SHIELD: Smuggled HEU Interdiction through Enhanced anaLysis and Detectors

# Detecting Small Low Emission Radiating Sources

M. Allmaras, W. Charlton, D. Darrow, Y. Hristova, G. Kanschat, P. Kuchment, J. Ragusa, G. Spence
Mathematics and Nuclear Engineering Departments, Texas A&M University

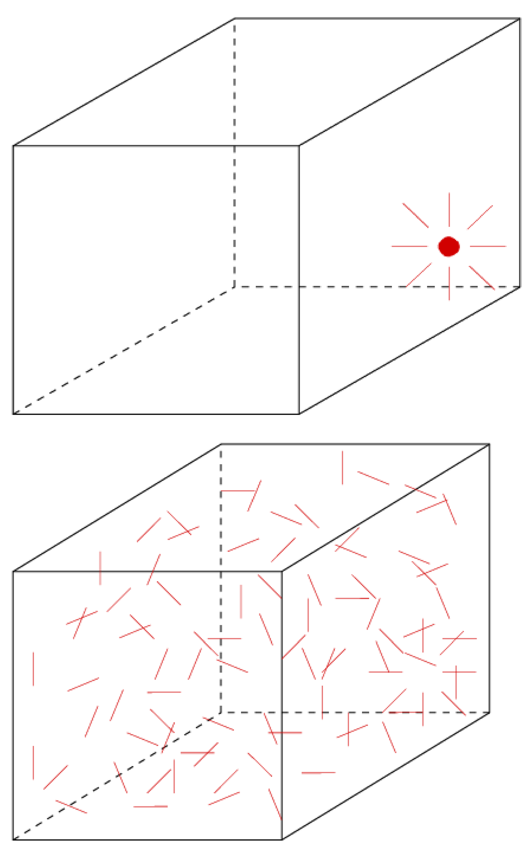
## Problem

**Goal**
Prevent smuggling of highly enriched nuclear material through border

**Idea**
- Can we use passive detector gates to classify containers into suspicious/non-suspicious?
- Only search suspicious freight manually

**Issues**
- Manual searches expensive and time-consuming
- Severe time constraints for detection
- Low emission from source, typically within a much larger background

## Setting



- Detect γ-photons, neutrons exiting cargo
- Sources are expected to be weak and shielded
- Background radiation my be orders of magnitude stronger than source (SNR ~0.1%)

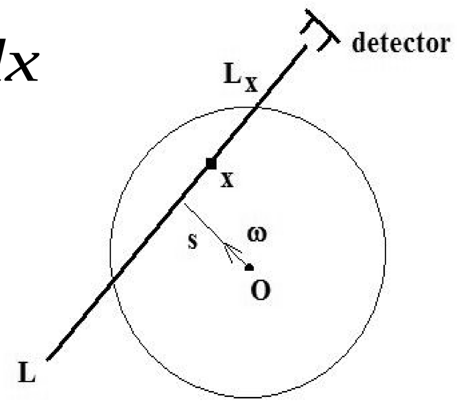
→ Direction insensitive measurements are not sufficient for detection as they cannot distinguish between source and background particles.

**Assumptions**
- Source is geometrically small compared to detection region
- Background radiation is random
- Source and background particles are indistinguishable
- Some directional information about incoming particles is available

## SPECT (Single photon emission computer tomography) imaging

- Let $f$ be unknown source distribution, $\mu$ attenuation
- Measurements are integrals over lines $L$:

$$T_\mu f(L) = \int_L f(x)\, e^{-\int_{L_x} \mu(y)\,dy}\, dx$$




- $T$ is attenuated Radon transform
- Lines are parametrized by normal $\omega$ and signed distance $s$ to origin

**Problem**
- Collimation is required, which would eliminate the weak signal
- Radon transform model does not apply when source is weak
- Reconstruction schemes cannot handle strong noise in signal

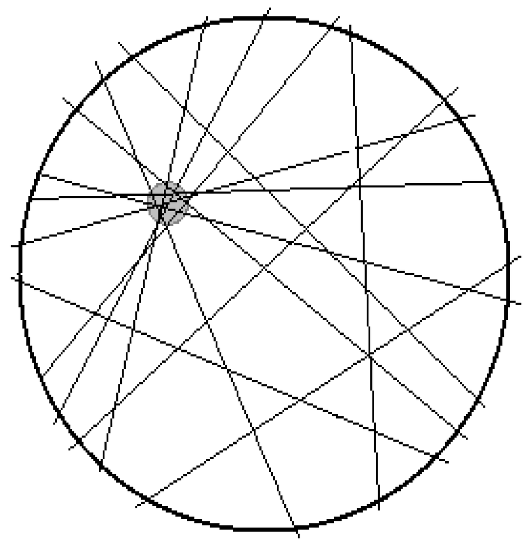
## Backprojection

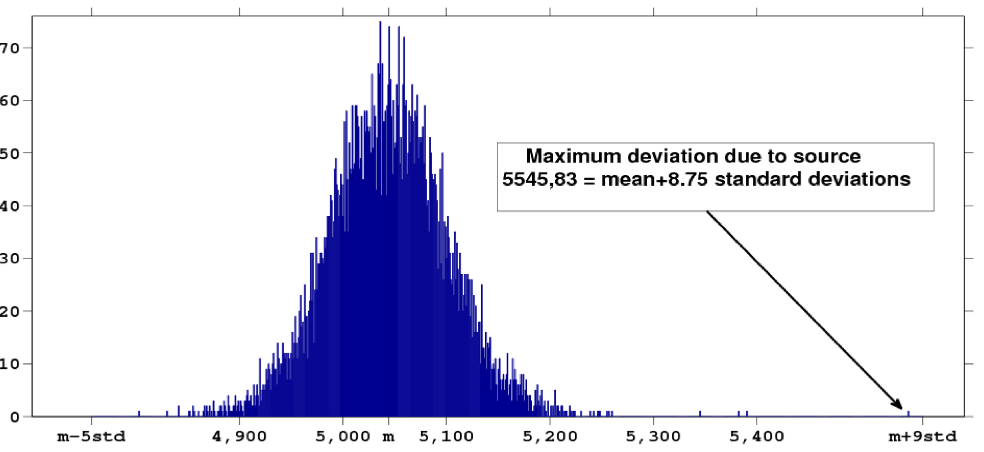
Small sources are geometrically singular, can this be used in detection?

**Backprojection**
- Assume we know the number of particles $g(\omega,s)$ that were detected at position $s$ coming from direction $\omega$. Then

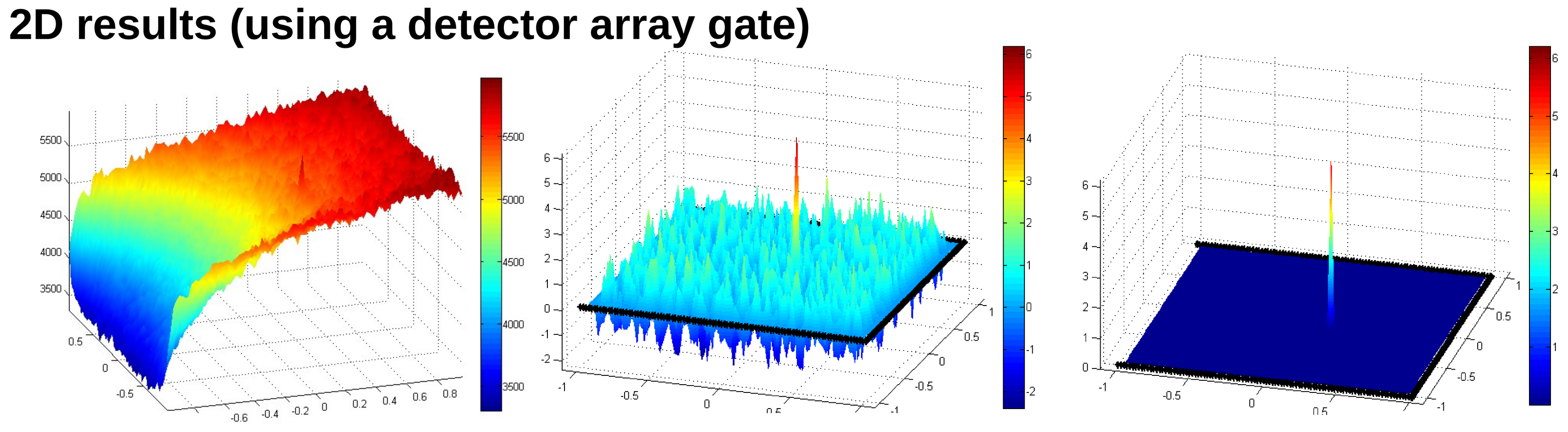
$$T^{\#} g(x) = \int_{|\omega|=1} g(\omega, x\cdot\omega)\, d\omega$$

- At point $x$, $T^{\#}$ integrates over all lines passing through $x$
- Reveals areas of unusually high concentration of lines
- Allows estimation of confidence of detection






### 2D results (using a detector array gate)

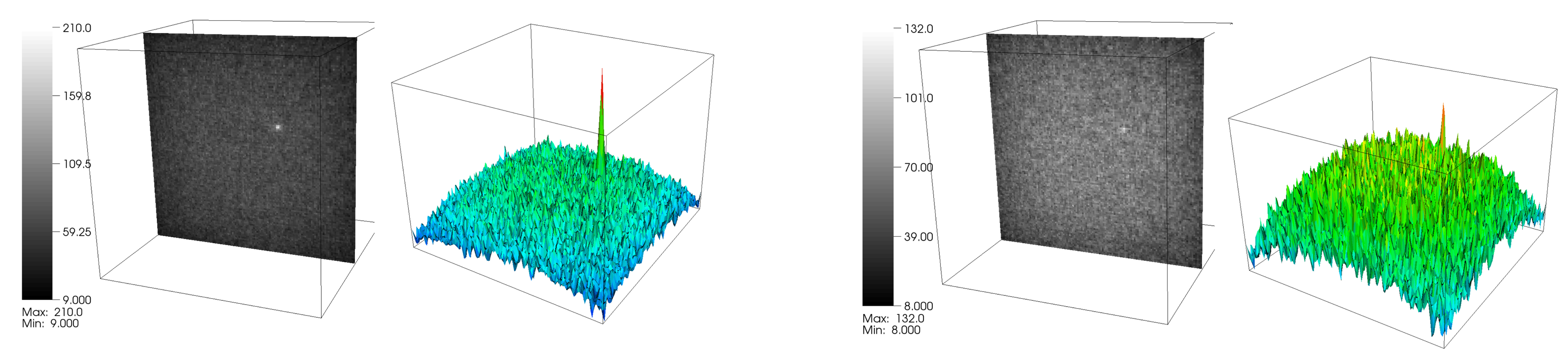


- 2D backprojection from x-ray measurements along 3 detector arrays
- $10^6$ background particles, ~1000 source particles, SNR ~0.1%

- After subtraction of local means

- After thresholding
- Detection confidence ~99.99%

### 3D results



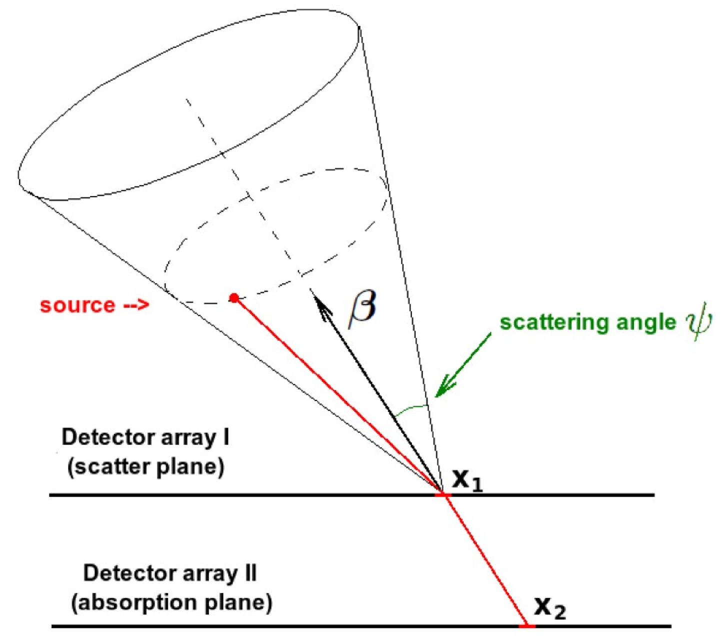
- 3D backprojection from x-ray measurements along eight sides of a cube
- $10^6$ background particles, SNRs ~0.05% (left), ~0.02% (right)
- Pictures show backprojection along a cut plane through center of domain

## Compton measurements

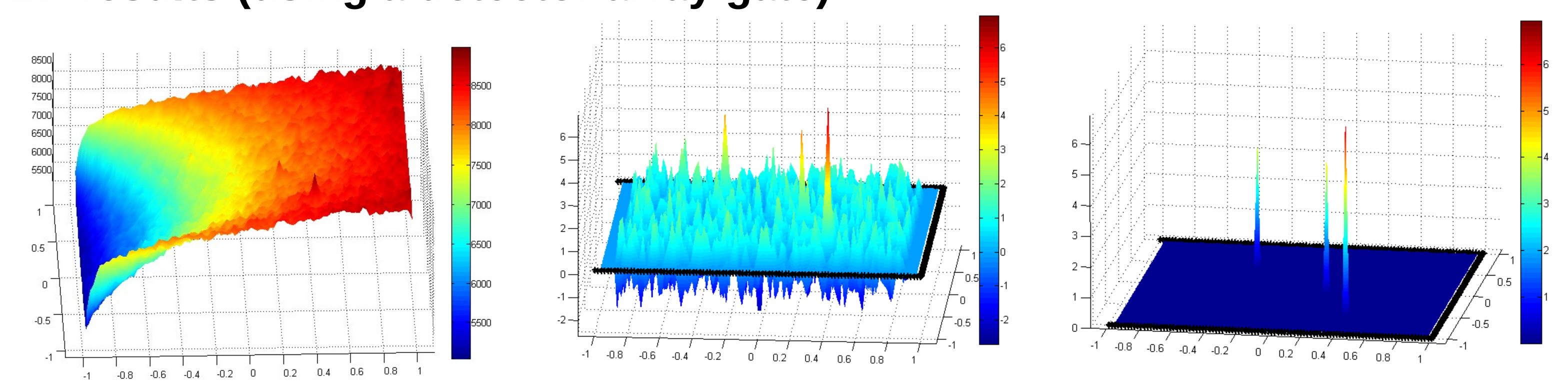
**Compton camera**

In practice, detectors can not determine the direction a particle came from without discarding most of the signal through collimation. Direction data is therefore not obtainable for low-emission sources with short count times.

However, Compton camera detectors can determine a cone of possible directions for each detected particle without collimation.




### 2D results (using a detector array gate)

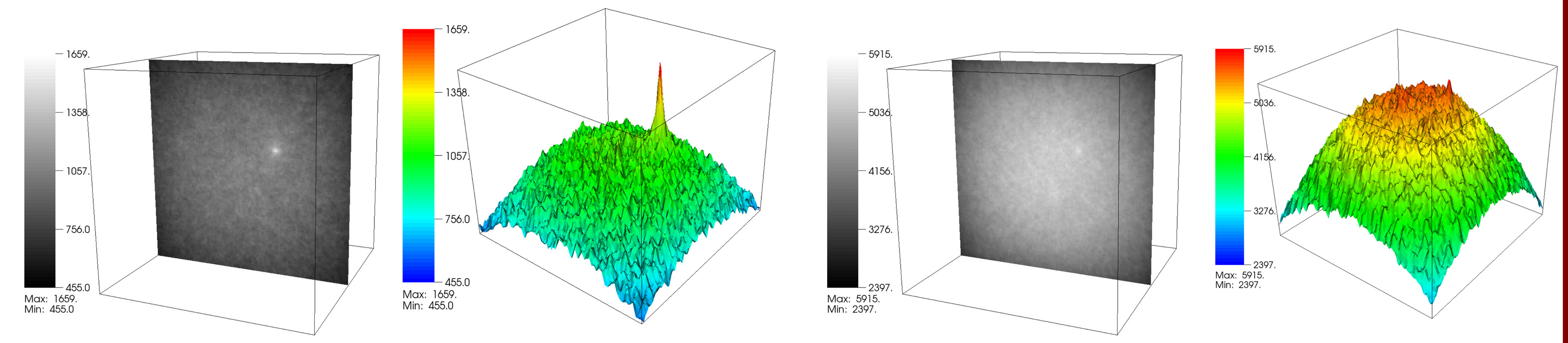


- 2D backprojection from Compton measurements along three sides
- $10^6$ background particles, SNR ~0.3%

- After subtraction of local means

- After thresholding
- Accurate detection of 3 sources
- Detection confidence > 91.97%

### 3D results



- 3D backprojection from Compton measurements along eight sides of a cube
- $10^3$ source particles, SNRs ~1% (left), ~0.7% (right)
- Pictures show backprojection along a cut plane through center of domain

### References

- *Detecting small low emission radiating sources,* M. Allmaras, D. Darrow, Y. Hristova, G. Kanschat, P. Kuchment (preprint, arXiv:1012.3373v1)