The Compact Compton Imager: a Spectroscopic, Large Field-of-View Gamma-Ray Camera

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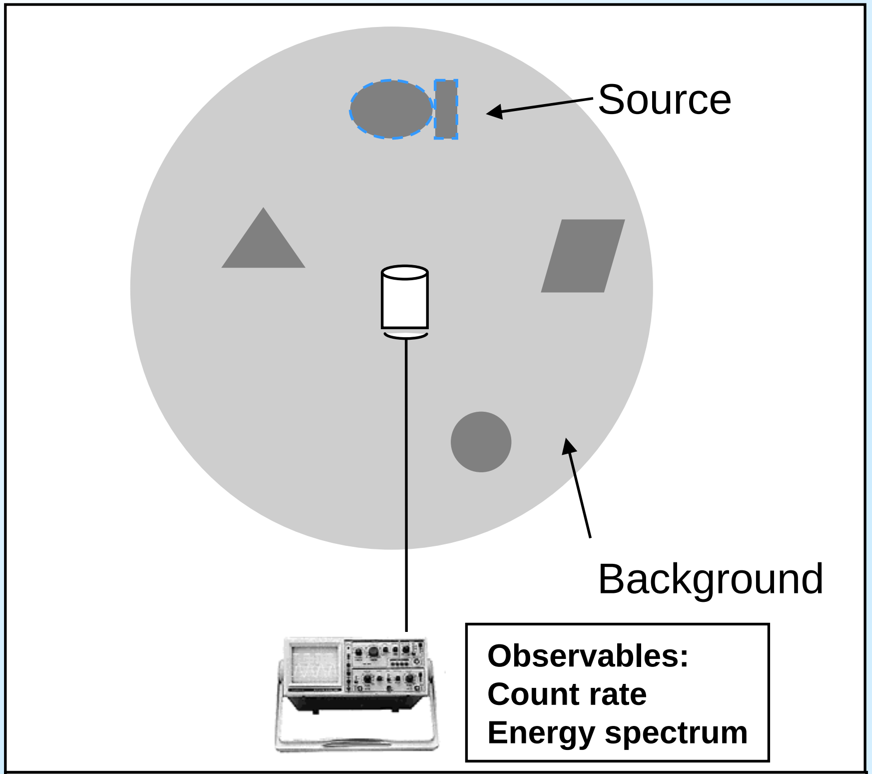
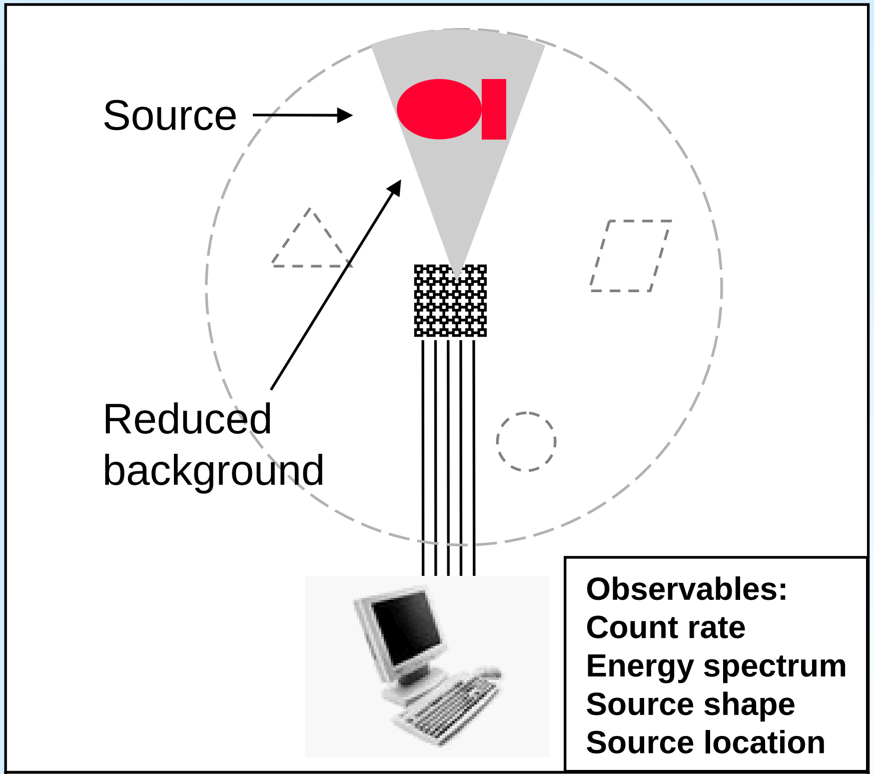
UCRL-PRES-226138

Gamma-ray imagers are detectors that separate radioactive objects from the local background

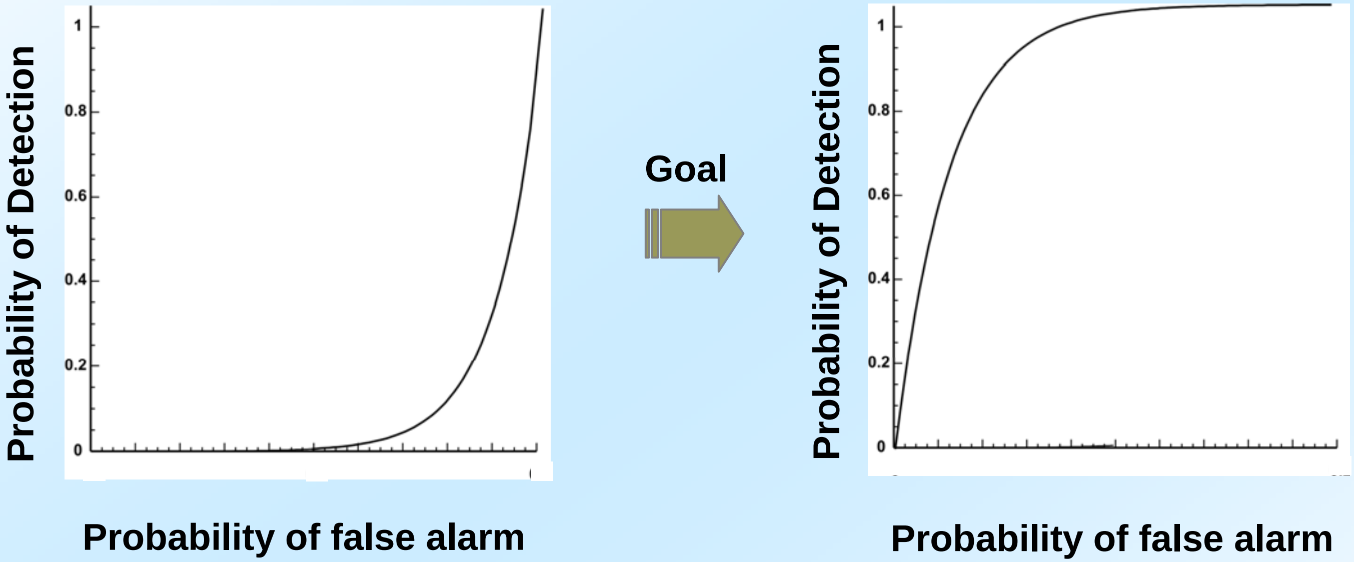


Conventional detectors accept gamma-rays from all directions and can be overwhelmed by local backgrounds



Gamma-ray imagers isolate sources from each other and from the local background

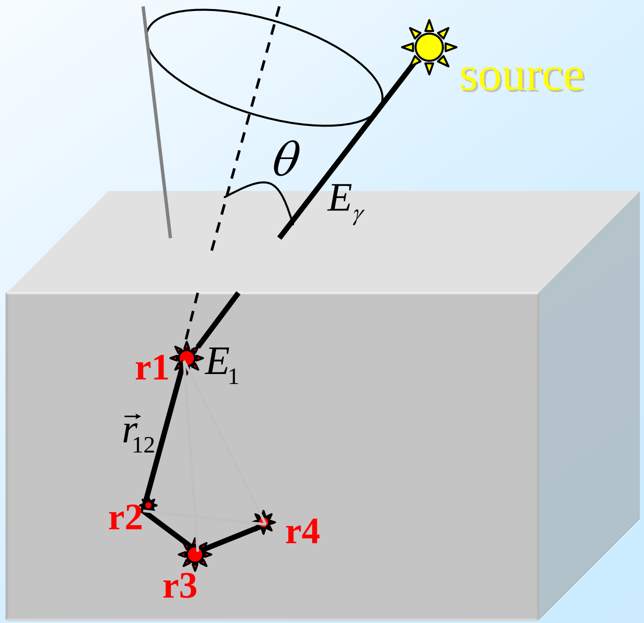
Gamma-ray imagers have the potential to improve the capability to detect and interdict radiological & nuclear threats



Improvements to the Receiver Operator Curve will arise from:

- **Better sensitivity (improved signal-to-background)**
- **Better selectivity (isotope identification, localization of source, spatial extension of source)**

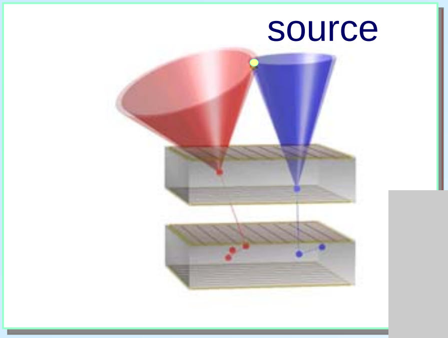
Concept of Compton scatter gamma-ray Imaging

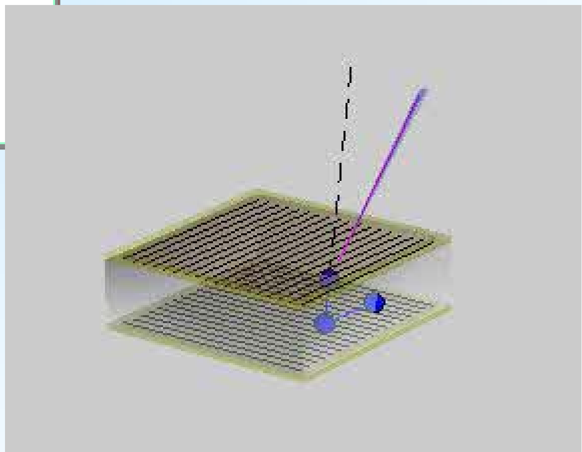


The Compton scattering formula gives θ:

$$\cos\theta = 1 - \frac{E_1 m_0 c^2}{E_\gamma \left(E_\gamma - E_1\right)}$$

$$E_\gamma = E_1 + E_2 + E_3 + E_4$$

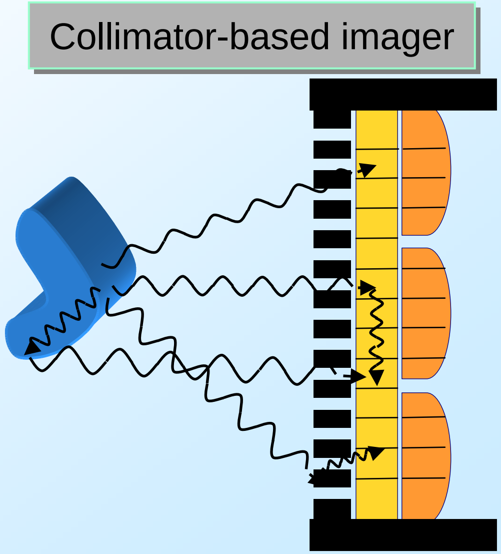


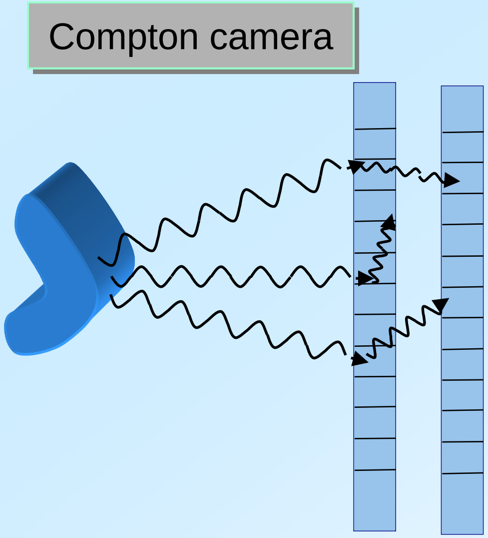


__2 components critical for Compton imaging:__

- **Position Resolution**
  (direction between first and second interactions)
- **Energy Resolution**
  (energy deposition/ scattering angle)

Compton imagers have fundamental advantages over collimator-based imagers





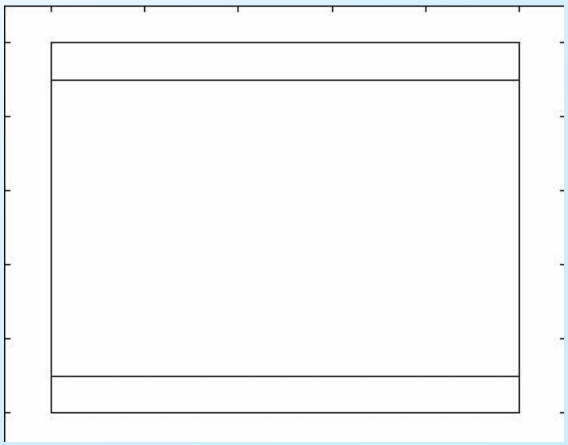
Advantages of Compton cameras:

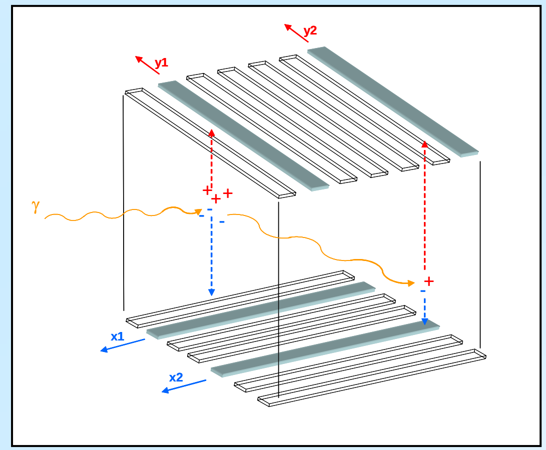
- No collimator-based trade-off between efficiency and resolution
- Sensitive to energies from 130keV to several MeVs
- Large FOV $(\leq 4\pi)$
- Compact and light-weight systems possible

Recent advances in detector fabrication and digital electronics allow us now to realize highly sensitive Compton imagers

The Compact Compton Imager (CCI)

The Compact Compton Imager (CCI) is a gamma-ray imaging prototype developed by LLNL. The system employs Double-Sided Segmented Si and Ge detectors.





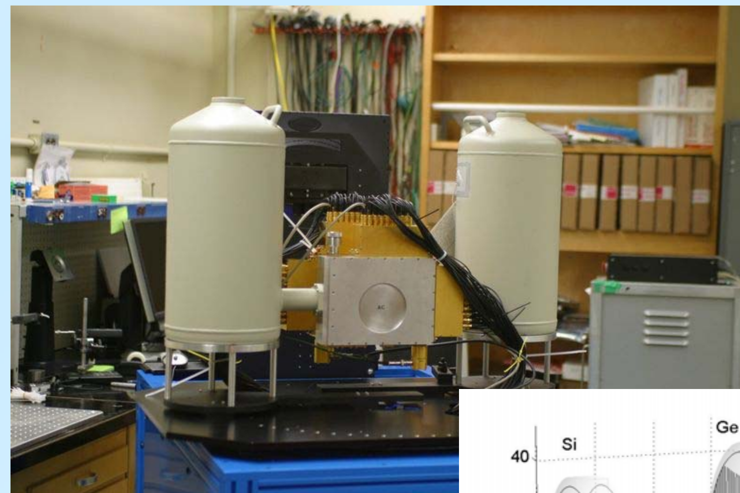
DSSD Si(Li) detector inside the cryostat (64x64x10mm^3 , 2mm pitch)

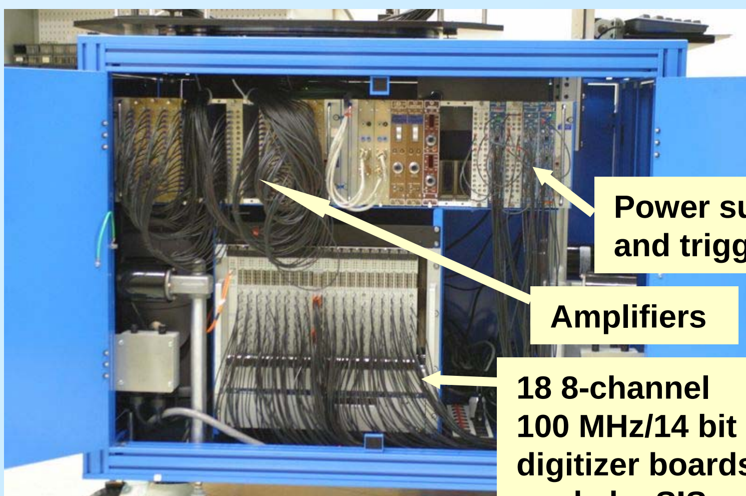
DSSD Ge detector inside the cryostat (76x76x11 mm^3, 2mm pitch)

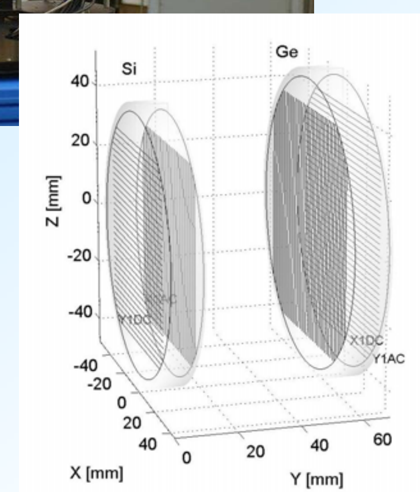
CCI-1: one Si(Li) and one Ge DSSDs

CCI-1 prototype, a transportable Compton imager system

Si-Ge Compton imager mounted on custom made cart which comprises detectors, data acquisition system and data analysis and display computer





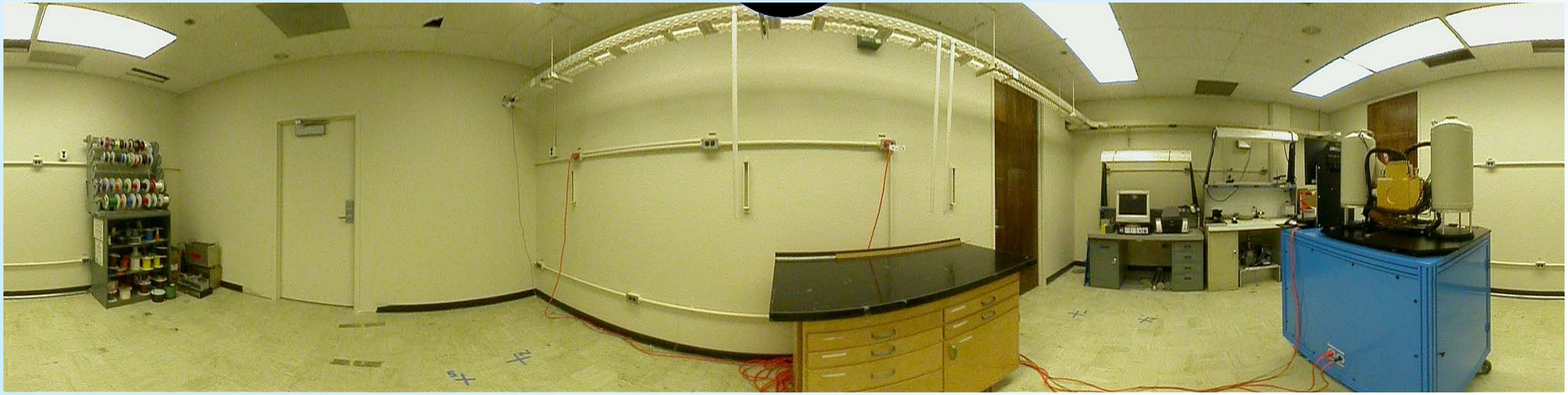


Test measurements with CCI-1 for 3D mapping of radioactive gamma-ray sources using a line Eu-152 source

Goals:

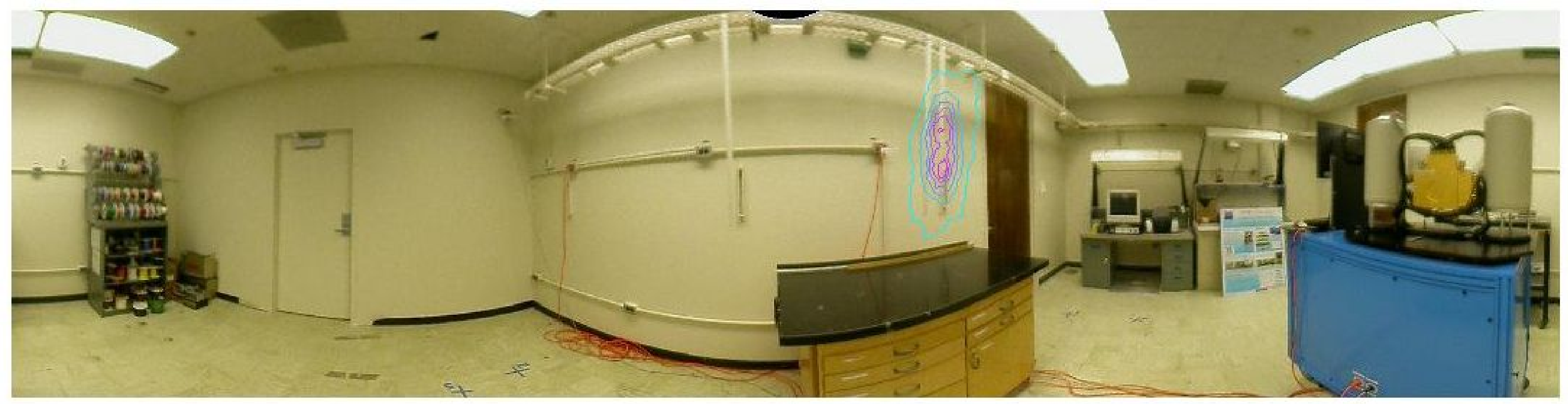
- *Image extended gamma-ray sources in 2D;*
- *Assess the combination of a lidar scanner with a gamma-ray imager for 3D imaging;*

Detailed view of the region where an Eu-152 line source (1 m long) was hidden in the right pipe

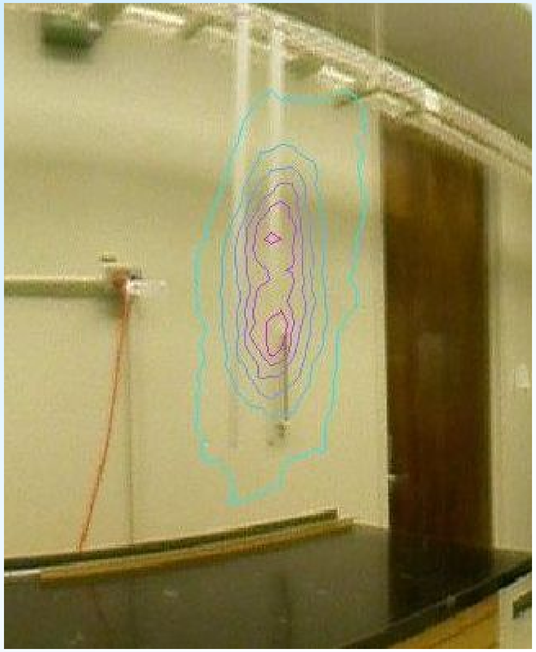


Panoramic image of the laboratory room

2D gamma-ray imaging with CCI-1



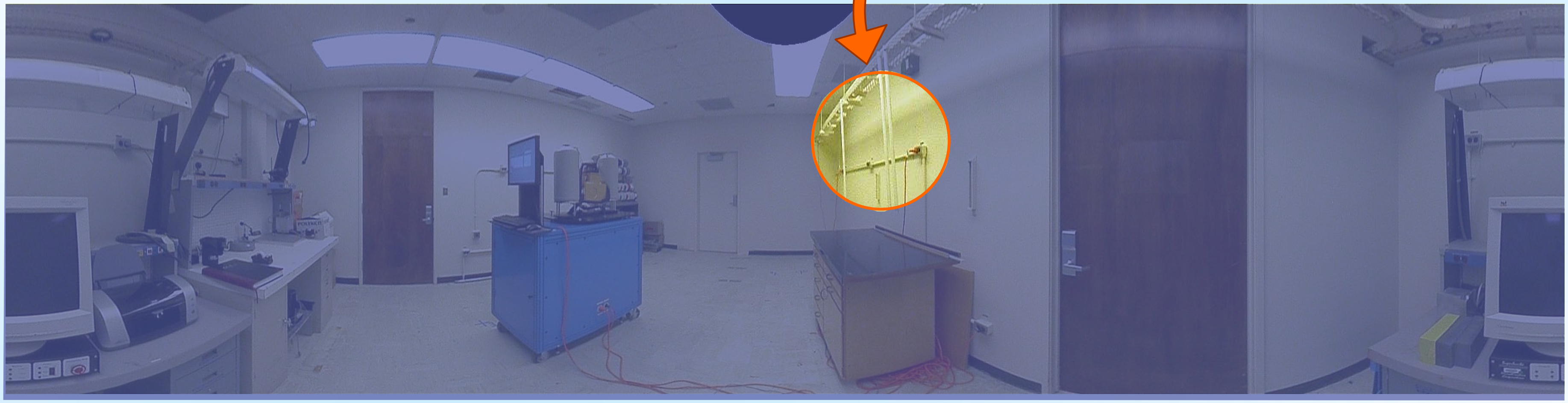
Combined maps –Maximum likelihood image reconstruction (5 iterations) on data-set position 6, energy window 338-348keV, 4000events



Reconstructed gamma-ray image of a Eu-152 line source hidden in a pipe is shown as contour plot on top of a visual panoramic image of the laboratory room. An energy window around the 344keV gamma-ray line was used.

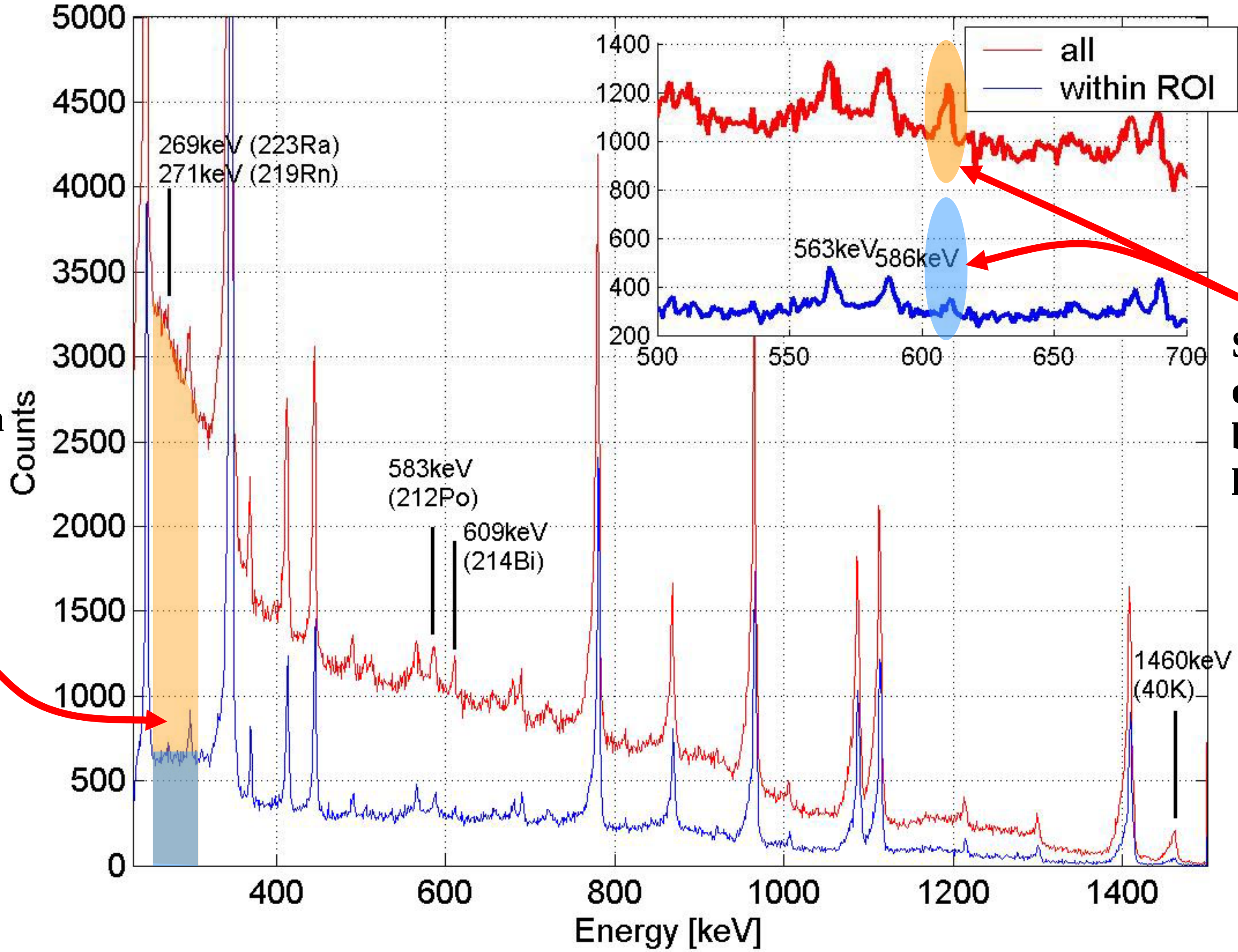
Acquisition of γ-ray spectra from limited image region-of-interest (RoI)

RoI



CCI system is able to build gamma-ray spectra from sources within a specific Region of Interest

Acquisition of γ-ray spectra from limited ROI



5x reduction In Compton continuum

Suppression of discrete background lines

CCI system is able to build gamma-ray spectra from sources within a gated region of the image

3D-Design Information Verification System (3D-DIV)

The 3D DIV system:

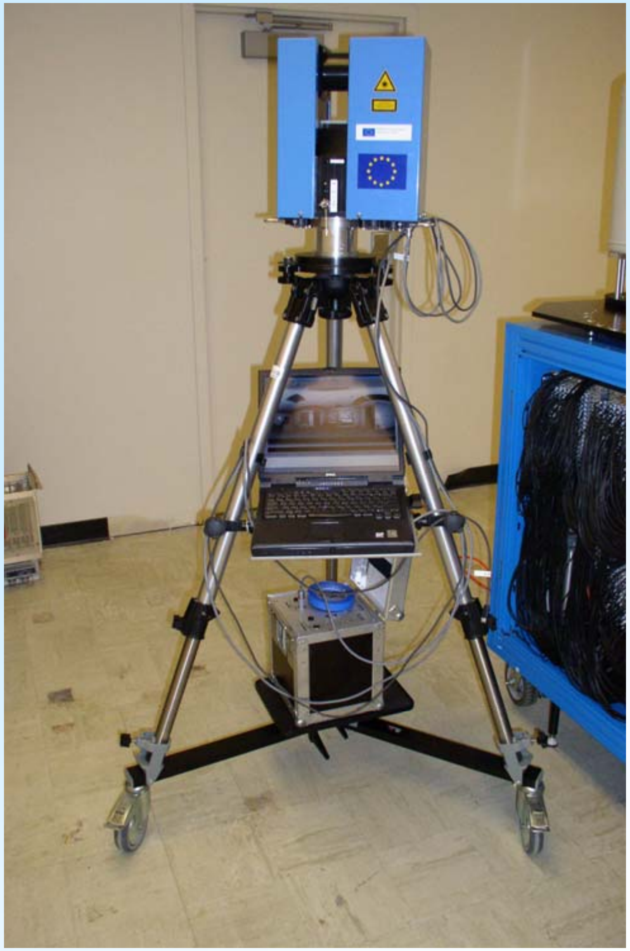
• is a lidar scanner developed by the Joint Research Center (JRC) - Ispra

• was used in our test measurements to map objects in the laboratory room.

The resulting range map was used to:

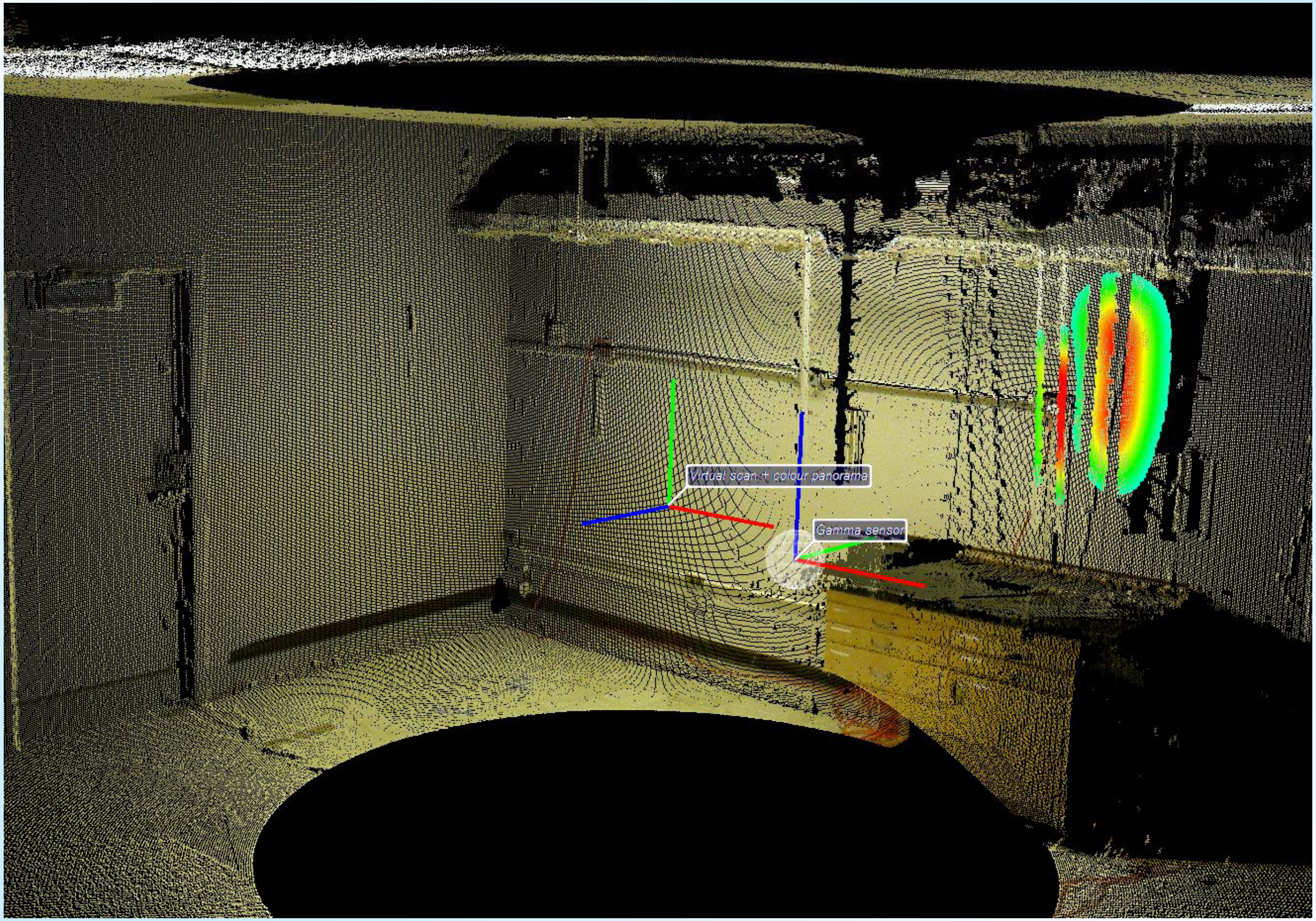
• project 2D gamma-ray images onto it;

• voxelize the interior of physical objects



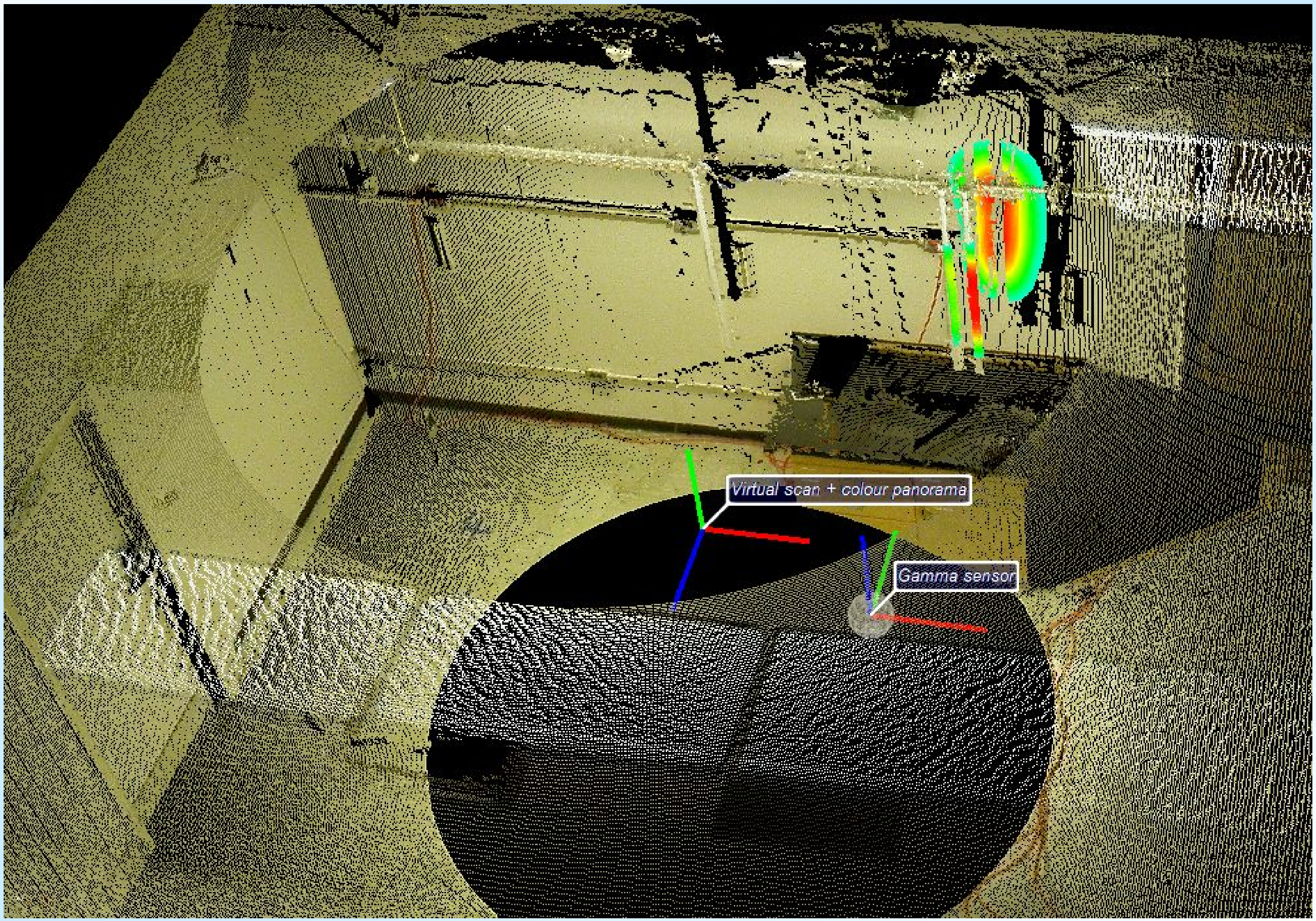
The 3D Design Information Verification (DIV) laser range scanner

Mapping of gamma-ray images onto 3D range maps – side view



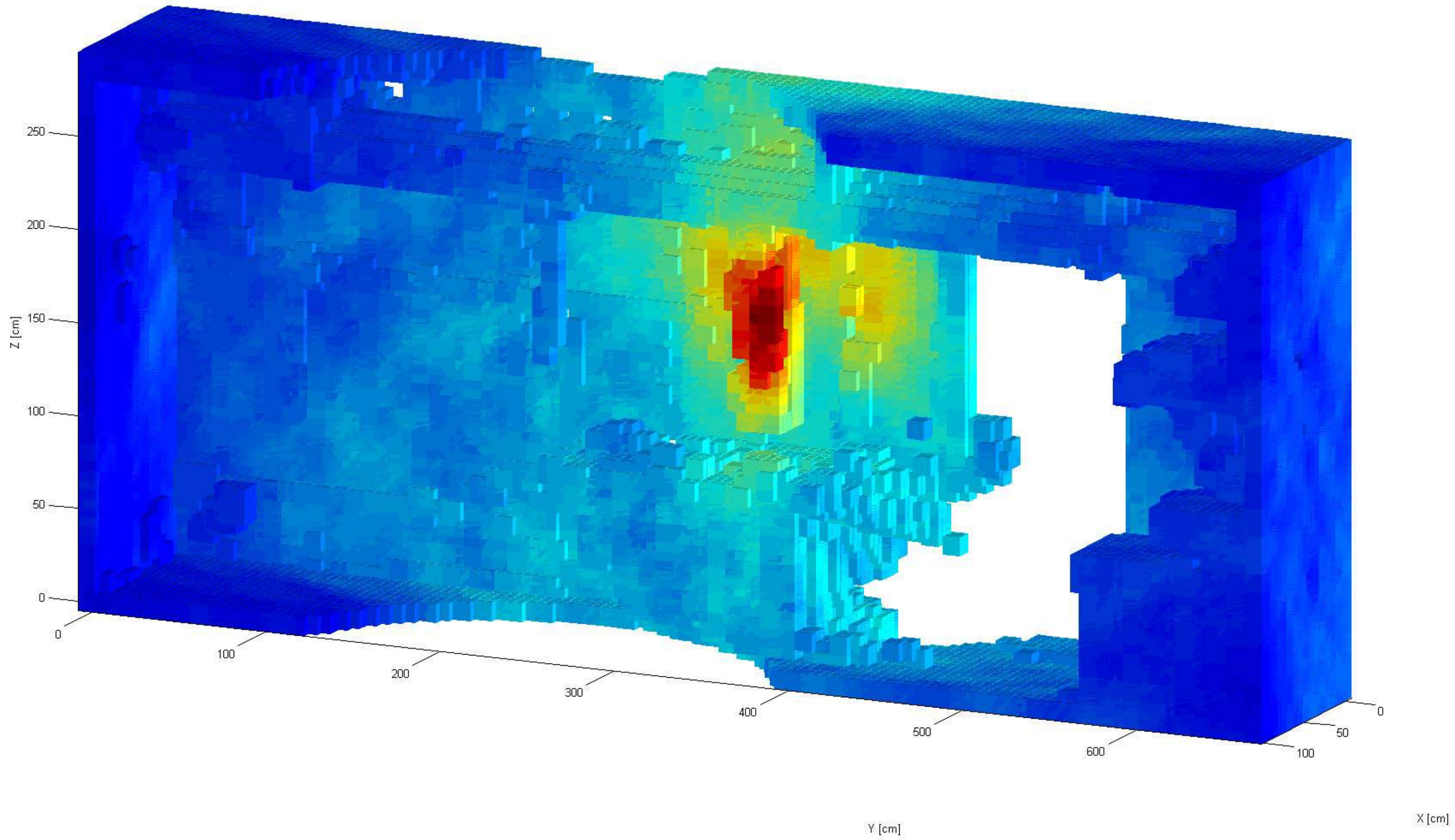
A 2D gamma-ray image is backprojected onto the range map – snapshot of the 3D model - side view;

Mapping of gamma-ray images onto 3D range maps – top view



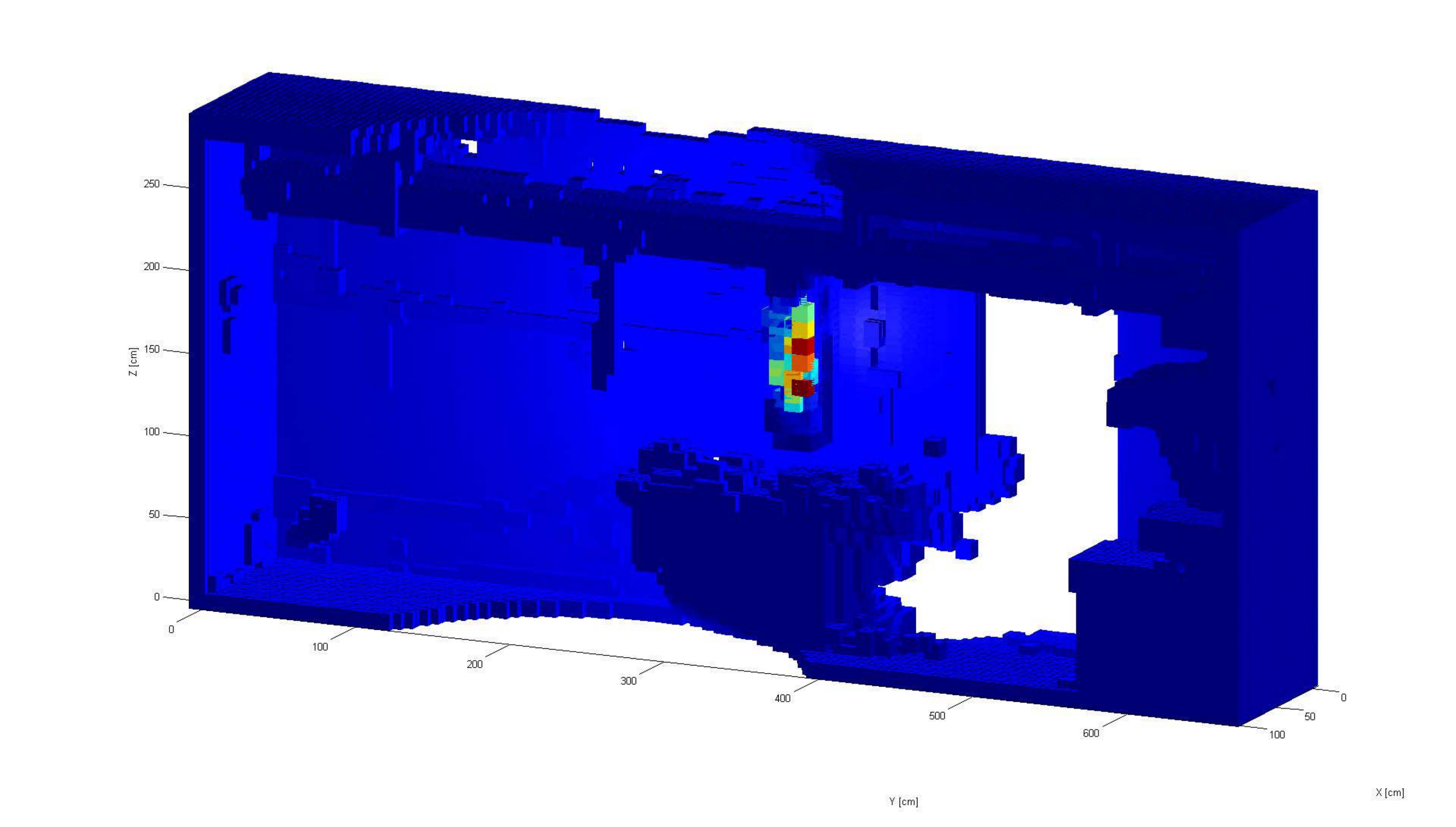
A 2D gamma-ray image is backprojected onto the range map – snapshot of the 3D model - top view

3D gamma-ray imaging results



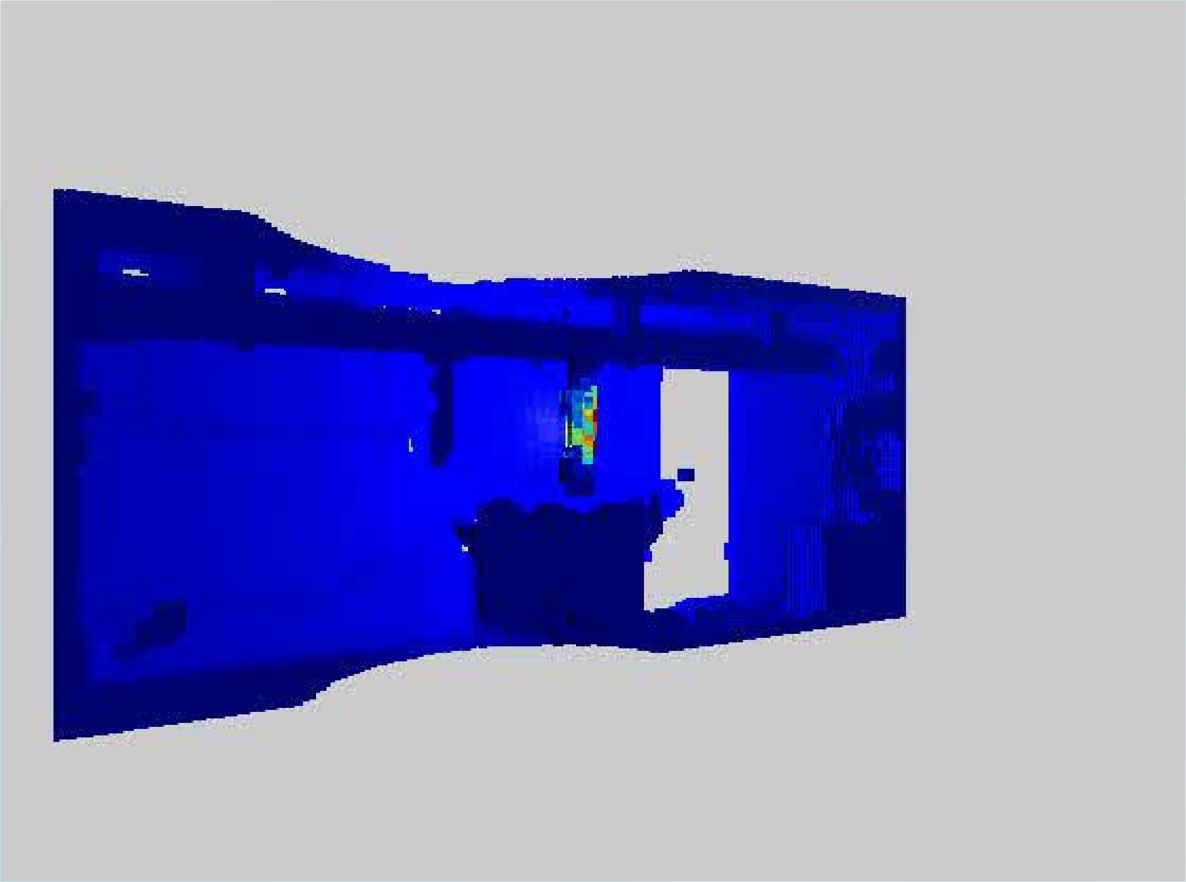
3D Backprojected image: 3000 total number of photons; 3 CCI posistions; 31000 voxel elements; 5x5x5cm^3 voxel size

3D gamma-ray imaging results



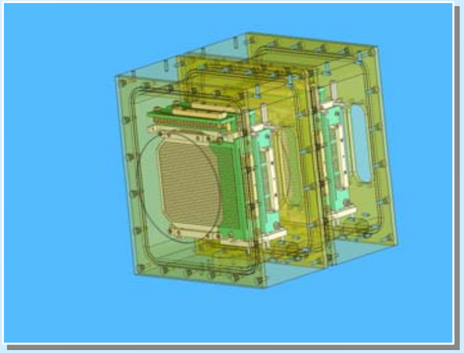
3D Reconstructed image: 3000 total number of photons; 3 CCI posistions; 31000 voxel elements; $5x5x5cm^3$ voxel size

First 3D gamma-ray imaging of far field sources

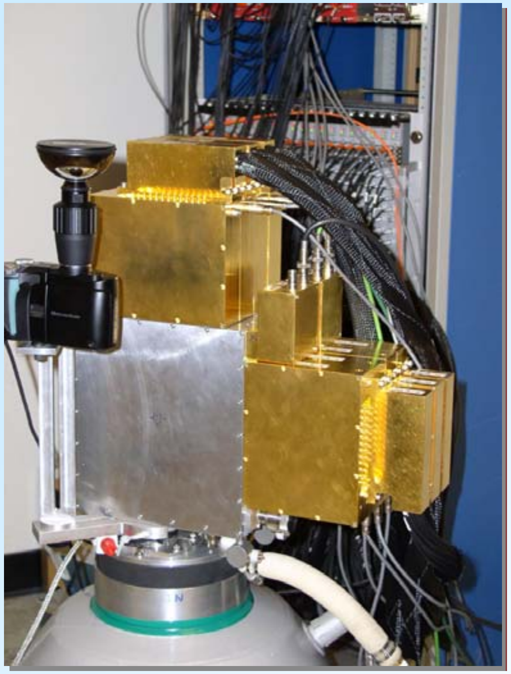


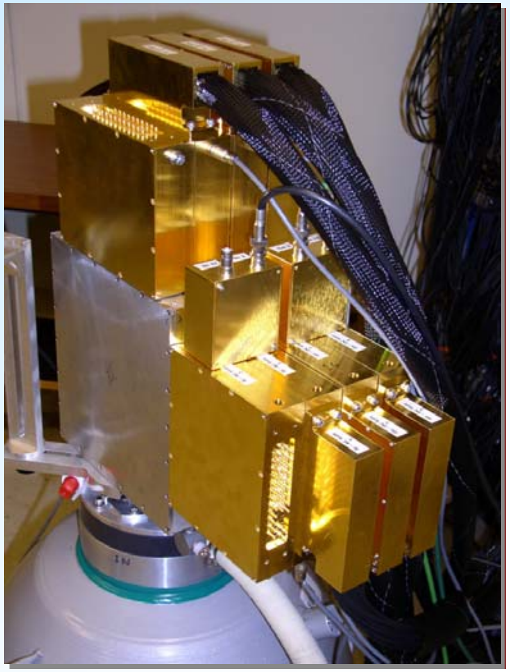
Current, second generation Compton imaging system (CCI-2)

- *Improvements in :*
  - *Sensitivity (x10 increase, as compared with CCI-1)*
  - *Count rate capability (x100 increase, as compared with CCI-1, now 10kHz)*
  - *Real-time imaging capability demonstrated in Sept. 2006.*



New prototype CCI system as of Sept. 2006 (CCI-2).
This system is one order of magnitude more efficient than CCI-1, and has two orders of magnitude higher count rate capability





Thanks to:

Kai Vetter, Dan Chivers, Morgan Burks, Lorenzo Fabris, Karl Nelson, David Hoyt, Ethan Hull, and Chris Cork
Lawrence Livermore National Laboratory

Davor Protic, Thomas Krings
Forschungszentrum Jülich

Paul Luke
Lawrence Berkeley Laboratory

This work was sponsored by the
Office of Research and Development / Department of Homeland Security.

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48. UCRL-PRES-226138

Data analysis process – imaging efficiency, image resolution, and alarming

Signal waveforms

Signal Feature Extraction

List of firing segments (E_i, t_i, a_i)

Comprehensive Event Selection

List of interactions, (E_i, $\mathbf{r}_i$)

Gamma-ray Tracking

Scattering angle θ, scattering direction s, position r, total energy E

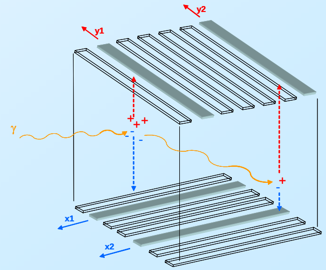
Image Reconstruction

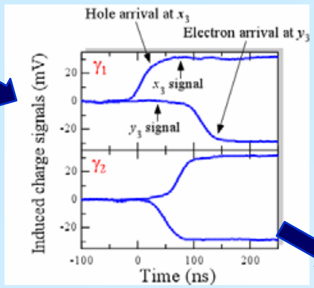
Image

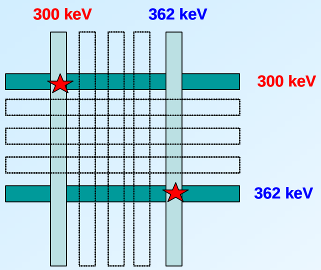
Image-Spectral Analysis

Threat identification, Diagnostics

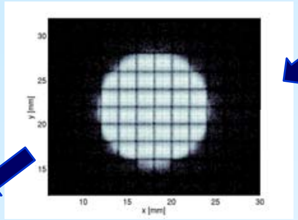
How to get from strip signal to image?

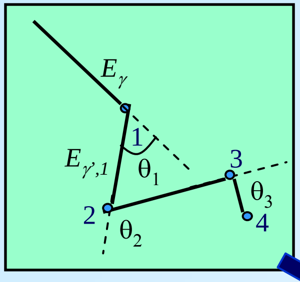


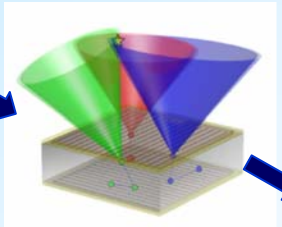




Case 1: Ideal
-Use correct x,y matching
-Use correct order of events



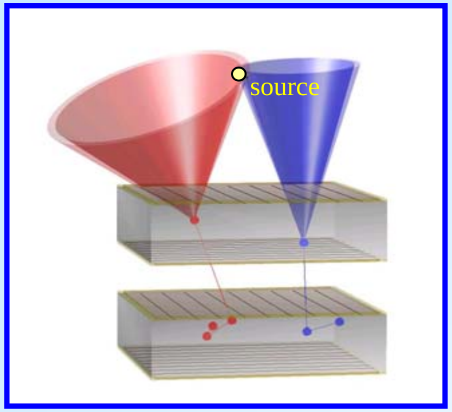




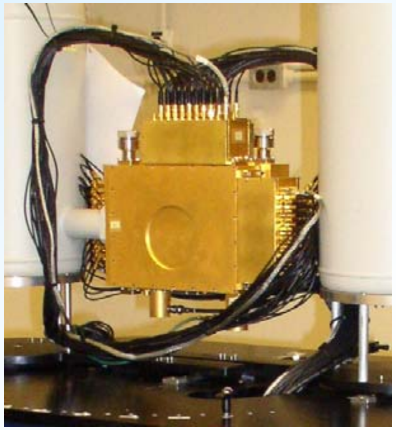
^{22}Na source identified on table

Advantages of Compton imaging with large volume Si and Ge detectors

- High efficiency by using large volume detectors
- High granularity through advanced data processing
- Energy resolution of 2 keV enables high angular resolution and an accurate identification of radioisotopes and nuclear materials.
- Angular resolution of about 2 degrees
- Large Field of view (close to 4π). This allows creation of panoramic images.
- Imaging sensitivity to gamma-ray photons of energies between 150keV to several MeVs.

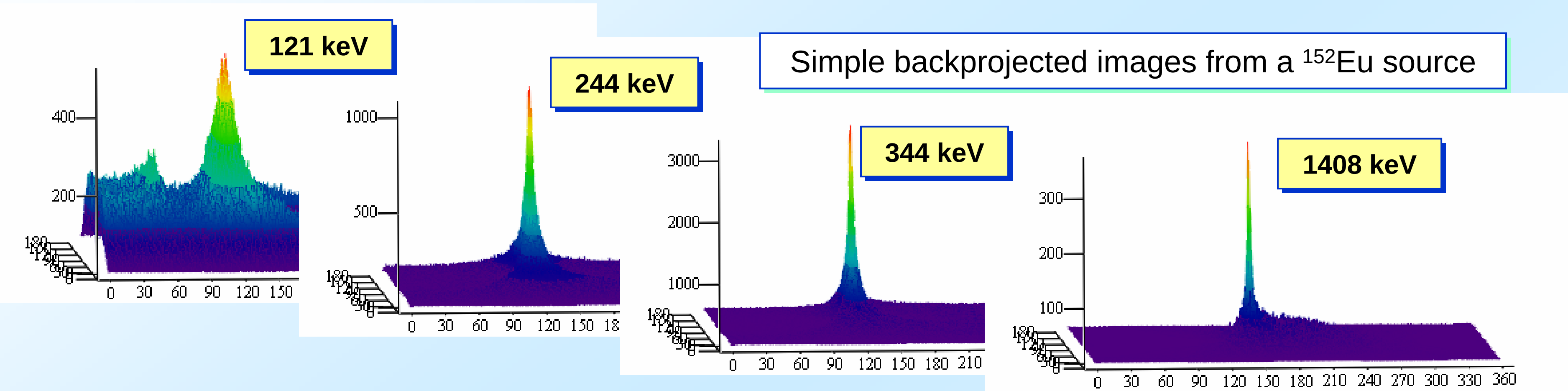


The positions and energies of all interactions are used to determine the scattering angle and scattering direction for the first Compton interaction.



With CCI-1 we have demonstrated Compton imaging for a range of energies and source locations

Simple backprojected images from a ^{152}Eu source



Angular resolution