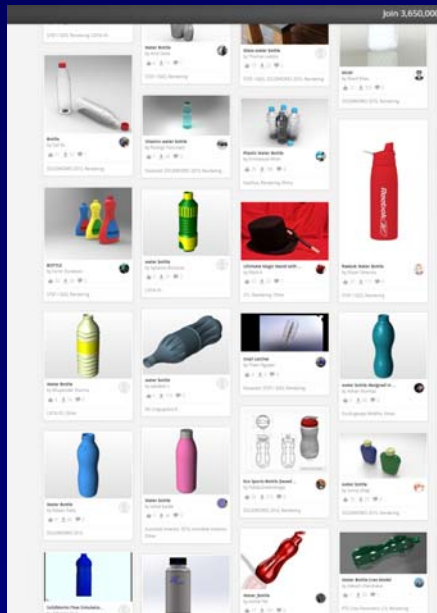
Horizontal Profile

Object Modeling Approches

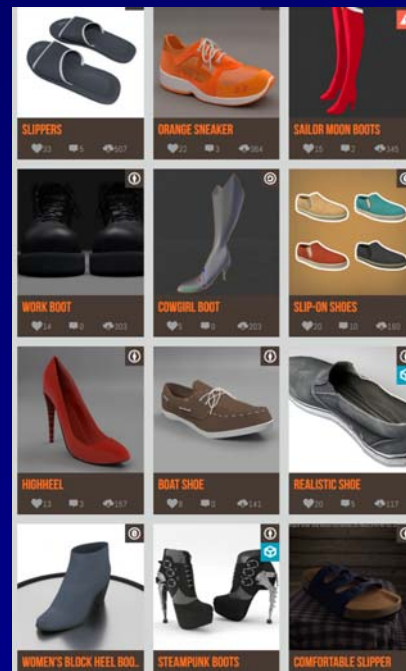
- Primitive shapes
 - Defined in text file
 - Difficult to model complex objects
- Voxelized models
 - Can model texture
 - Require large memory
 - Partial volume issues
- Polygonal meshes
 - Standard CAD output
 - Can model complex shapes and assemblies



Mesh Object Models



Grabcad results for a search of 'water bottle'



Blendswap results for a search of 'shoe'



CAD model of Raspberry Pi board available on GrabCad