Decision Sciences
Security Solutions

Cosmic-Ray Air Cargo Screening

Multi-Mode Passive Detection System (MMPDS)
Detection of WMD and Contraband

ADSA09

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Michael J. Sossong, Ph.D.

DSIC Vice President for R&D

Conclusions

- Cosmic-ray produced charged particles are useful for scanning for both nuclear and conventional explosives
  - Charged particles provide useful signatures for explosives detection.
  - Acceptable scan times (Shorter than you're thinking)
  - 3D imaging reduces difficulty with clutter.
  - No accelerator required (but could be applied).
- Charged particle imaging is a fertile ground for research.

Team

- Michael Sossong – Particle Physicist
- Sankaran Kumar – Physicist
- Gary Blanpied – Particle Physicist
- Priscilla Kurnadi – Particle Physicist
- Andre Lehovich – Medical Imaging Mathematician
- Sean Simon – Particle Physicist
- Joel Kindem – Medical Imaging Physicist
- Weidong Luo – Medical Imaging Physicist
- Chuanyong Bai – Medical Imaging Physicist
- Shawn McKenney – Algorithms and Software
- Limited University/National Lab Collaboration

Development History

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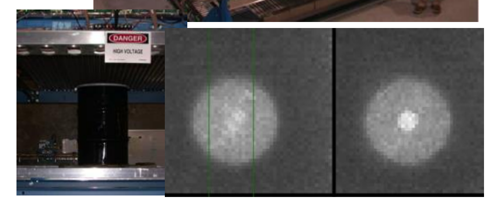
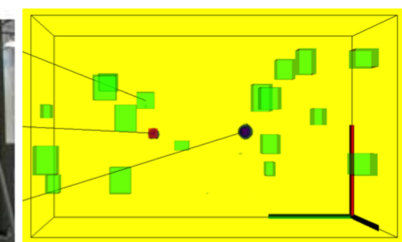
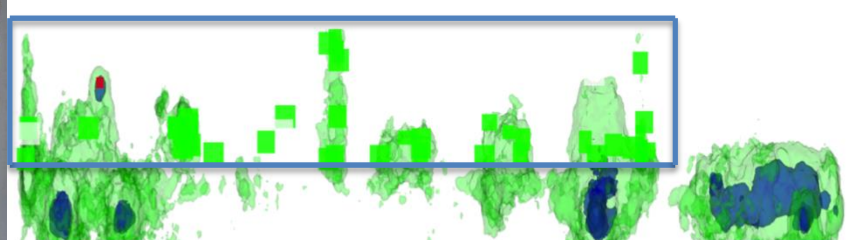
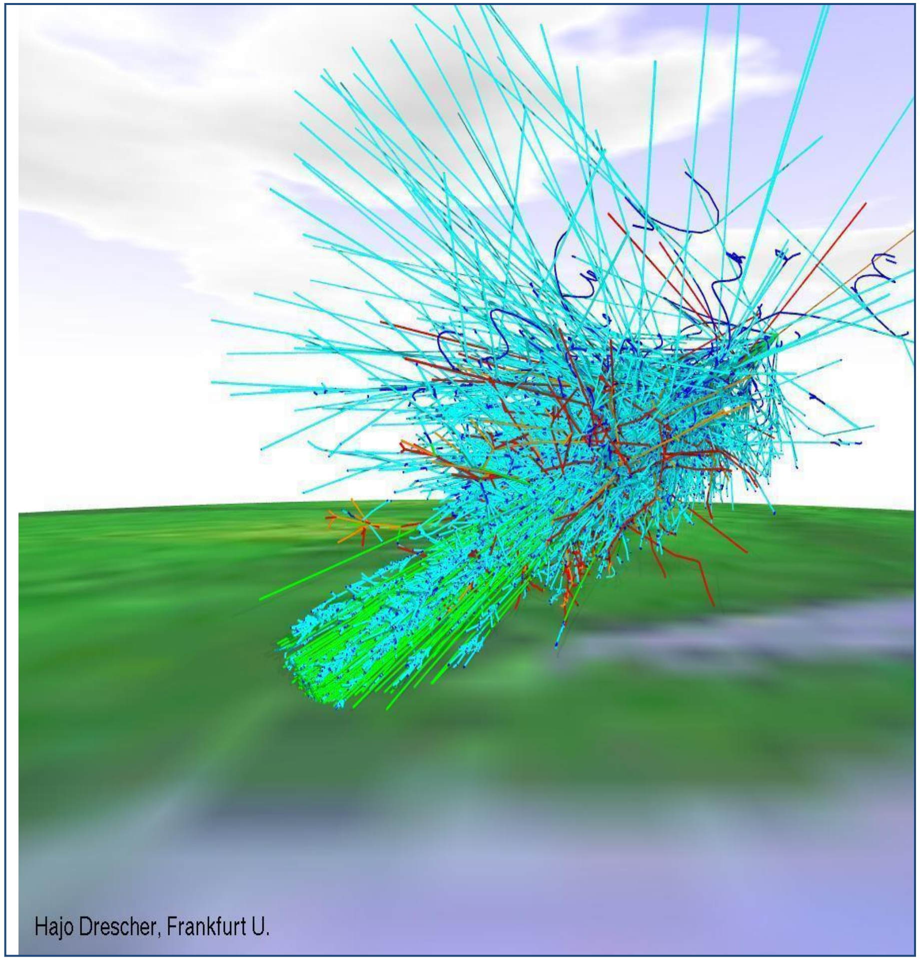
- Technology invented at Los Alamos National Laboratory (LANL)
  - Early funding from LDRD, NA-22, DTRA, DNDO
- DSIC begins funding LANL development in 2006
  - Completely privately funded
- First system demonstrated at DSIC in 2009
  - Independent testing
- First truck scanner constructed at DSIC in 2011
- First port deployment at Freeport Container Port in Bahamas 2012
- Work begins on explosives detection, 2012
- US Government (DNDO) (Nuclear) characterization ongoing
  - Expected completion Q2, 2014





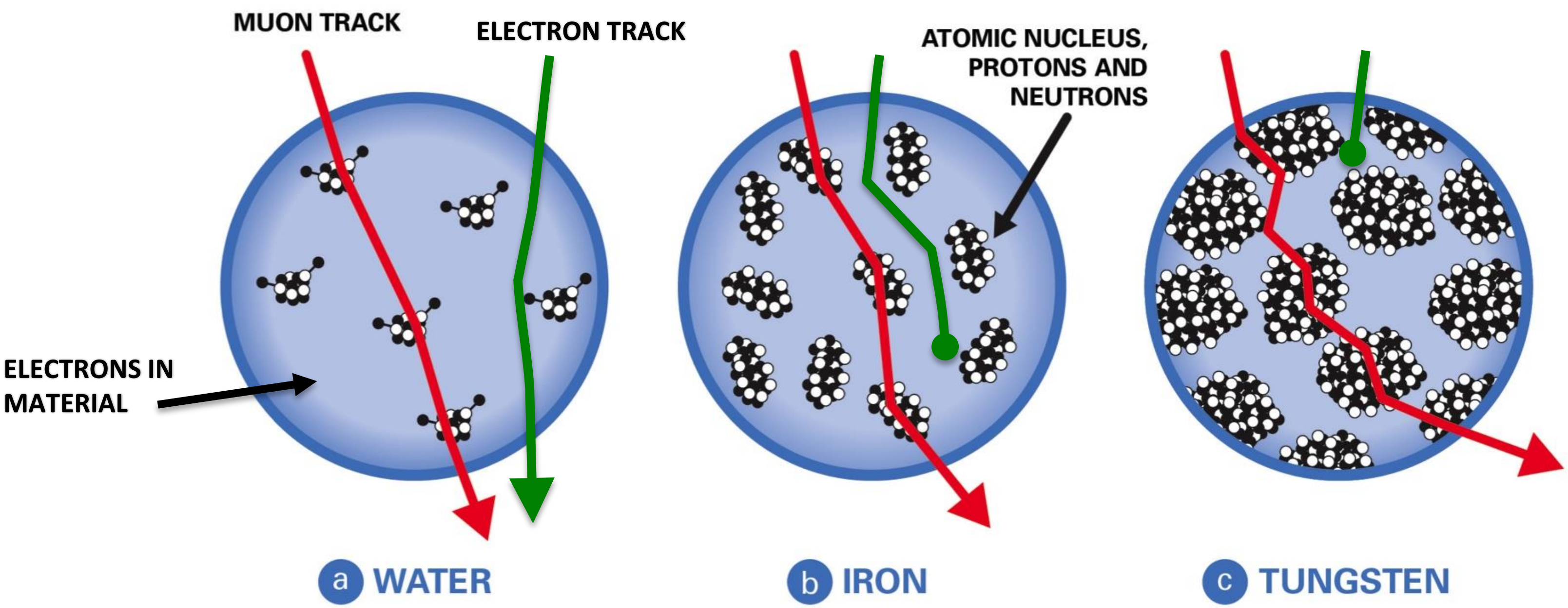


Cosmic Ray Generated Charged Particles



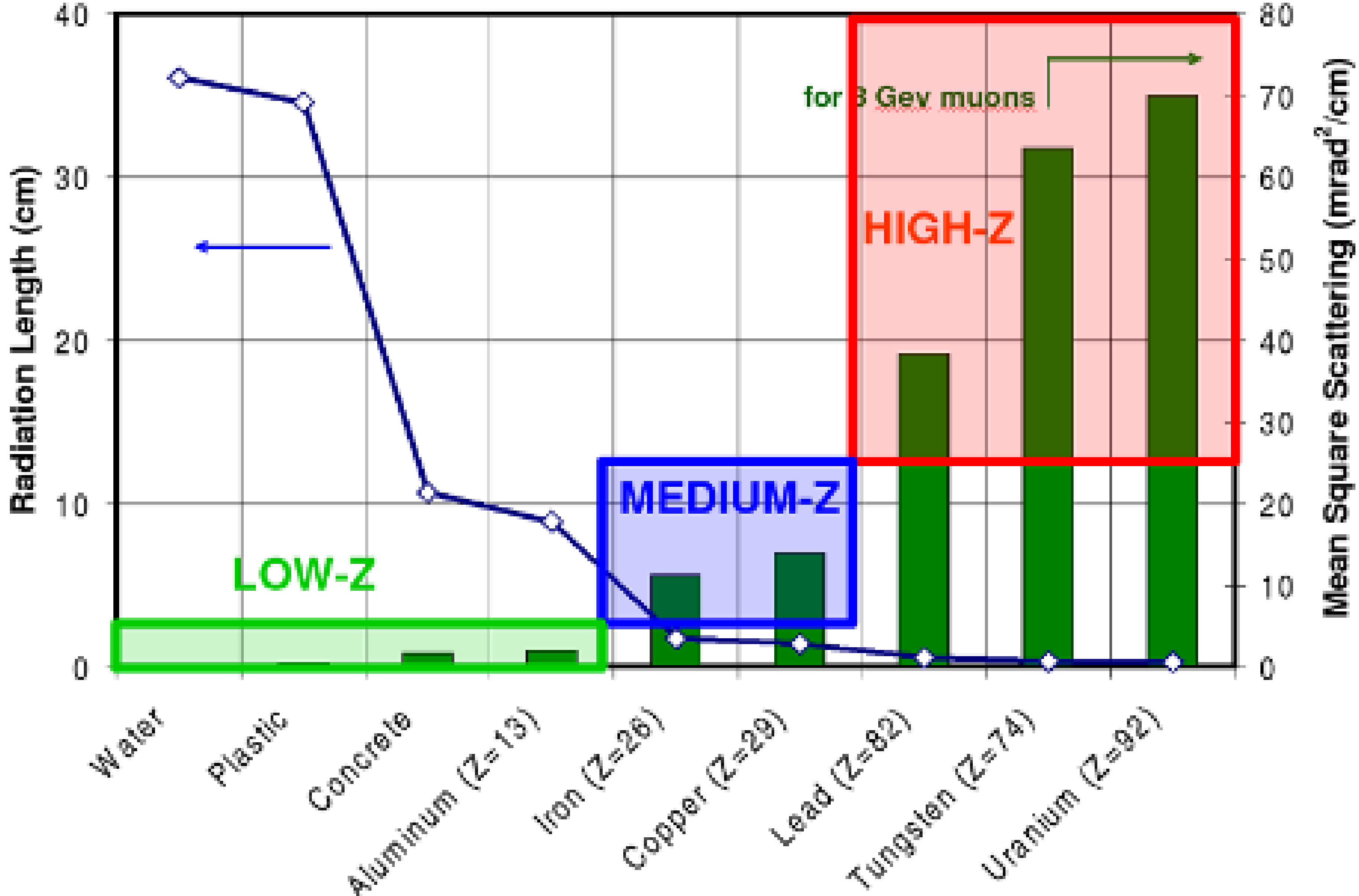
- High energy protons interact with upper atmosphere producing showers of secondary particles
  - Muons:
    - Long lived (~60 µs or 60,000 feet)
    - Highly penetrating
      - Heavy (200x mass of electron)
      - Mean energy 3 GeV
      - No nuclear interaction
    - 100/liter/minute
  - Electrons:
    - Less penetrating than muons
    - 25/liter/minute
- Distributed with $\cos^2$ off-zenith (37° mean)

Charged Particle Interactions



- Scattering is interaction with nuclear charge
- Stopping is due to energy loss to electrons in material
- Muons primarily penetrate and are used for scattering
- Electrons stop much more readily and are useful for discriminating low-Z materials

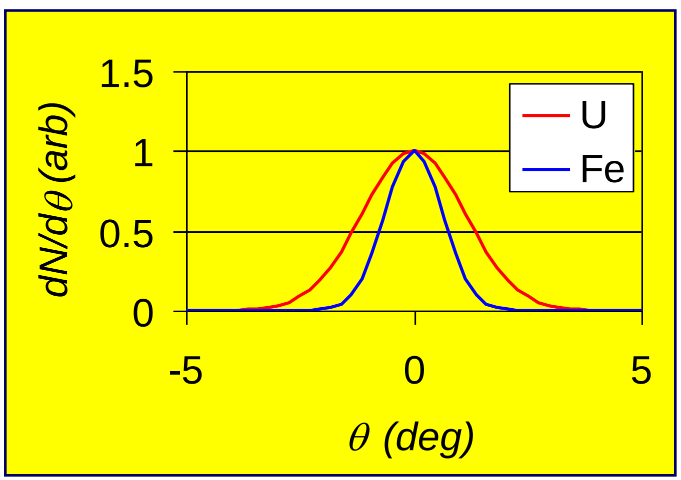
Muon Scattering Signature



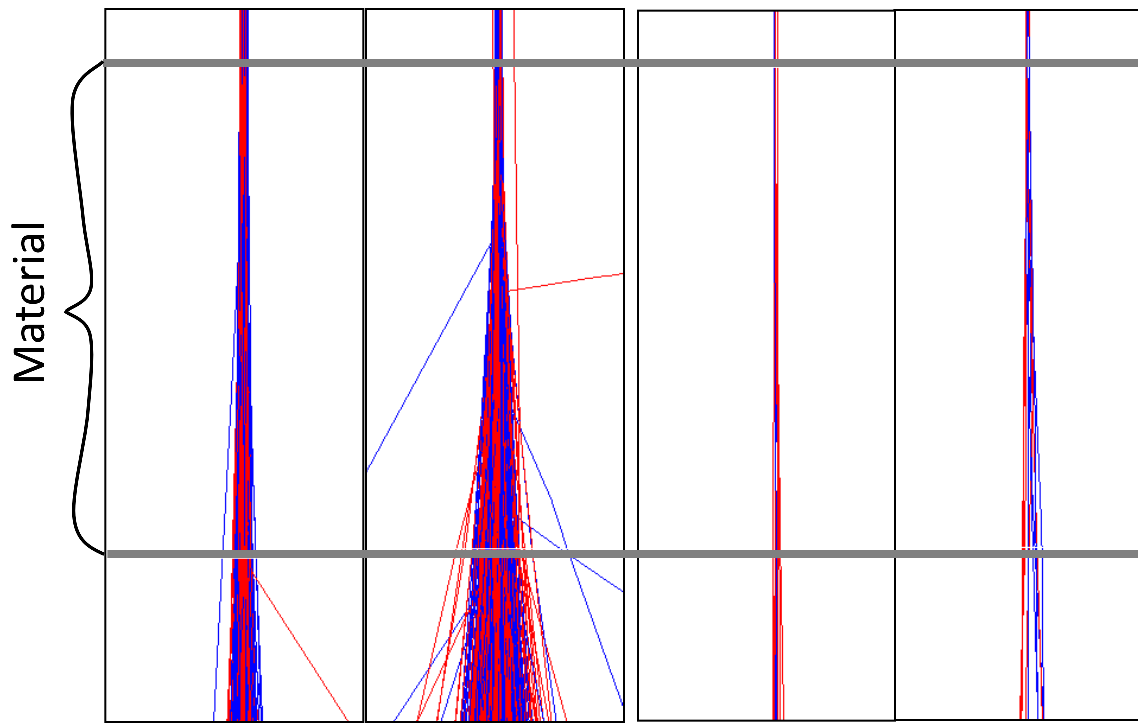
Multiple Coulomb Scattering

$$\frac{dN}{d\theta_x} = \frac{1}{\sqrt{2\pi}\,\theta_0} e^{-\frac{\theta_x^2}{2\theta_0^2}}$$

$$\theta_0 = \frac{13.5}{p\beta}\sqrt{\frac{x}{X_0}}$$



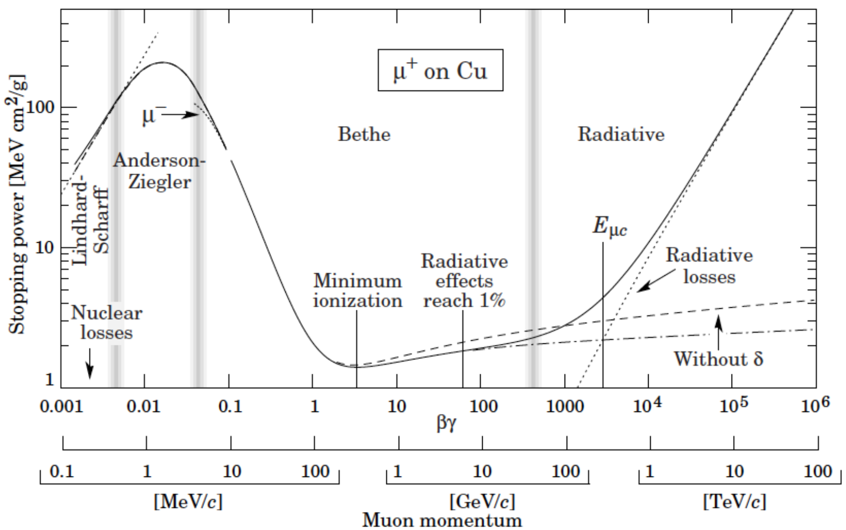
GEANT simulation of Iron and Uranium Plates			
1000 Muons		10 Muons	
Iron	Uranium	Iron	Uranium

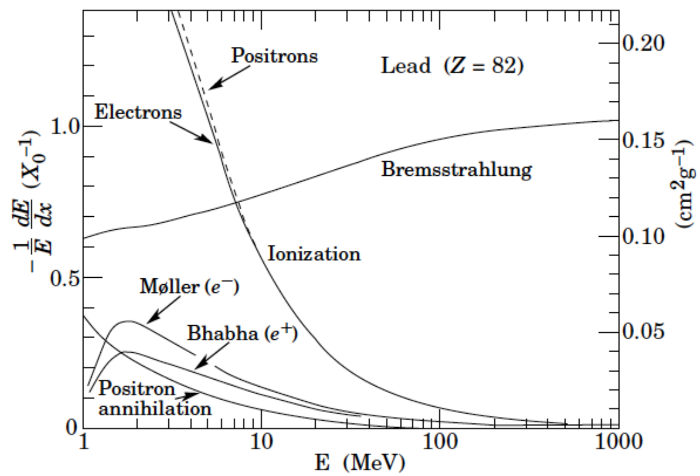


As few as 10 Muons Provides 95% Discrimination (known momentum)

Charged Particle Attenuation

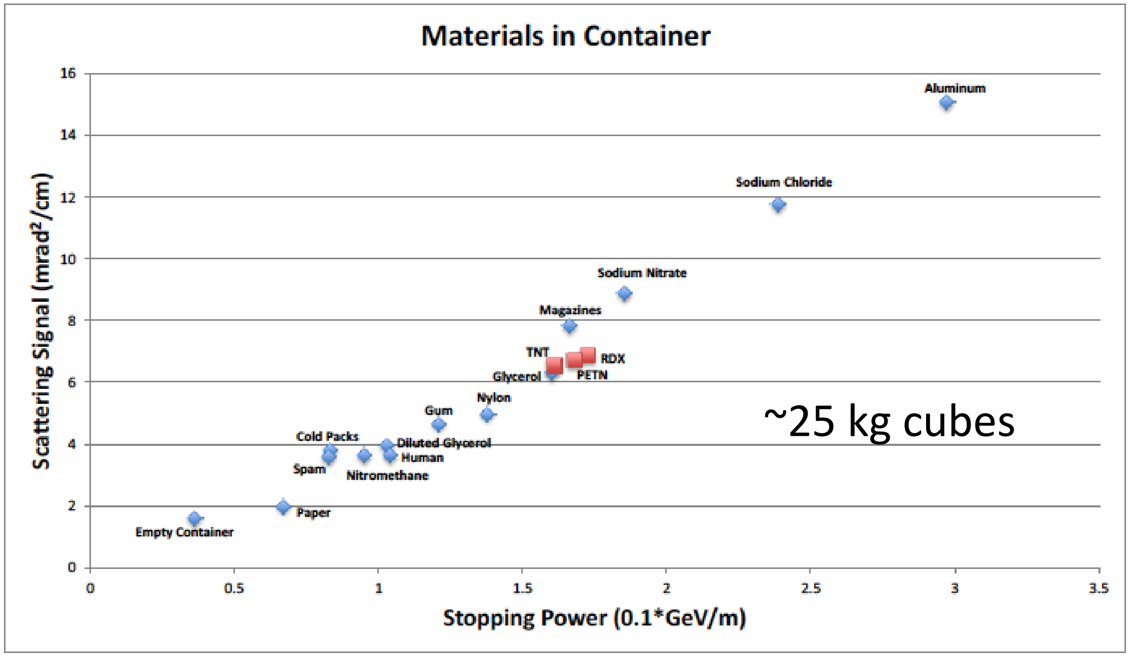
From Particle Data Book 2012

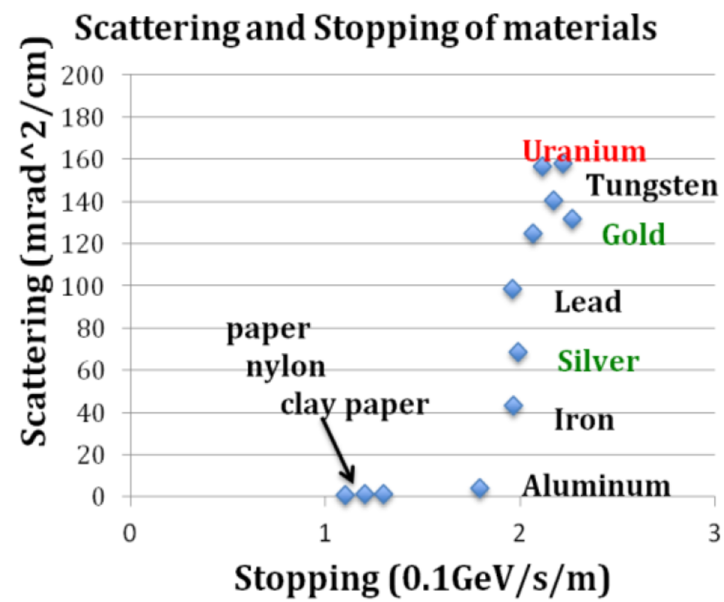




- Developing physics model incorporating relevant interactions
- Implemented simple uniform dE/dx model for fully attenuated (stopped) particles
- Measure Stopping Power for materials by counting stopped particles

Combined Signatures

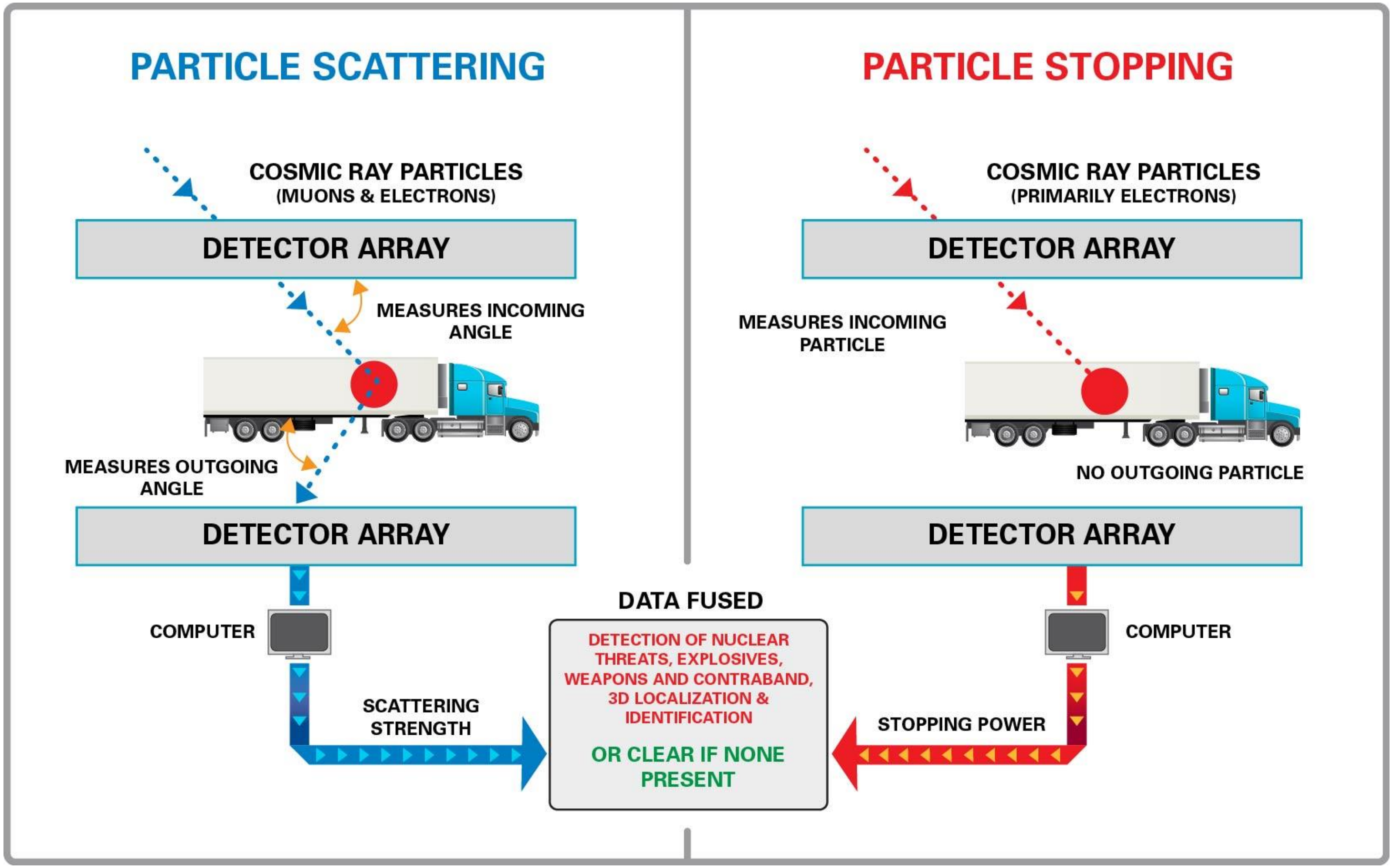




10 minute exposures, statistical uncertainty smaller than points
Blue diamonds measured, Red squares simulated

- Materials can be discriminated based on combined scattering/stopping signatures
- Regions of interest can be defined on this plane to provide automatic detection

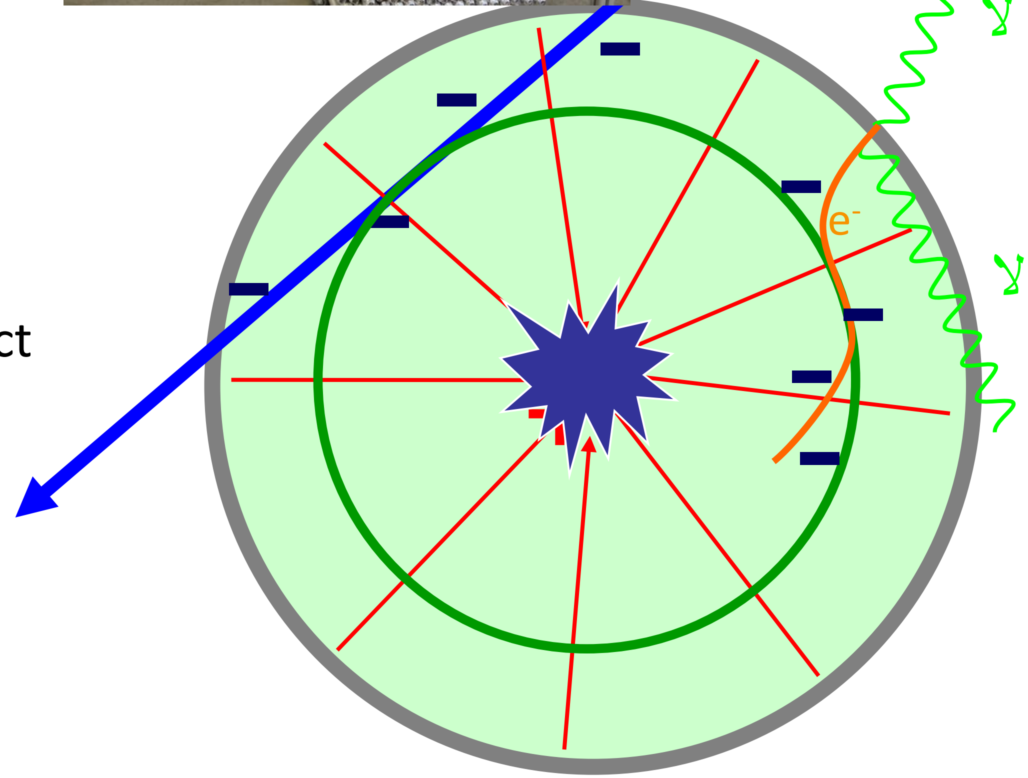
MMPDS: How It Works



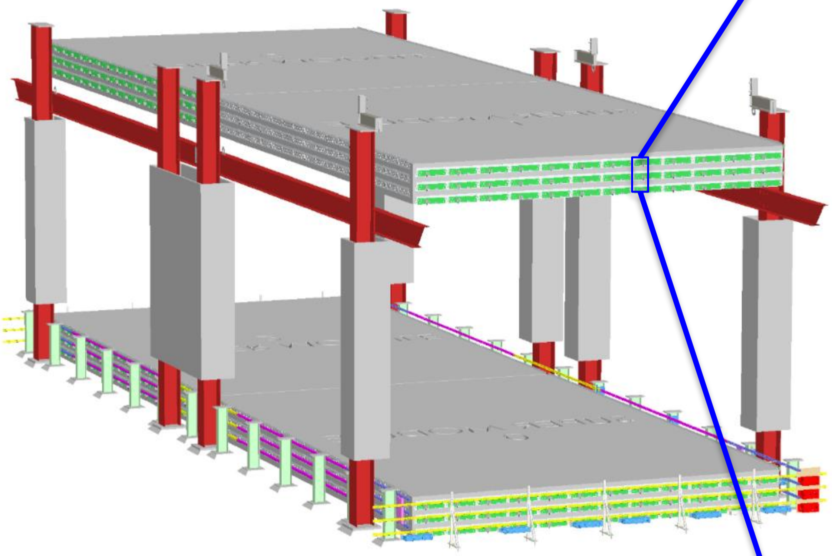
Base Technology: Sealed Drift Tubes

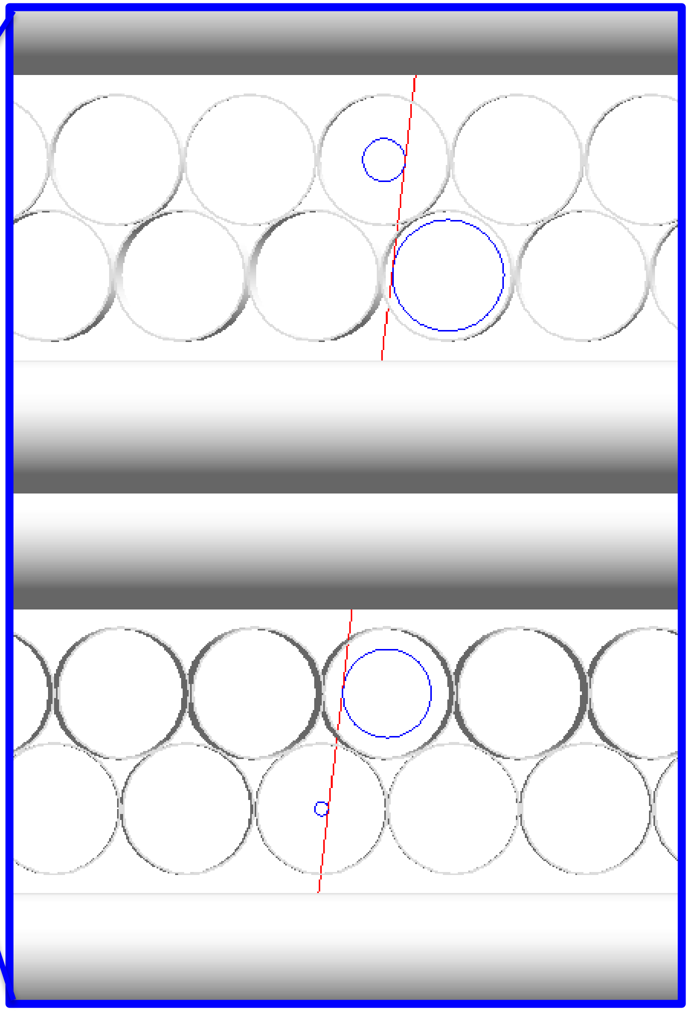
Simple "light-bulb" design

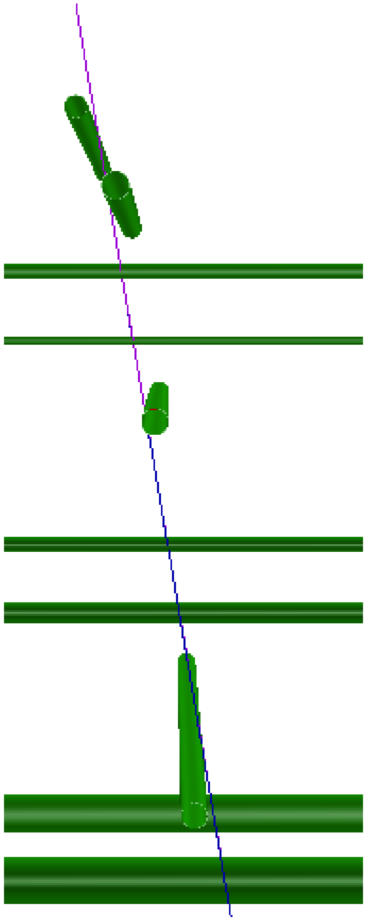
- Positive voltage on center wire generates radial electric field
- Muon ionizes gas along path
- Electrons drift at constant velocity along E-field toward anode wire
- High field near wire causes charge amplification via "avalanche" effect
- Drift time converted to closest approach distance giving radius to ~250 micron
- Gammas produce Compton electrons in tube wall which ionize gas as well, providing raw gamma count rates



Layers of Tubes Provide Tracking

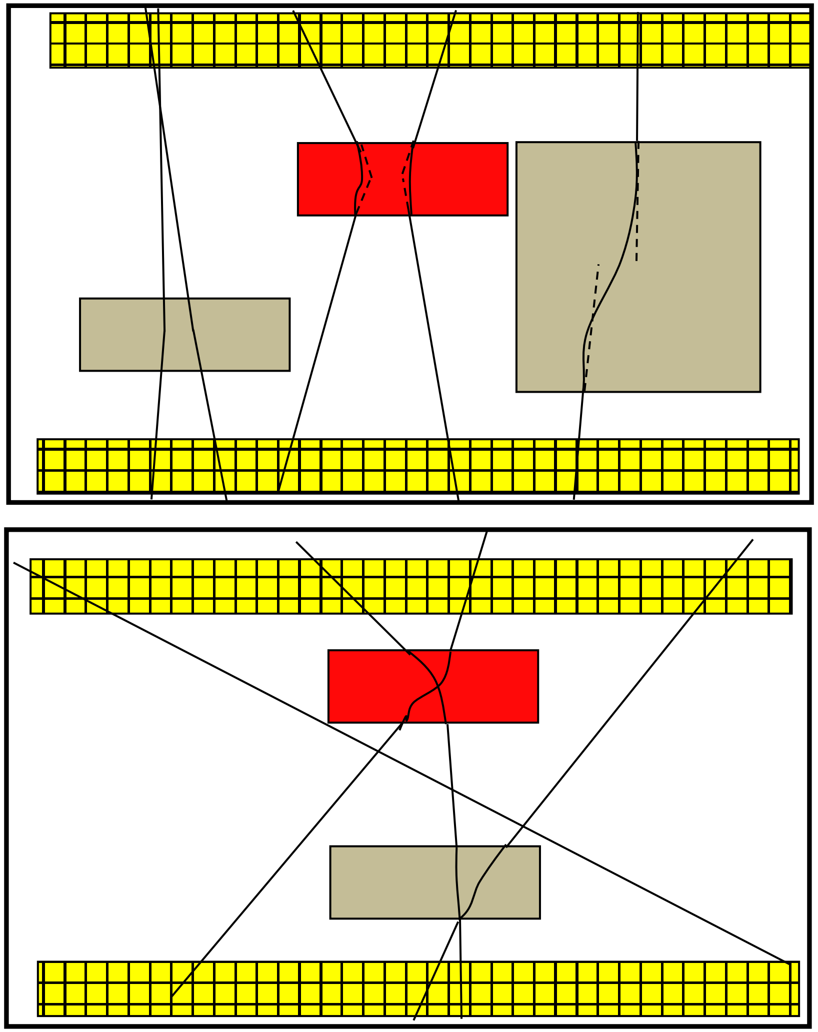






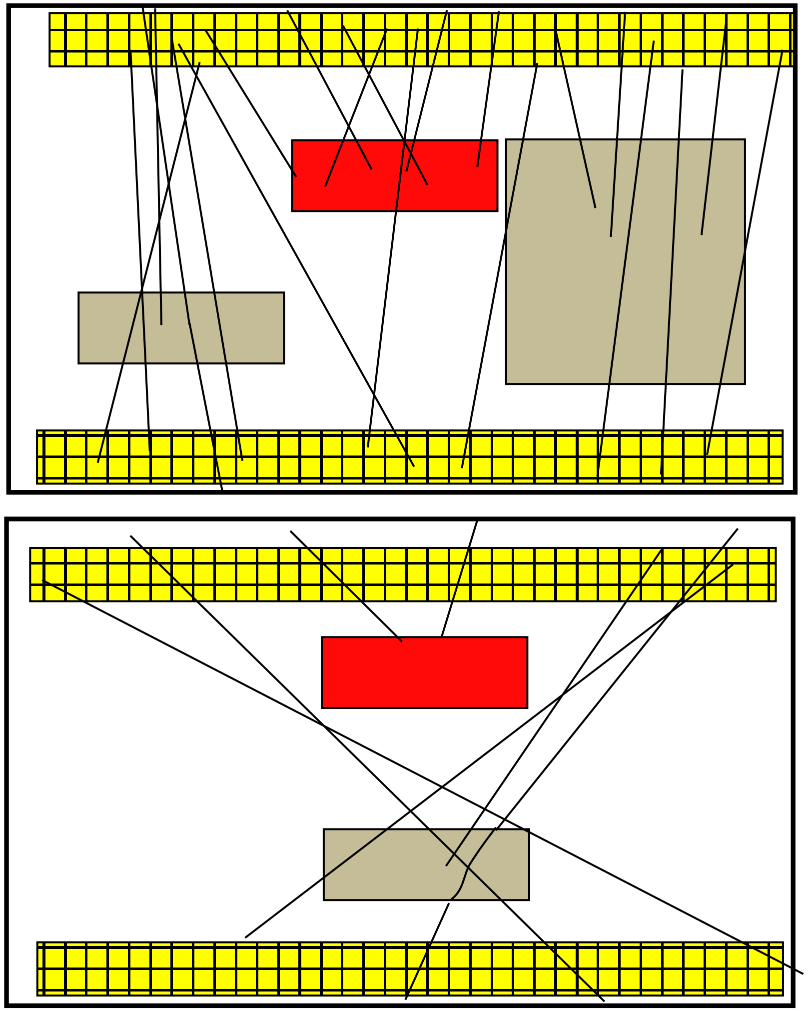
3D Imaging Using Charged Particles – Scattering

- Particle scattering reflect atomic density
  - Scattering angle – Radiation length
  - PoCA/path – location
  - DoCA – thickness
- Particles explore volume from many angles
  - Provides better vertical localization
  - Resolves vertical clutter
- Reconstruction techniques adapted from medical imaging
  - PET



3D Imaging Using Charged Particles – Stopping

- Each incoming particle is tracked
  - Stopped trajectories point to region of stopping
- Volume explored from many angles
  - 3D imaging
  - Path lengths through objects
    - Absolute measurement of density, not relative contrast
- Measurement of momentum is better for lower energy particles that stop
  - Helps identify materials
- Ratio of stopped to through particles provides more statistically significant data than standard attenuation radiography
- Stopping is incorporated with existing scattering reconstruction
  - SPECT



Scattering Images

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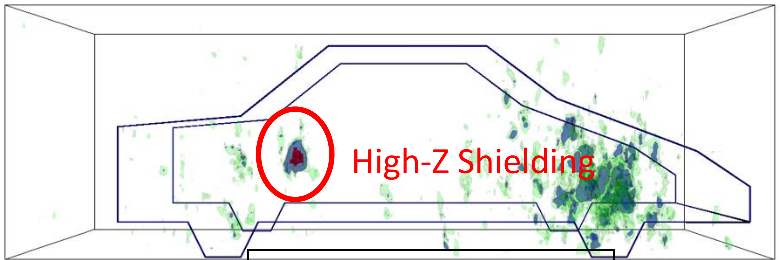
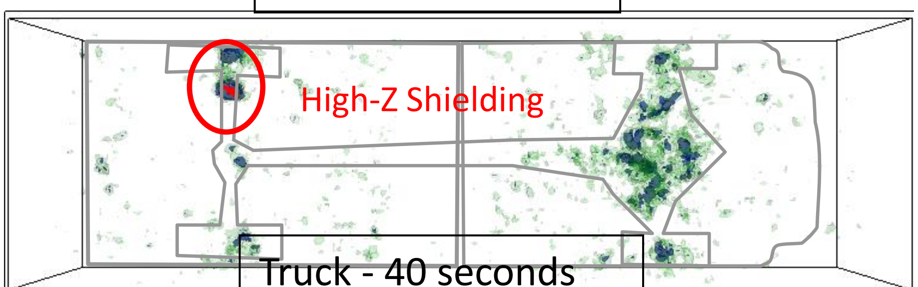
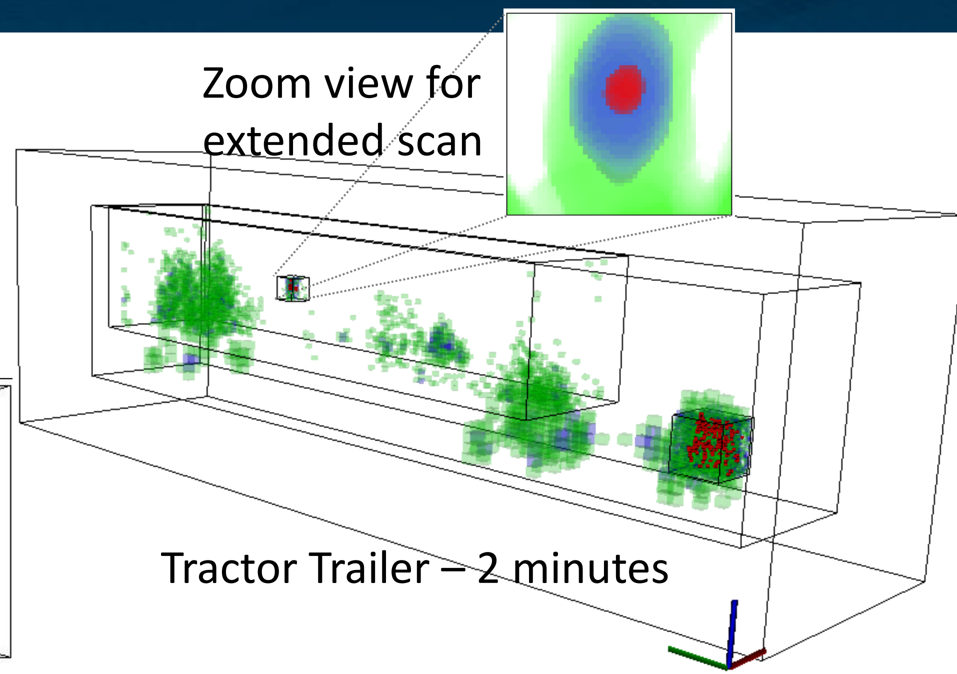


Car - 30 seconds

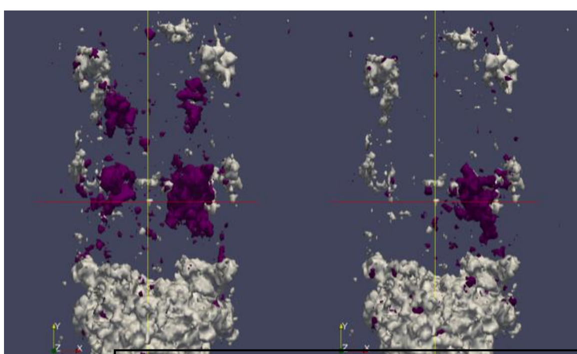


Truck - 40 seconds

Zoom view for extended scan



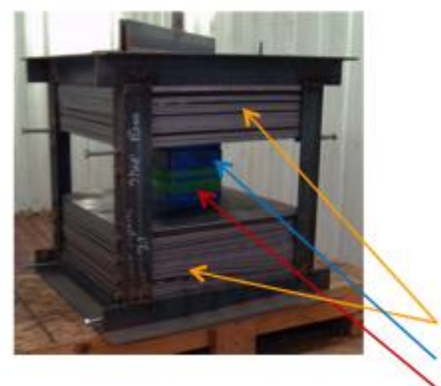
Tractor Trailer – 2 minutes



Car/Passengers, 3 minutes

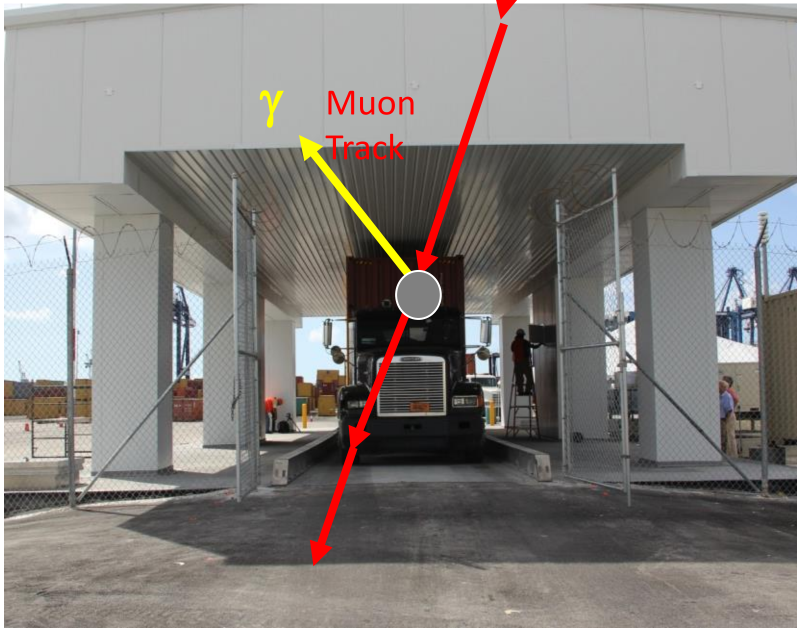
35 seconds

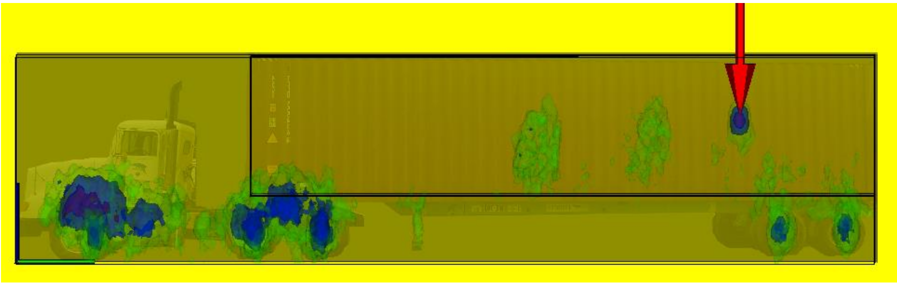
View From Above



Basic detection system concept (SNM/RDD)

- Cosmic-RayTomography – Non-Intrusive Imaging (NII) using background muons/electrons, tracked by simple sealed drift tubes
  - Searches for SNM or enough shielding to block gamma emissions
  - Highly penetrating (> 16” steel demonstrated)
  - Identifies material by atomic number/density
  - Fast results (sub-minute times to clear)
  - Only available **passive** NII solution
- Sensitive gamma detection is built-in
  - Very large area gives high sensitivity
  - Natural cosmic background count subtraction
  - Many independent sensors allows position and distribution measurement for better discrimination of NORM
  - Provides a great deal of information in combination with MT
    - Source strength
    - Gamma energy





Combined Scattering/Stopping Reconstruction

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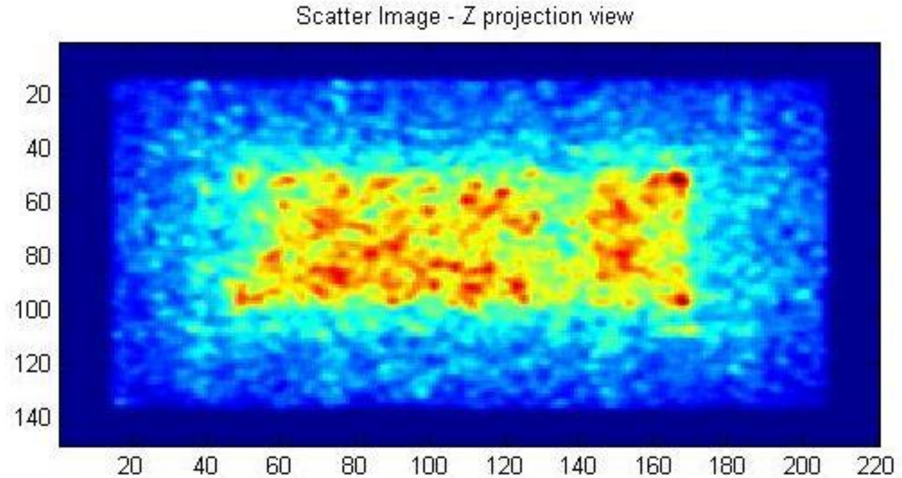
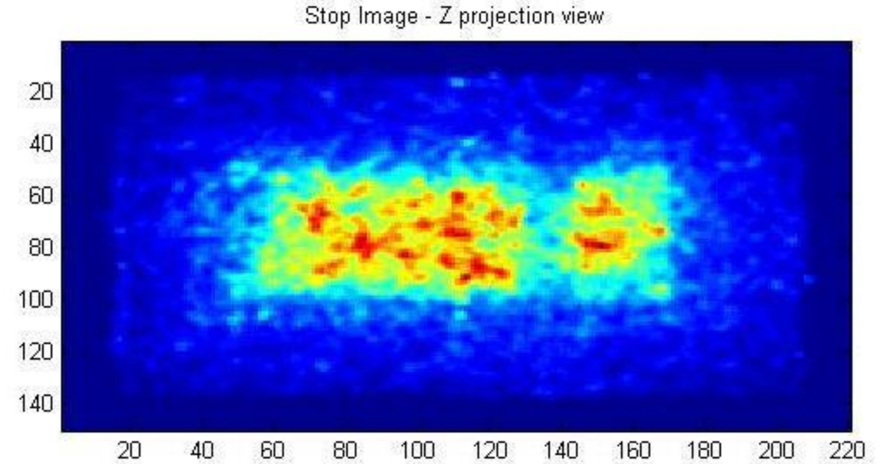
- Use scattering image as prior for attenuation reconstruction and vice versa
- Two reconstructed scalars for each voxel
  - Stopping power
  - Scattering density
- Detect threats/contraband of interest based on library of scattering/stopping signals for threat materials



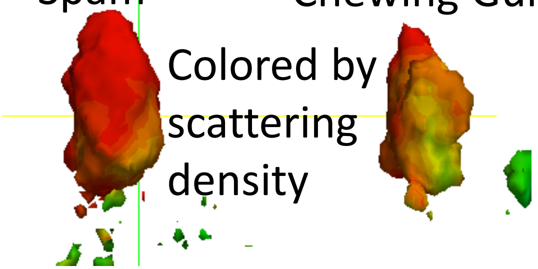


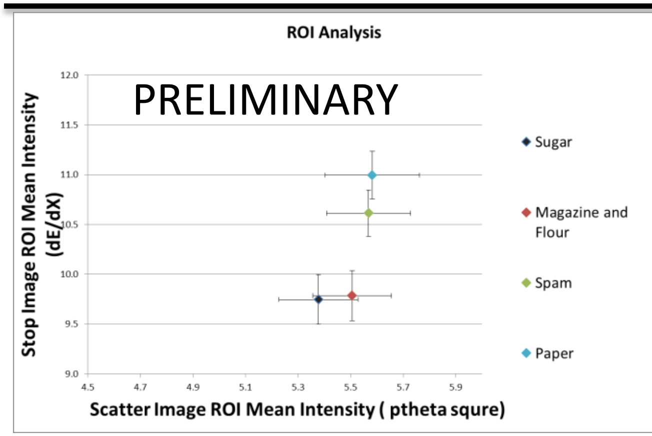
8 pallets of office paper
3 minute exposure

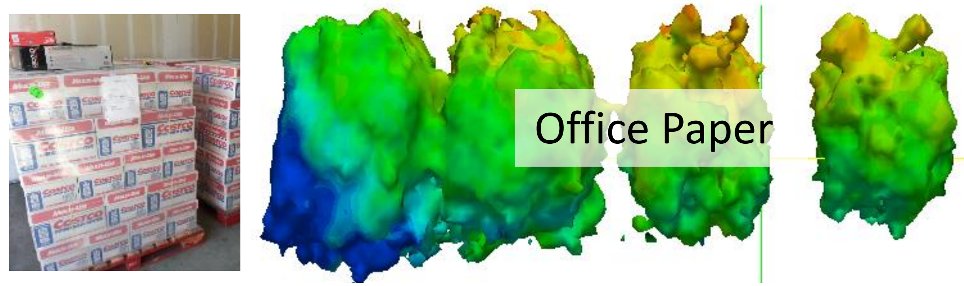
Imaging of Low-Z Pallets

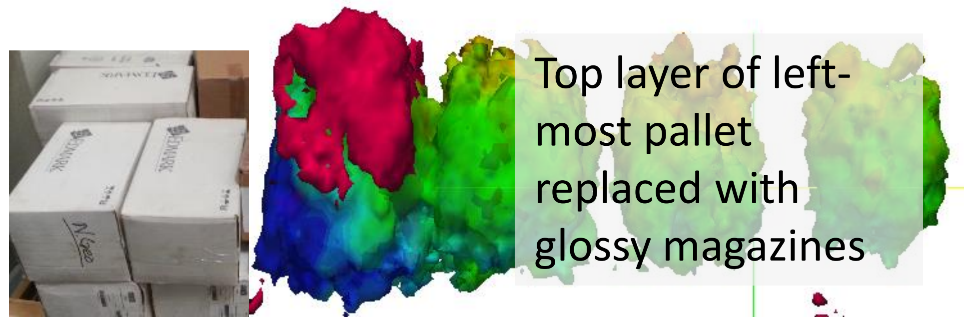
Spam

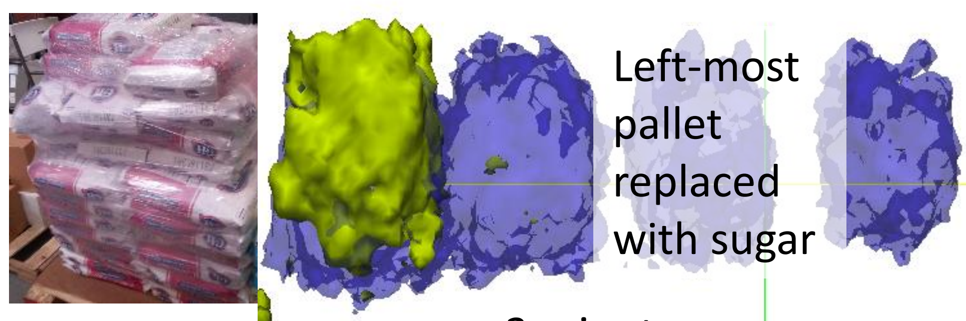
Chewing Gum











- 3 minute exposures

Advanced Imaging Algorithm Development

Challenges

- Sparse data
- Limited angular acceptance
  - Vertical thickness measurement critical to material discrimination
- Measurement uncertainty
  - Tracking and momentum
- Low latency required
- Complex, high-clutter scenes

Approaches

- Higher fidelity physics models
- Compressive sensing/adaptive measurement
- Iterative algorithms
- Filtering/deconvolution
  - Filtered back-projection
- Point cloud approaches

First Production Unit – Freeport, Bahamas

Scanning Containers Daily – US Government Characterization Ongoing – Expected Completion 2014

MMPDS Is Scalable to Provide Complete Architecture

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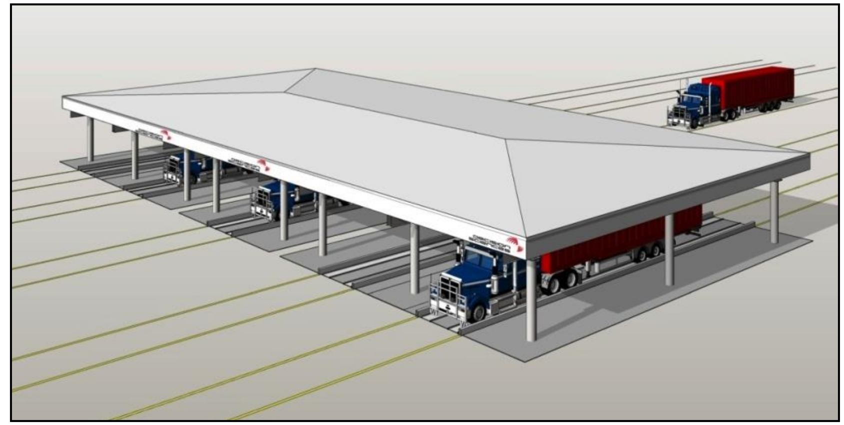

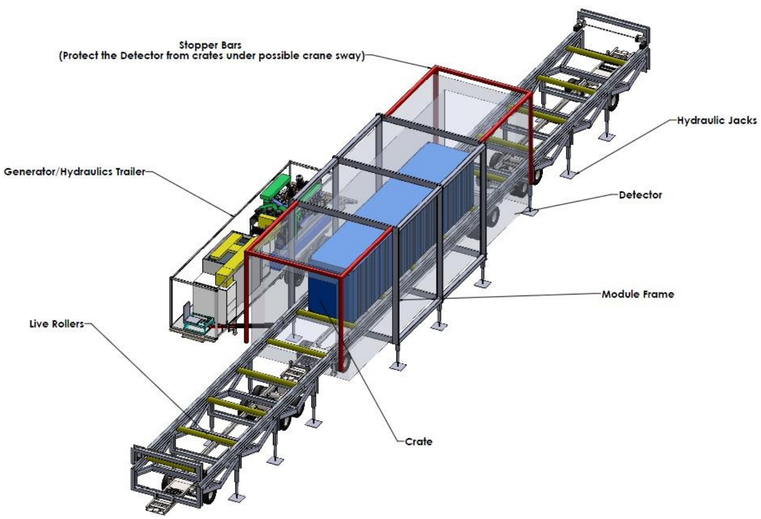

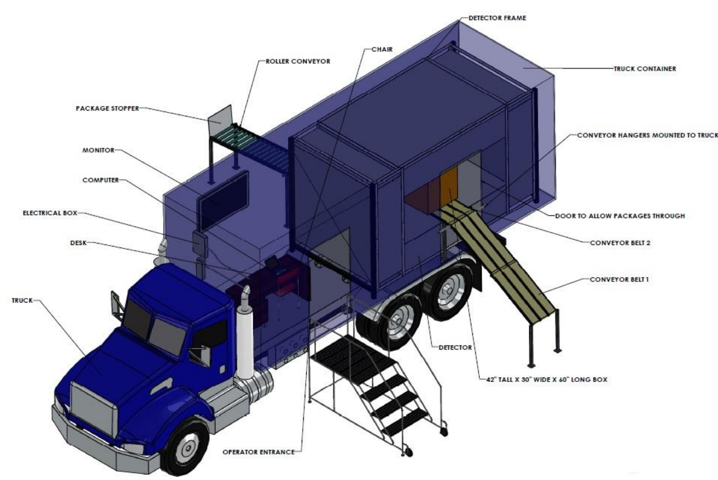

Current Threats to Air Cargo Industry

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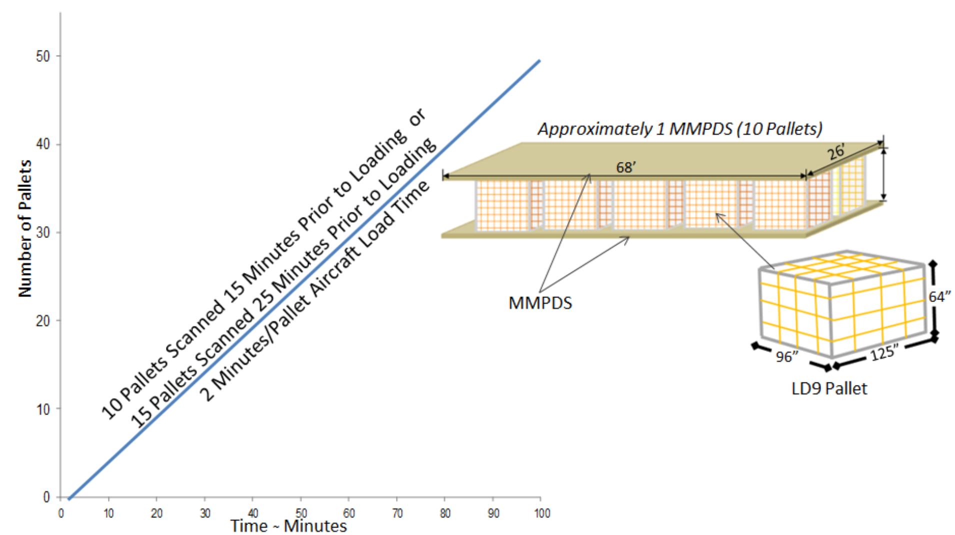
- Printer ink cartridge terror plot containing plastic explosives and a detonating mechanism discovered on two separate cargo planes. (Oct. 2010)

Scanning Logistics for Small Threat Quantities

- For small threat sizes, the number of particles decreases for a set scan time
- For sub-kilogram quantities of explosives, resolution of false positives may require 45 minute scan times
  - Package scanners could be used in drop-off locations while awaiting pick-up
  - Many pallets could be scanned simultaneously during loading process



Summary

- Cosmic-ray charged particles are useful
  - Nuclear materials detection
  - Explosives detection (in development)
  - Numerous application spaces including air-cargo scanning
- Charged particle imaging algorithm development is fertile ground for research

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