Polaris 3-D CdZnTe (CZT) Gamma-Ray Imaging Spectrometers

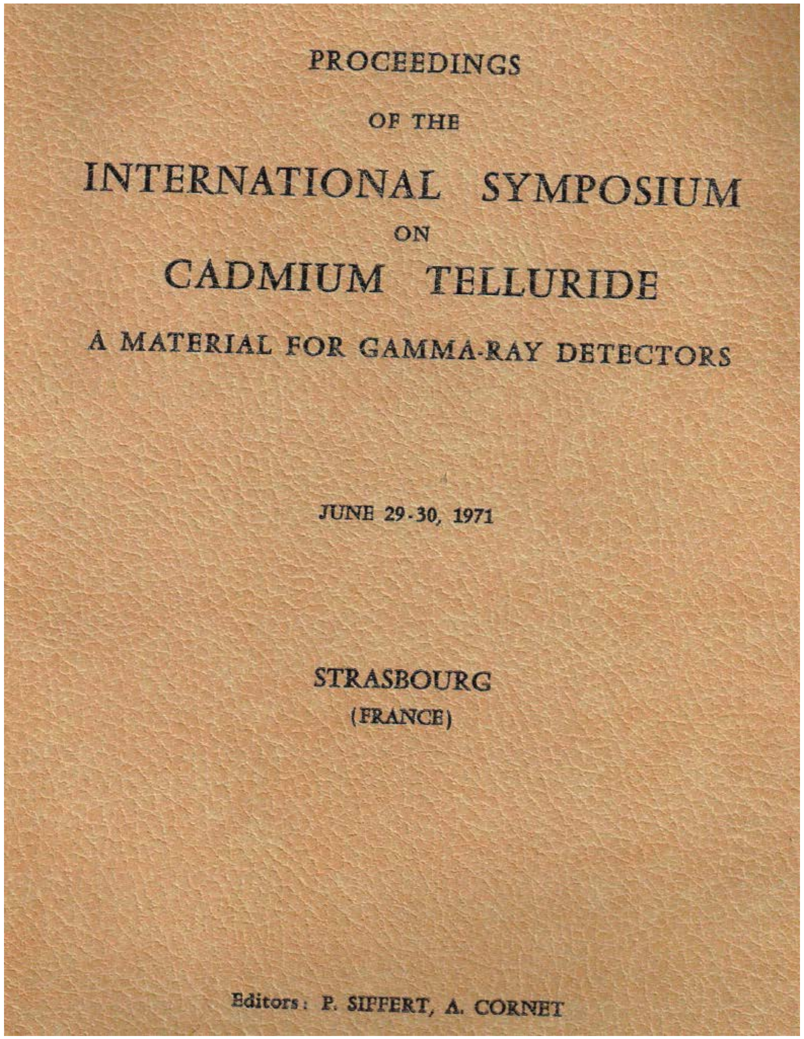
Zhong He

UNIVERSITY OF MICHIGAN

ISOE-ALARA Symposium, January 12, 2015

Acknowledgements:
DOD, DOE and DHS

John M. Palms Outstanding Innovation Began in early 1960s



PROCEEDINGS

OF THE

INTERNATIONAL SYMPOSIUM

ON

CADMIUM TELLURIDE

A MATERIAL FOR GAMMA-RAY DETECTORS

JUNE 29-30, 1971

STRASBOURG

(FRANCE)

Editors: P. SIFFERT, A. CORNET

XXIII-1

THE EVALUATION OF CdTe FOR GAMMA AND X-RAY SPECTROMETERS AND COUNTERS*

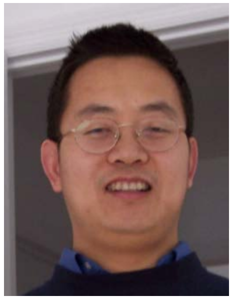
J. M. Palms
Physics Department
Emory University
Atlanta, Georgia 30322

Summary

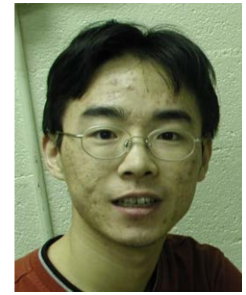
Radiation detectors have been fabricated from high resistivity (semi-insulating) and low resistivity n-type CdTe, vapor grown and grown from the melt. These devices were Al and Au surface barrier detectors having thicknesses from 0.8mm to 1.5mm, and areas from $2mm^2$ to $25mm^2$. The pulse-height response of these devices to low energy gammas and x-rays were studied as a function of detector bias (0 to 1000 volts) and temperature (-75°C to 52°C). The pulse-height spectra of all devices was affected by the presence of trapping sites and material inhomogeneities. All devices showed the mechanisms of trapping and detrapping of charge carriers. The total counting efficiency for most devices was, however, high (>85%). For a typical detector, an Al surface barrier detector fabricated from n-type CdTe, the total system resolution was approximately 10.7 keV (FWHM) for the 122 keV gamma from ^{57}Co. For this device the 136 keV and 122 keV gammas from ^{57}Co were clearly resolved; the peak-to-valley ratio for the 122 keV line was 4 to 1 and the K_α x-ray escape peaks were clearly visible. The response of other CdTe detectors to gammas and low energy x-rays are presented.

Thank you!

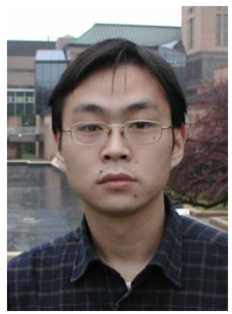
20 Ph.Ds Graduated





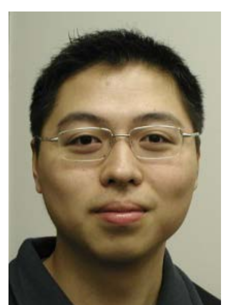






HED Inc.



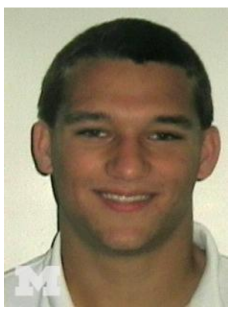



Current Orion group members


Zhong He


Yuefeng Zhu


Jim Berry


Josh **Mann**


Steven **Brown**

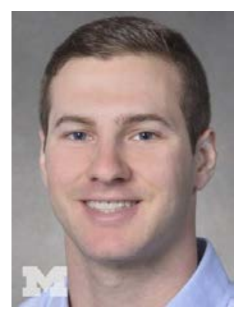

Will **Koehler**

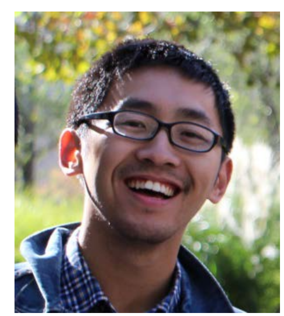

Michael **Streicher**


Sean **O'Neal**


Jiyang **Chu**

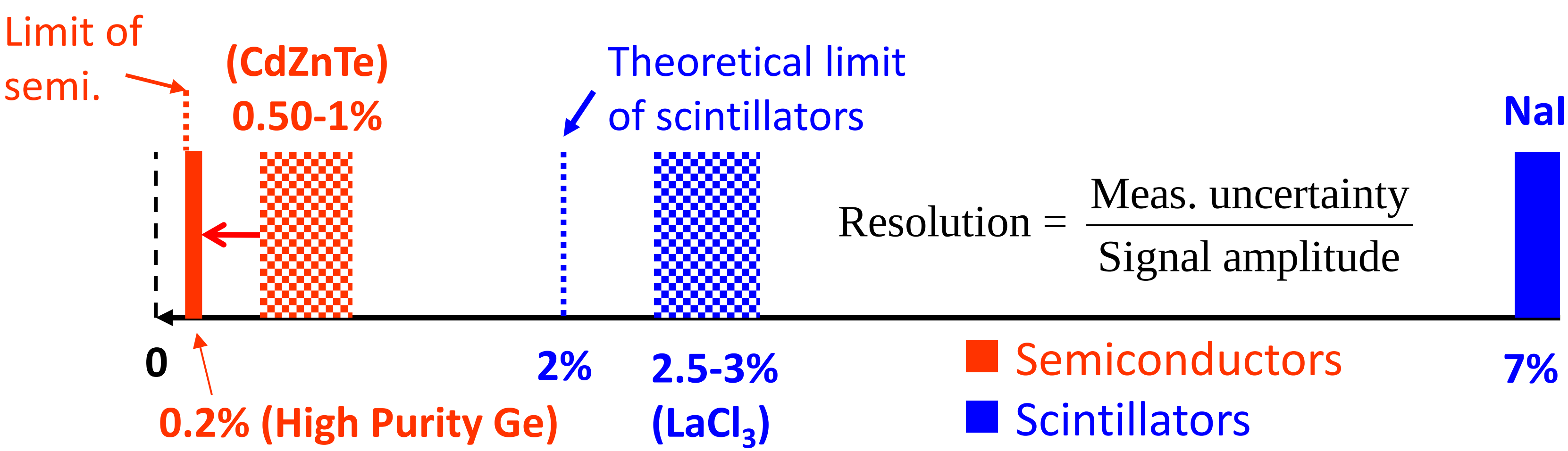

David **Goodman**


Bennett **Williams**


Jiawei **Xia**

Why CdZnTe?

(1) Superior energy resolution



(2) Higher sensitivity per unit volume (higher **Z** and **density**) – **compactness**

CdZnTe(**48**-30-**52**, **6.0**), High-purity Ge(**32**, **5.32**)

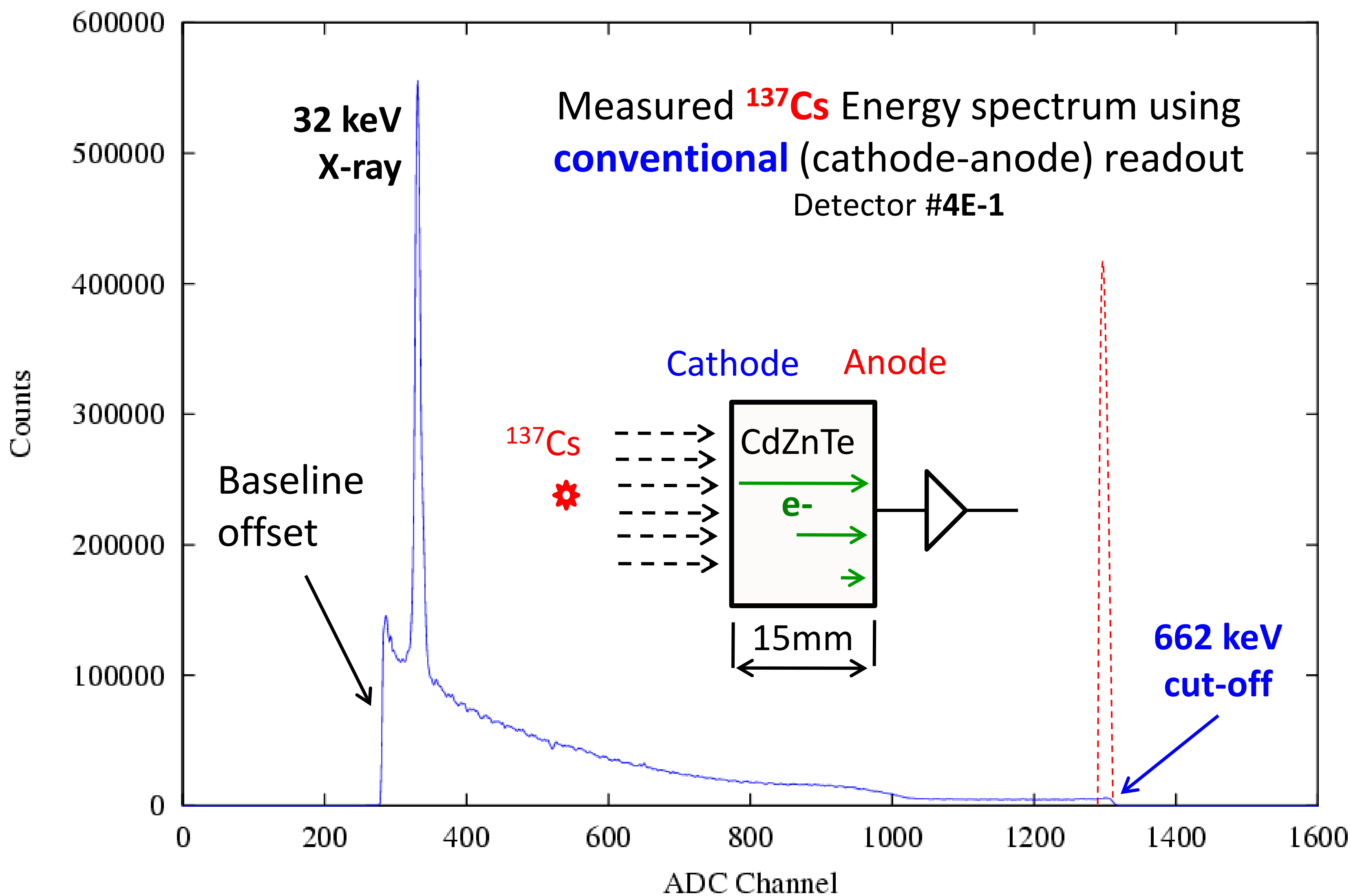
(3) Room-temperature operation (no cryogenic cooling) → Wide band-gap

Technical challenges

(1) Severe hole trapping & electron trapping cause signal deficit

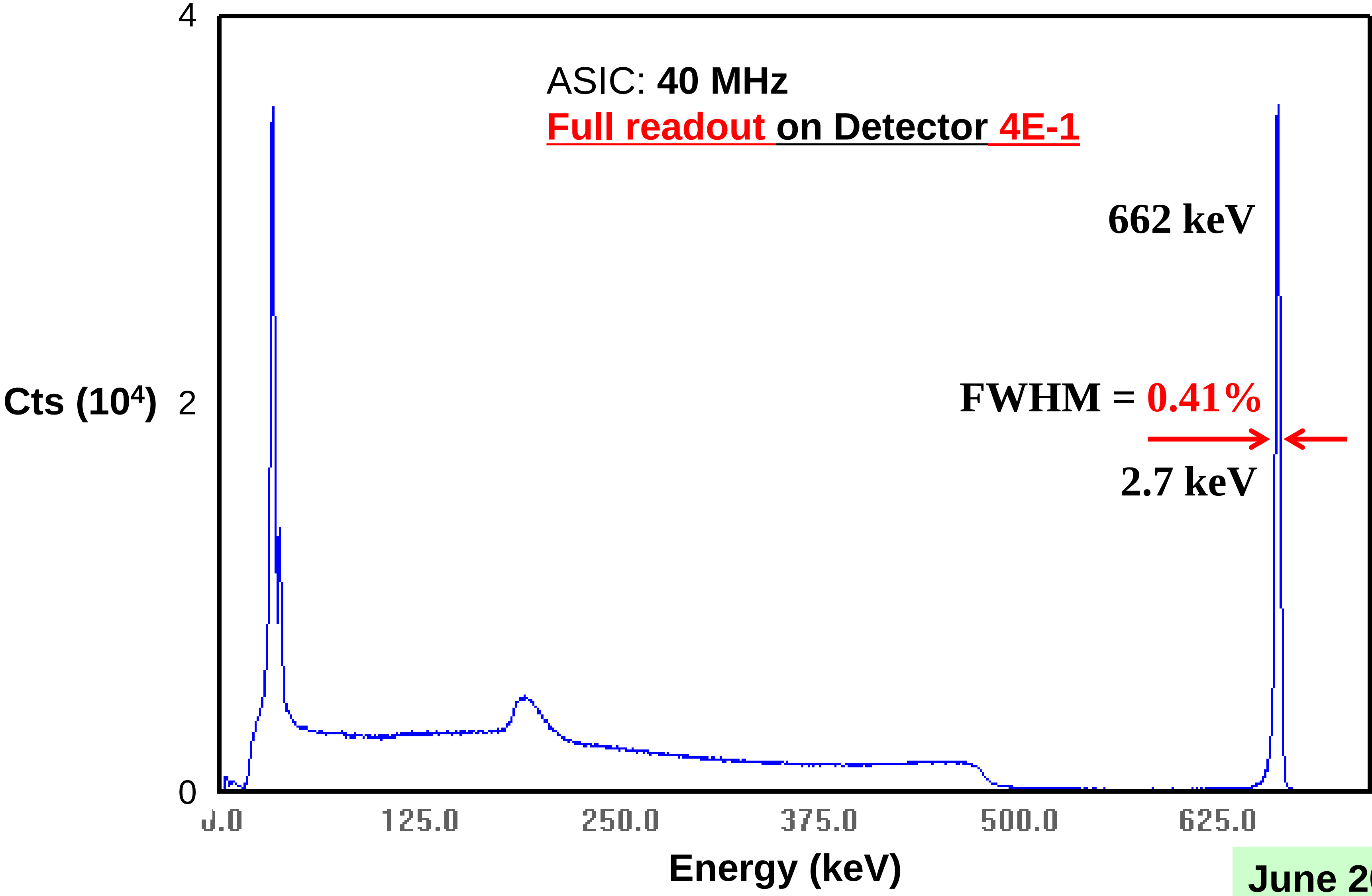
(2) Crystal yield (cost) and non-uniformity

Before 1994



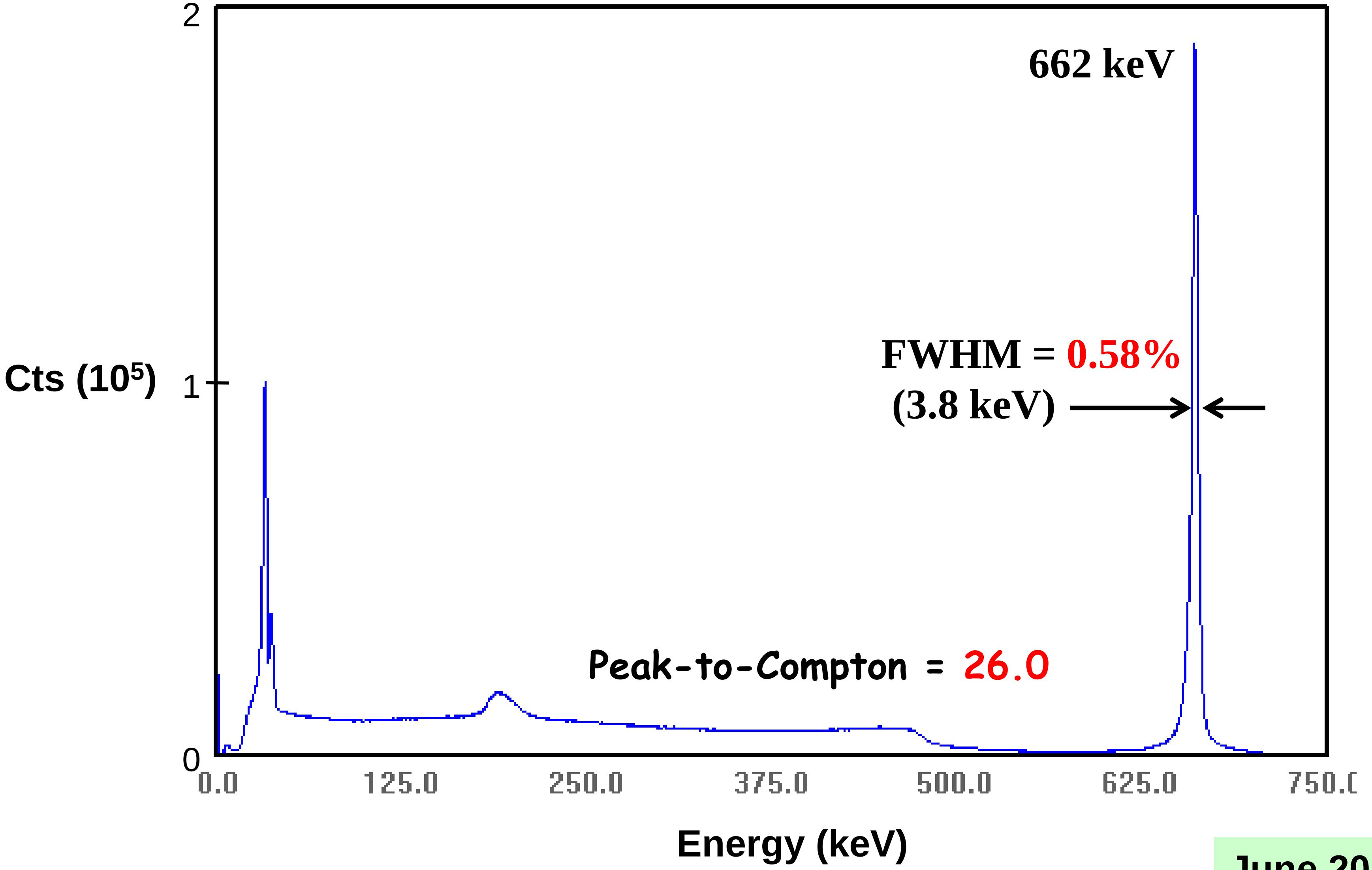
Signal amplitude = gain×(**n·e$_0$**)×(normalized electron drift length **z**) ∝ **Energy** × **z**

Improvement Using 3-D Readout Technology



June 2013

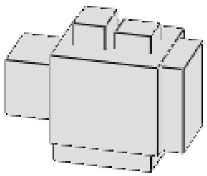
All-events (no selection)

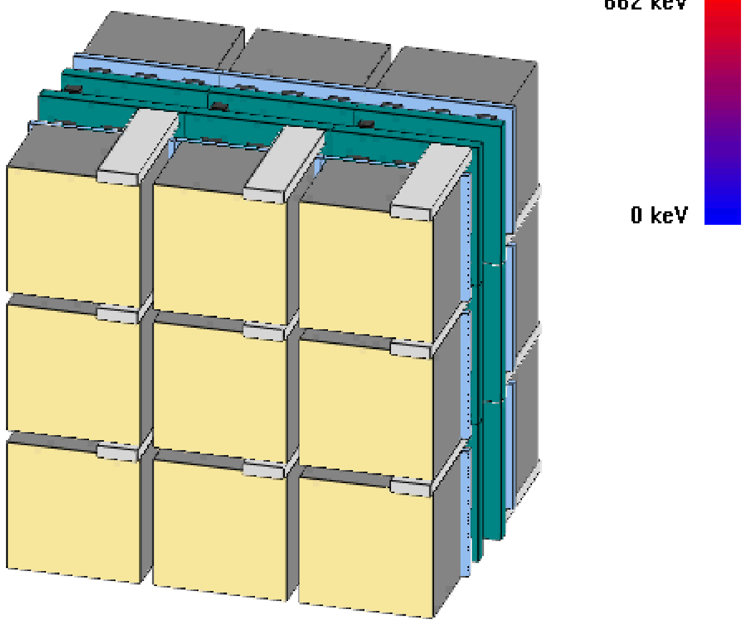


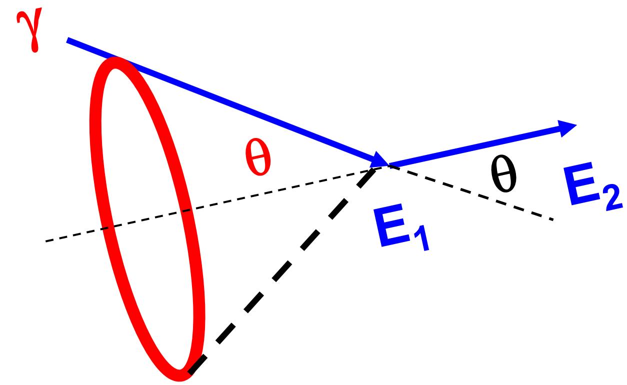
June 2013

Polaris Systems

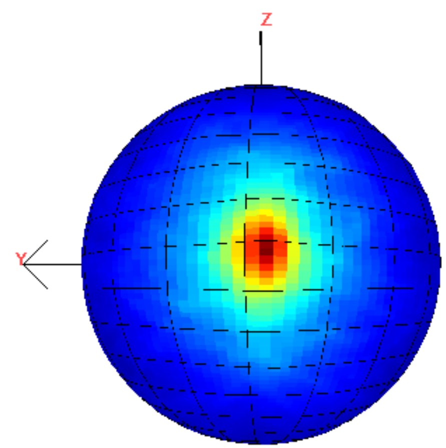
Eighteen 2×2×1.5 cm³ CdZnTe detectors
(108 cm³, 648 grams = 1.43 lb)







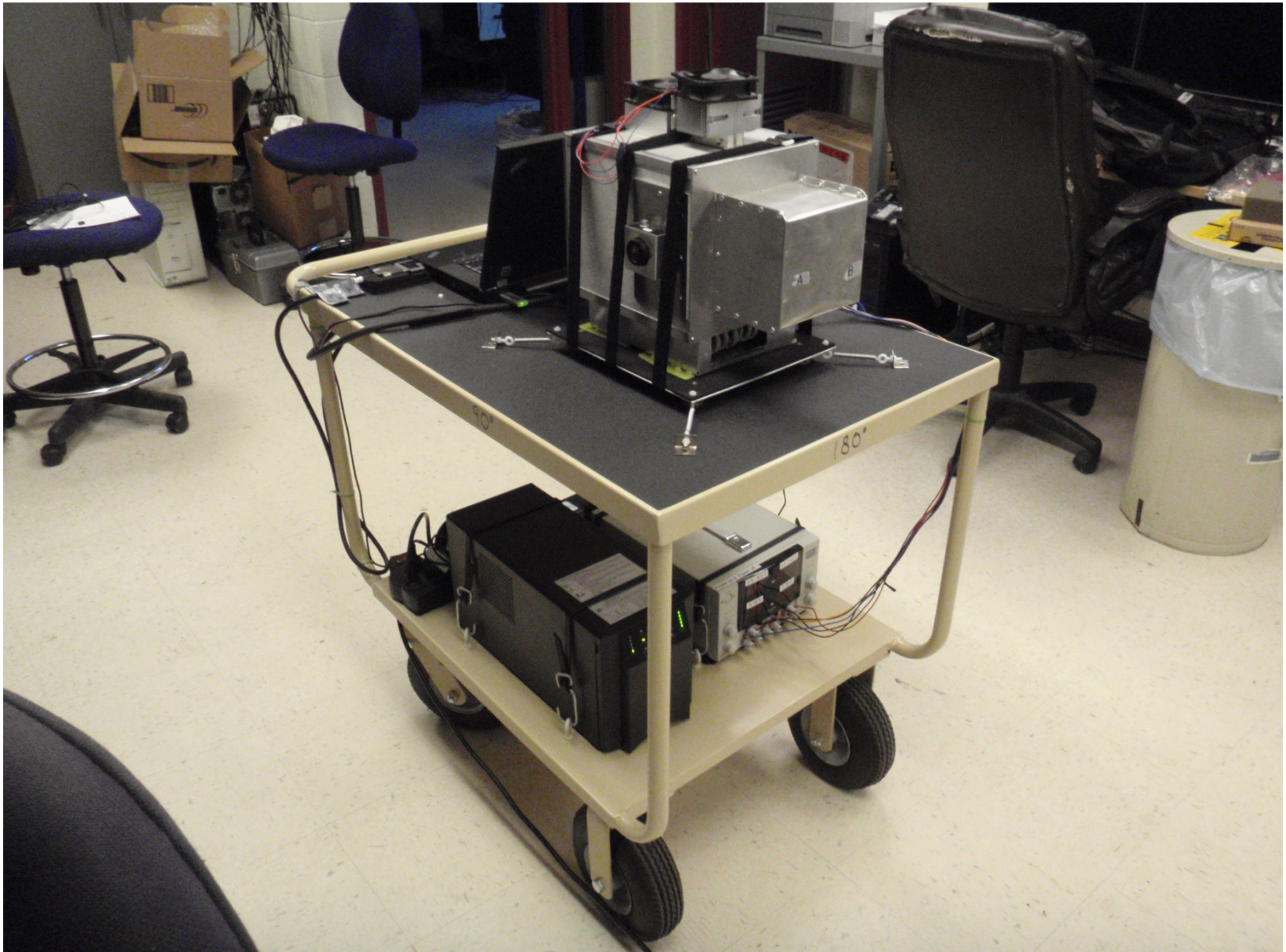
$$\cos\theta = 1 - \frac{E_1 m_e c^2}{(E_1 + E_2)\cdot E_2}$$



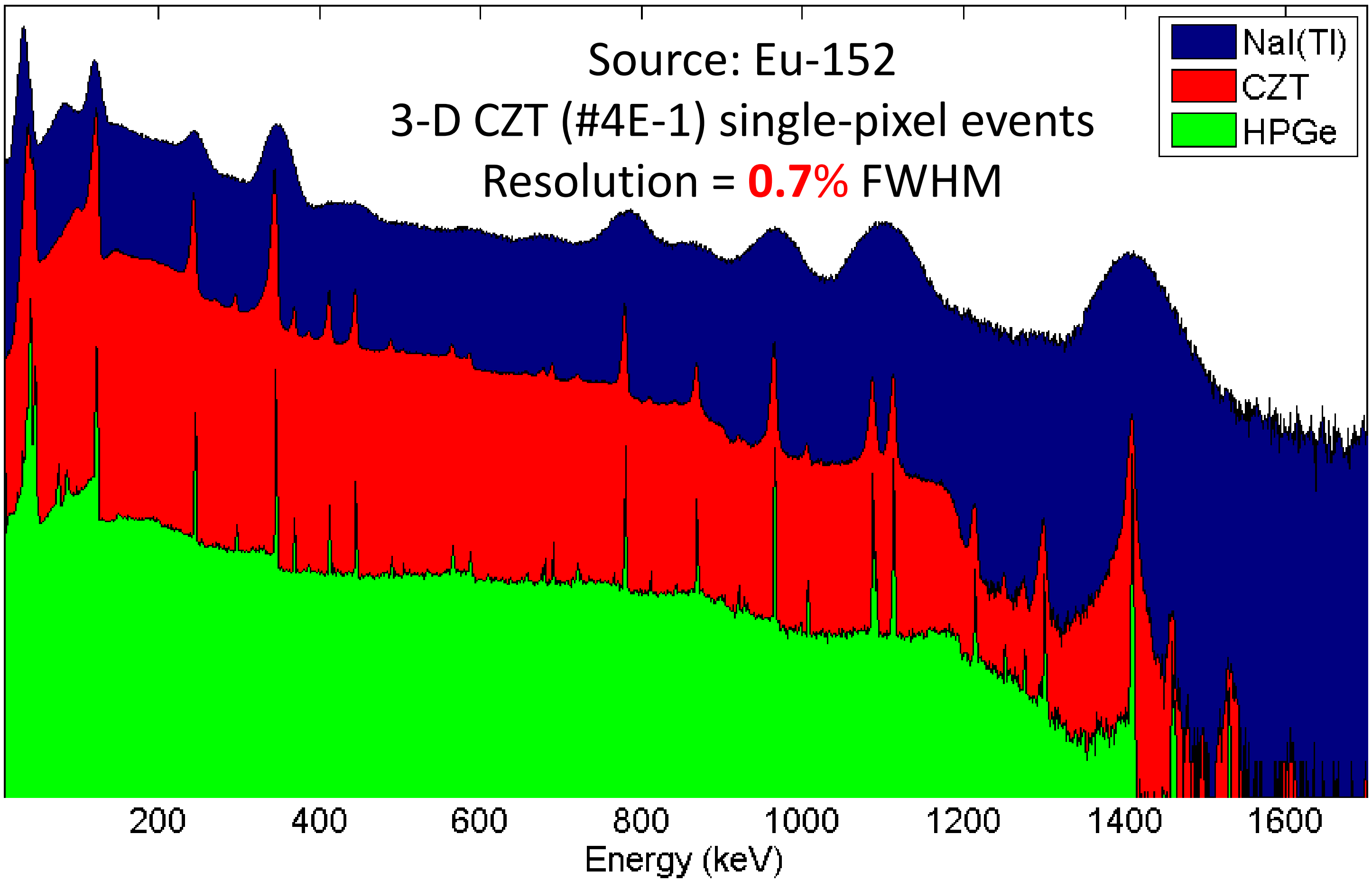
Number of photons: 2033

<u>Performance Goals</u>
ΔE/E ≤ 1% FWHM (at 662 keV)
Real-time γ Imaging + isotope I.D.

Polaris 1.1 (GMI ASIC) – August 2010

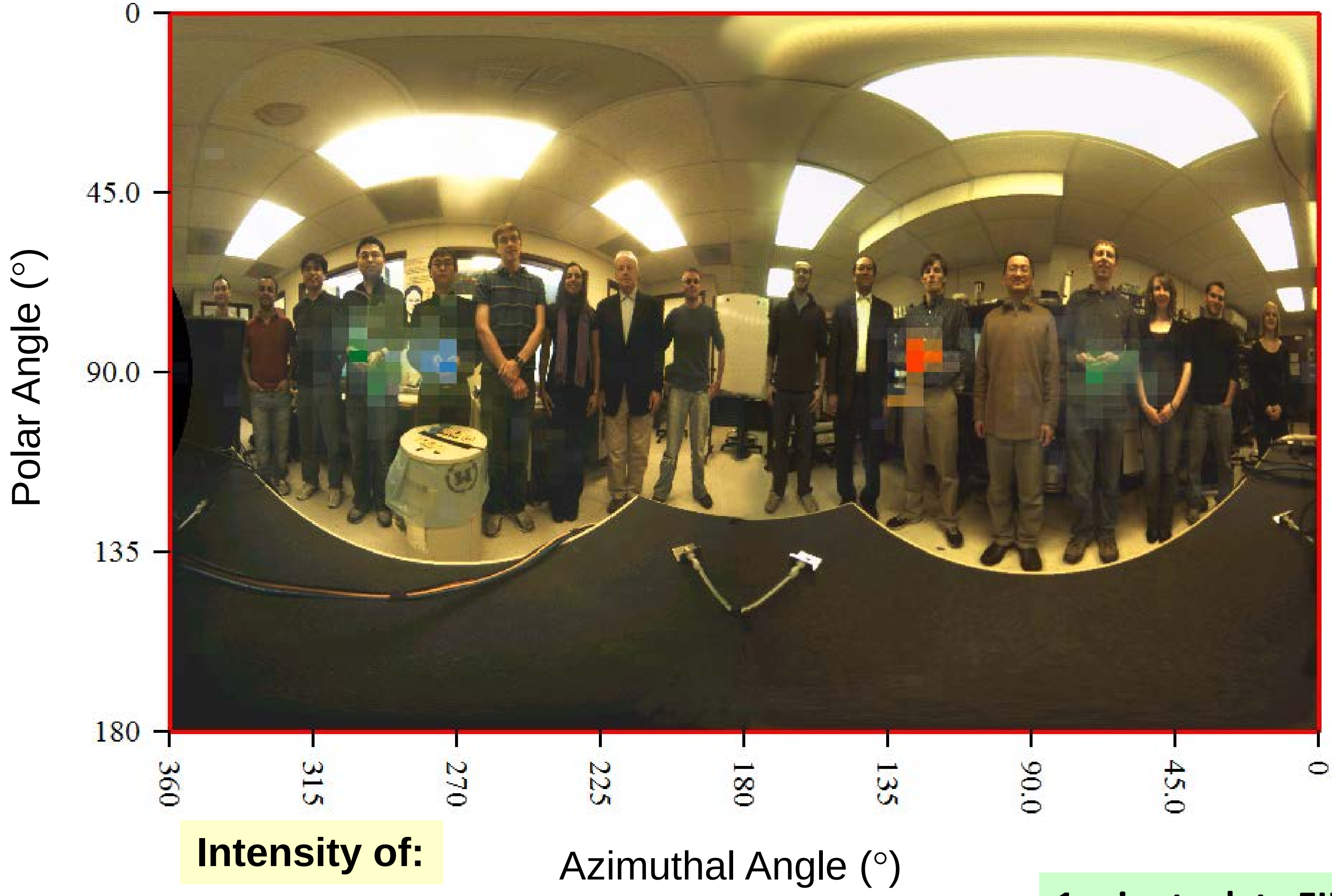


Comparing to Other γ Spectrometers



High resolution → High isotope selectivity/ID & low background

Gamma Imaging Capability

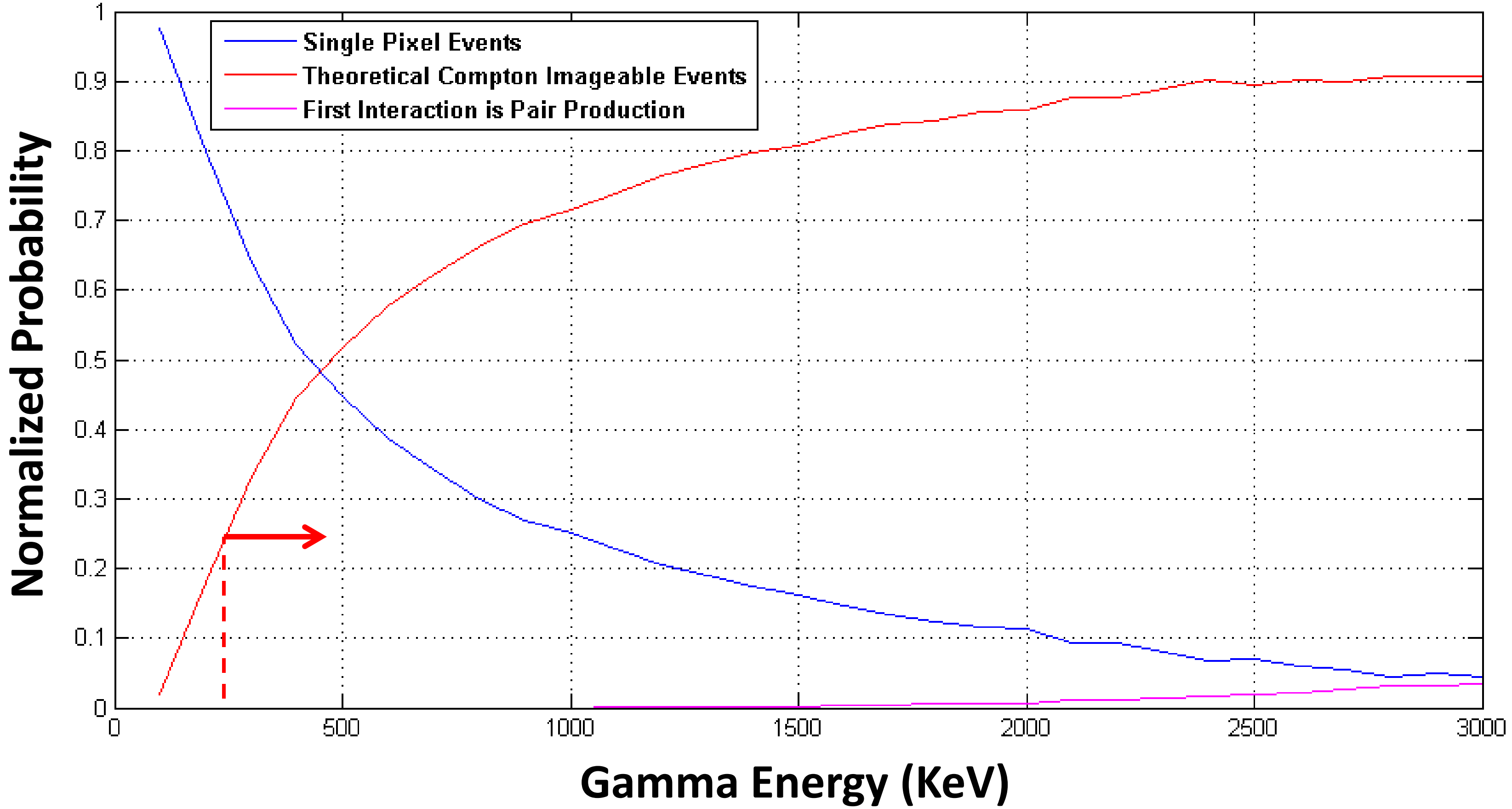


Intensity of:

^{22}Na ^{60}Co ^{137}Cs

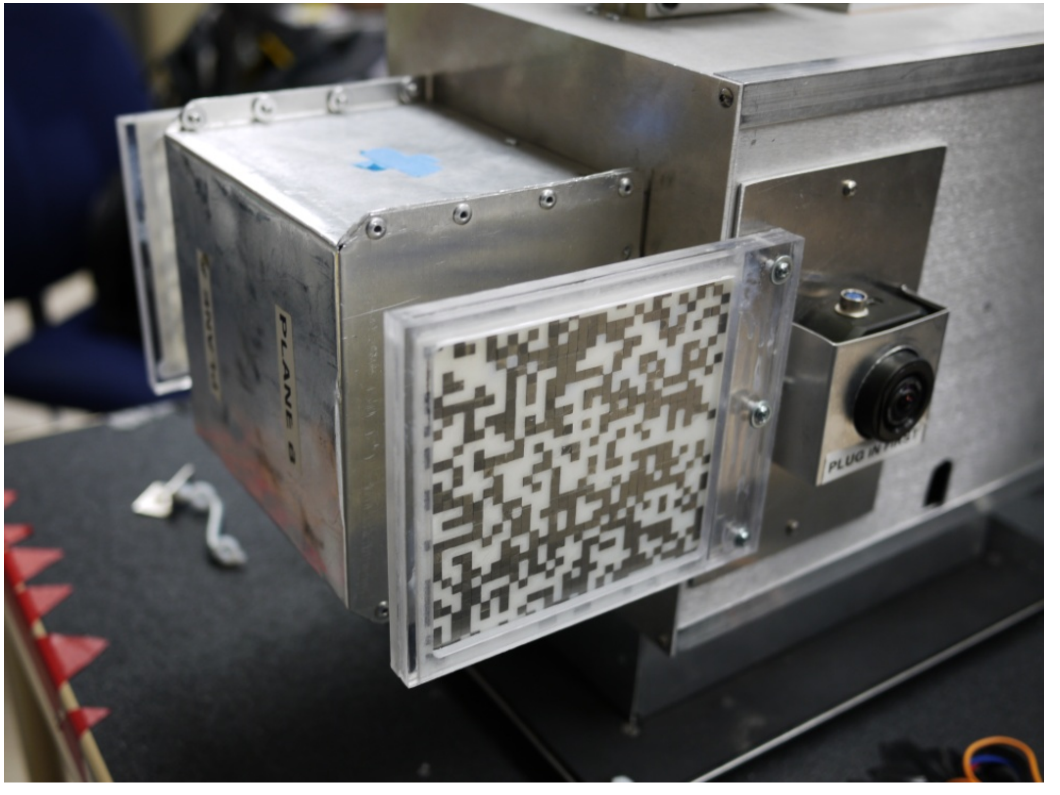
1 minute data EIID

Energy Range of Compton Imaging



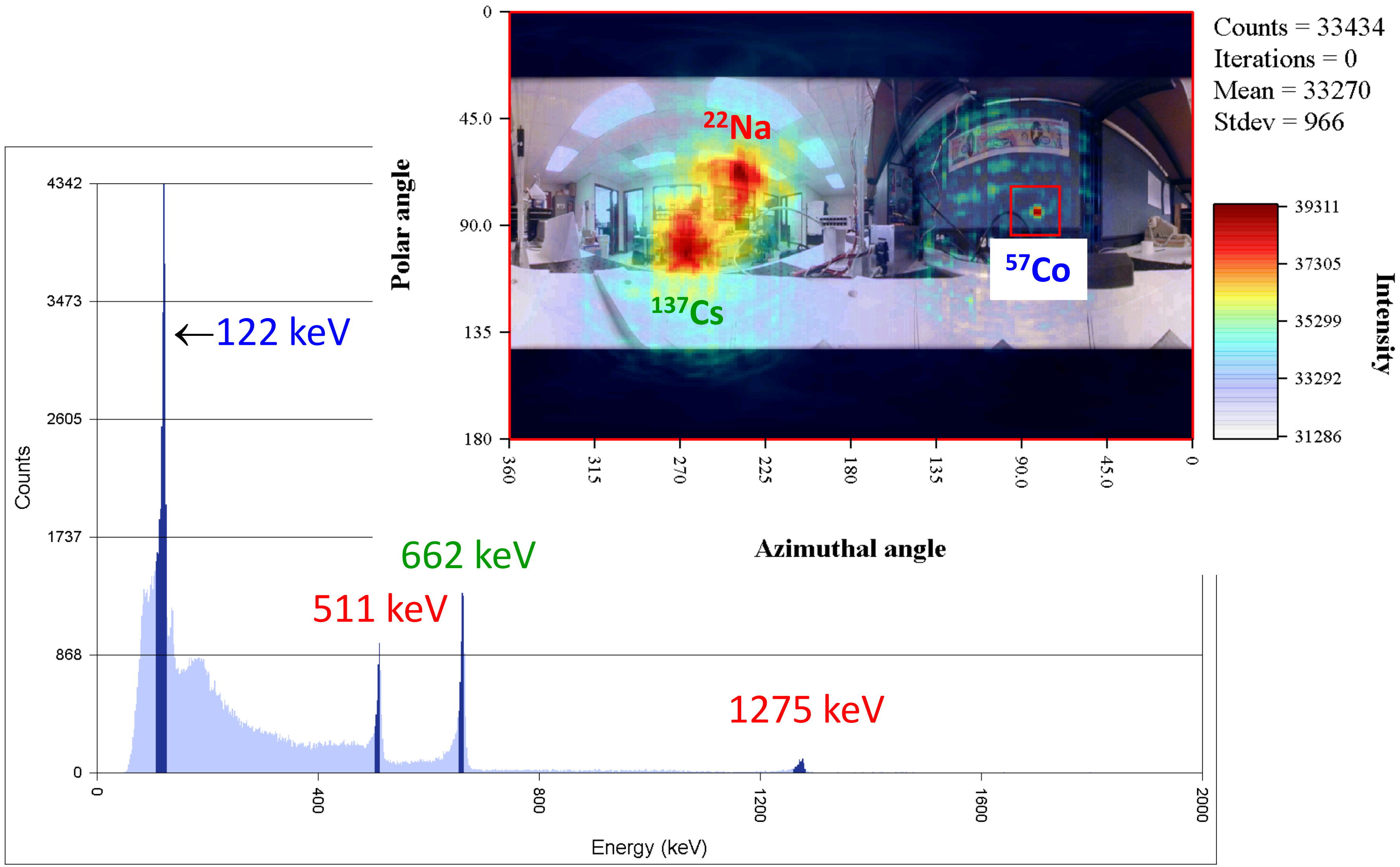
Polaris-H performs Compton imaging for γ-rays with E ≥ 250 keV

Coded Aperture Imaging at E ≤ 250 keV



<u>Principle</u>: Recognize unique mask shadows from different incident gamma-ray angles

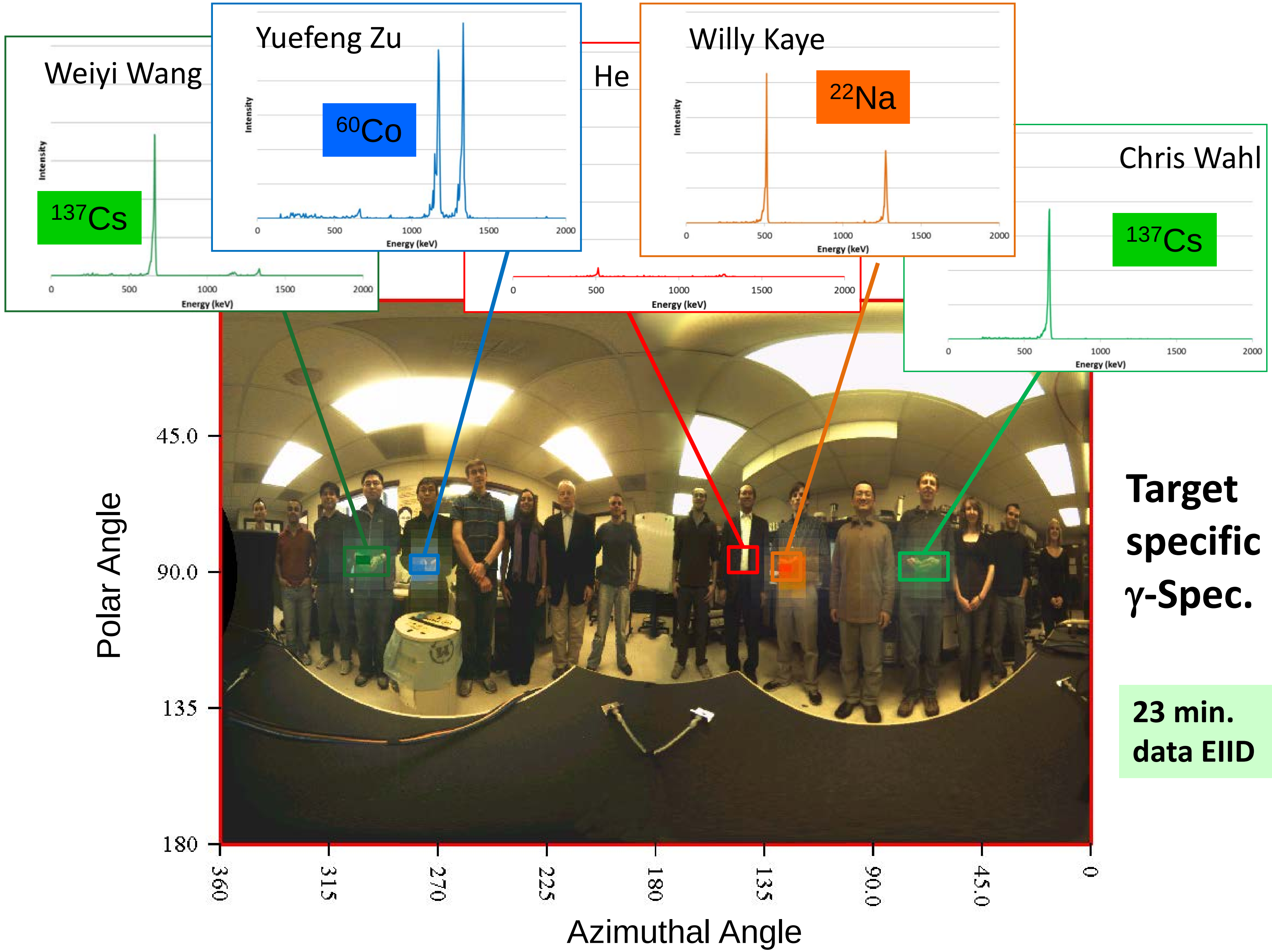
Real-Time Combined Coded Aperture and Compton Imaging



Advanced Capabilities

Example 1

Directional spectroscopy



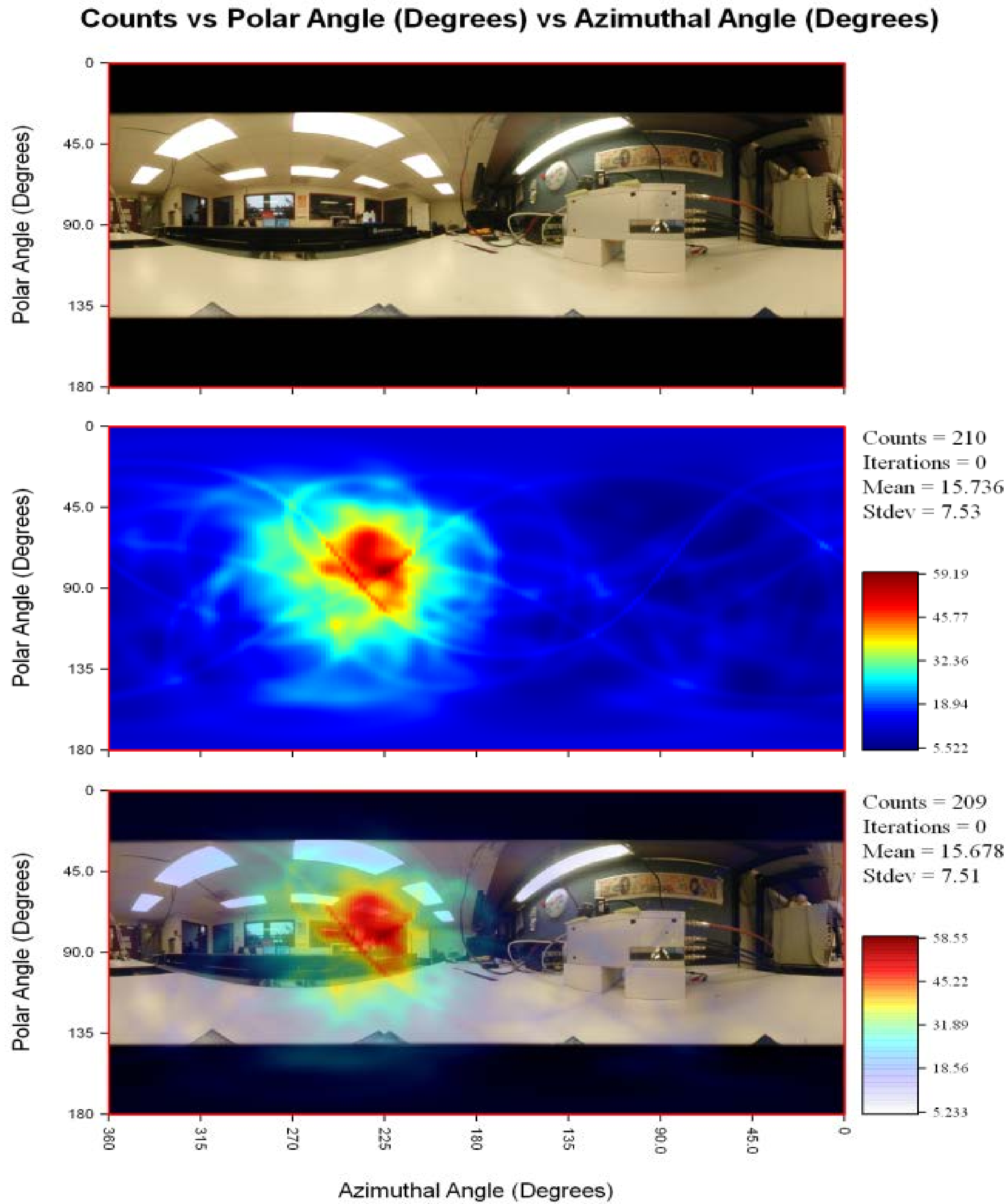
Weiyi Wang
137Cs
Yuefeng Zu
60Co
He
Willy Kaye
22Na
Chris Wahl
137Cs
Intensity
Energy (keV)
Polar Angle
Azimuthal Angle
Target specific γ-Spec.
23 min. data EIID

Advanced Capabilities

Example 2

Detect and Characterize moving sources

Tracking Moving Targets



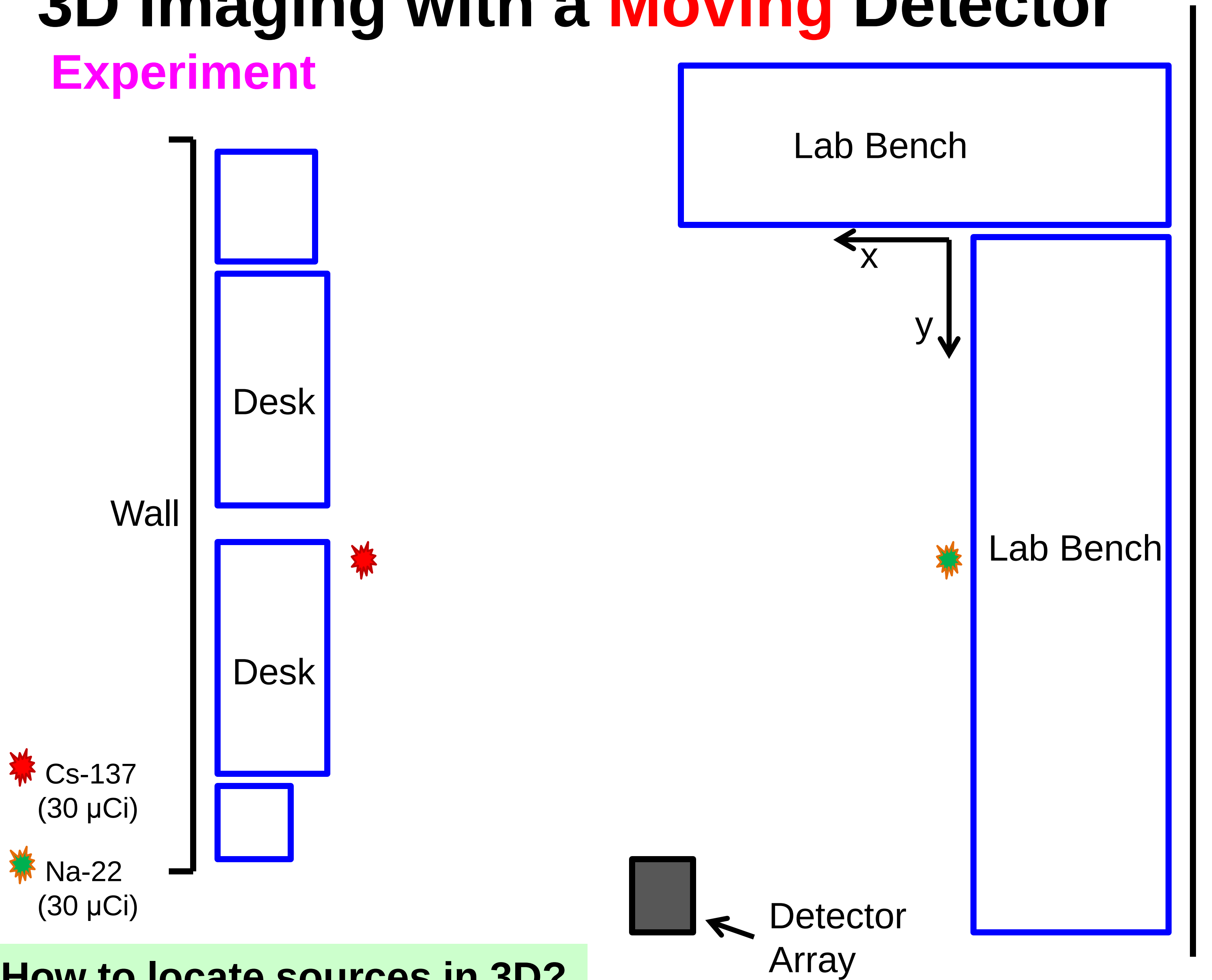
Advanced Capabilities

Example 3

3-Dimensional Imaging

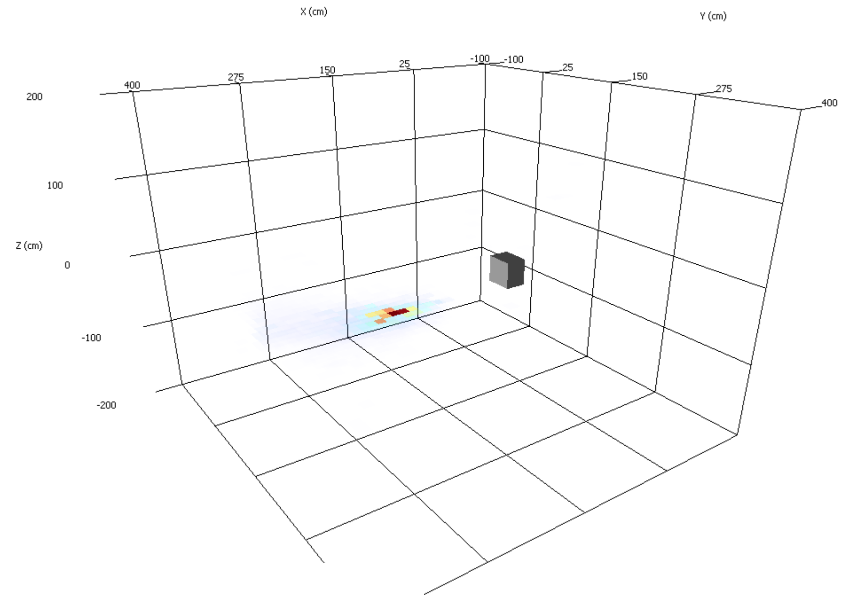
3D Imaging with a Moving Detector

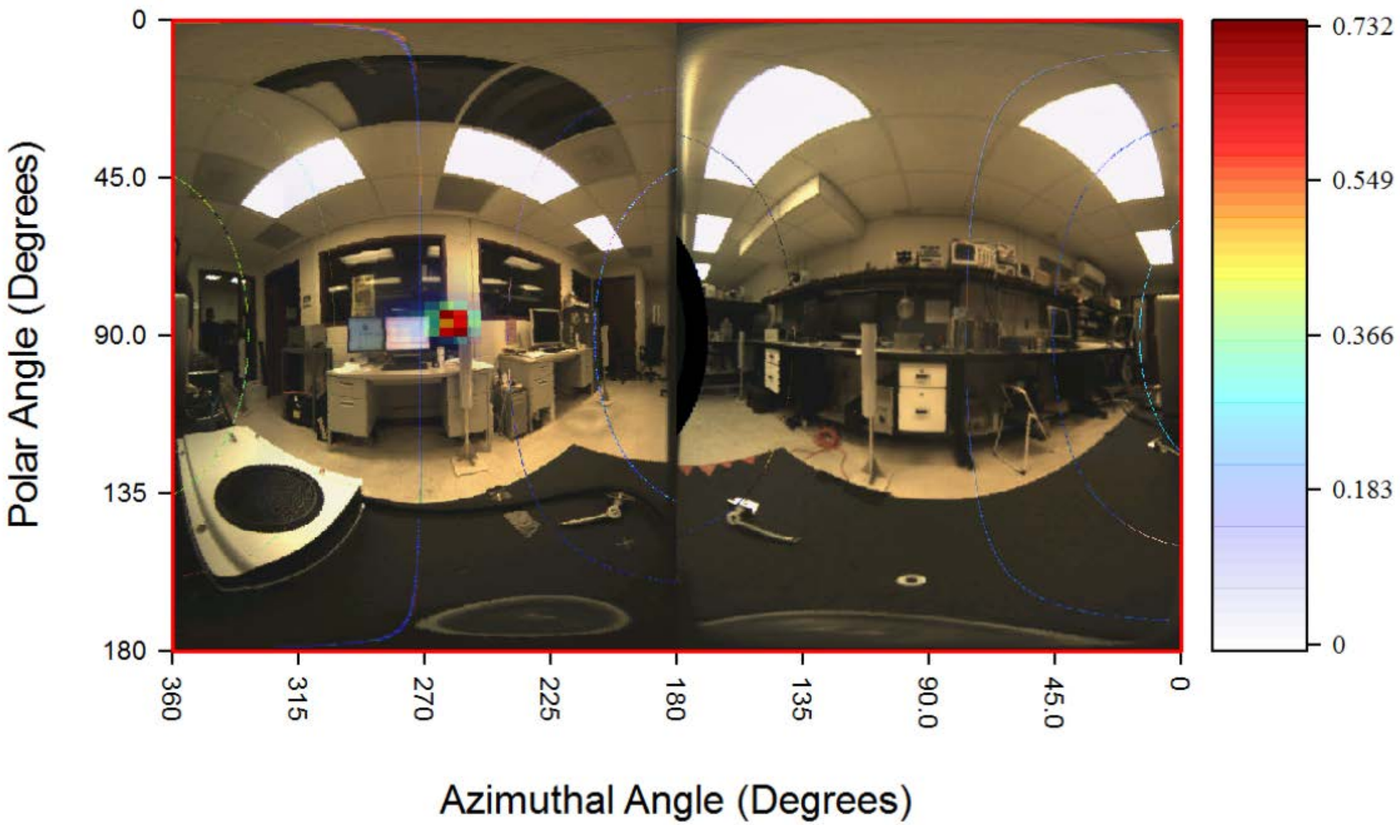
Experiment



How to locate sources in 3D?

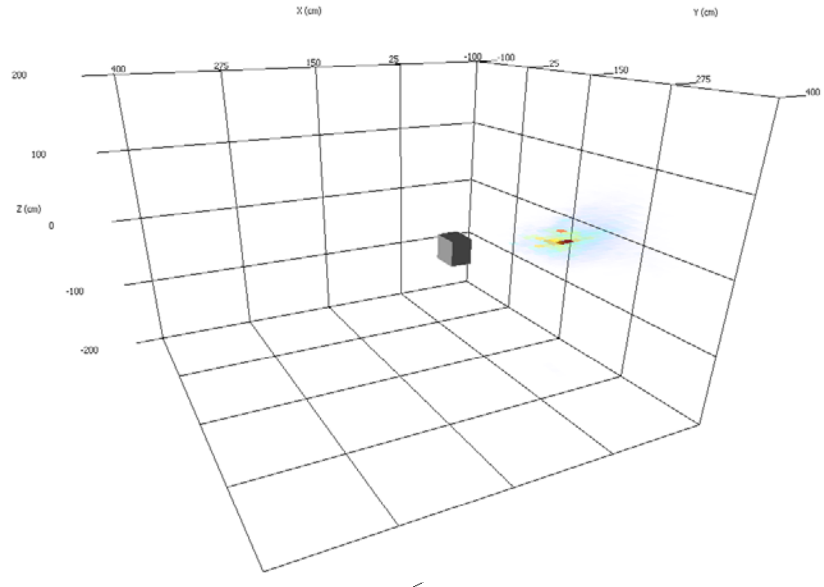
MLEM Imaging with a moving detector

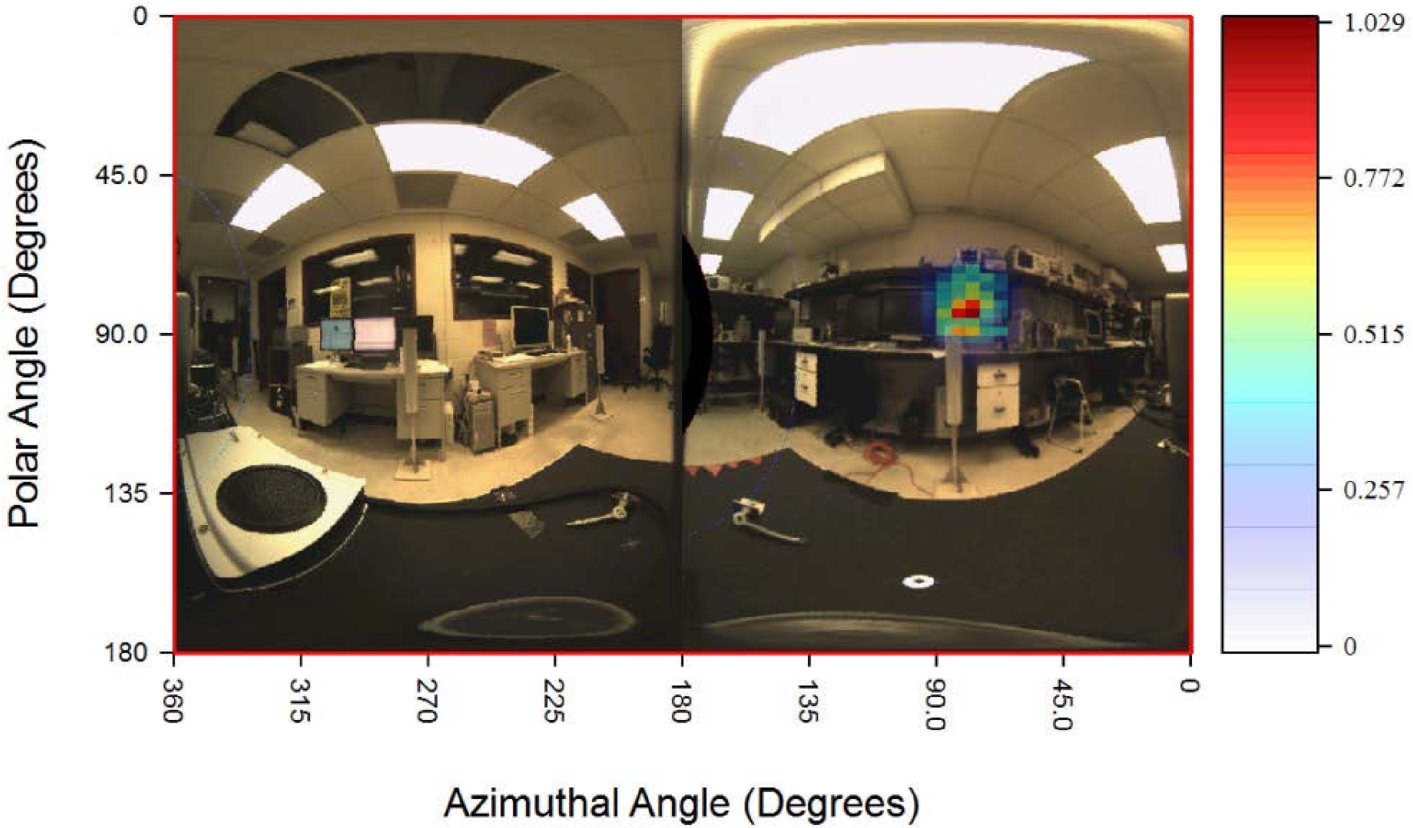




Energy Window:
Cs-137

MLEM Imaging with a moving detector





Energy Window:
Na-22

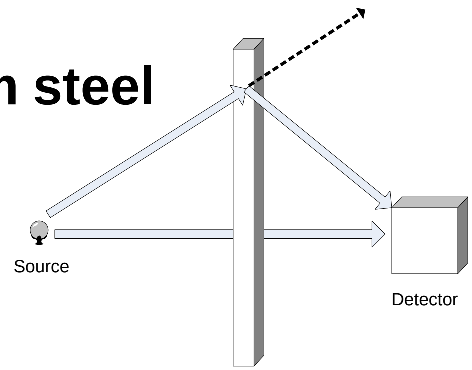
Advanced Capabilities

Example 4

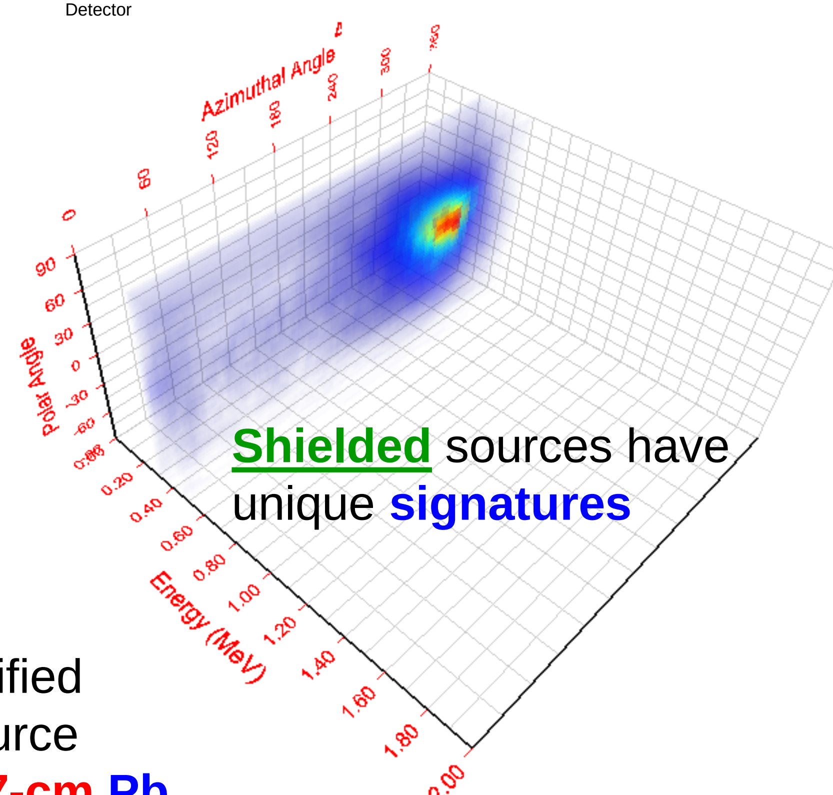
Detection of Source Shielding

Detection of shielded source

^{137}Cs behind 3.7-cm steel



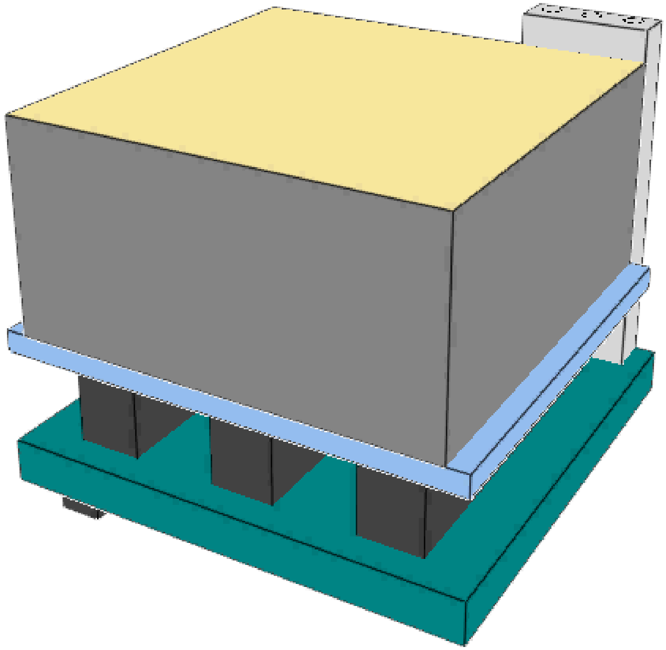
Cs-137 no shielding



Shielded sources have unique **signatures**

Also identified a ^{60}Co source behind **2.7-cm Pb**

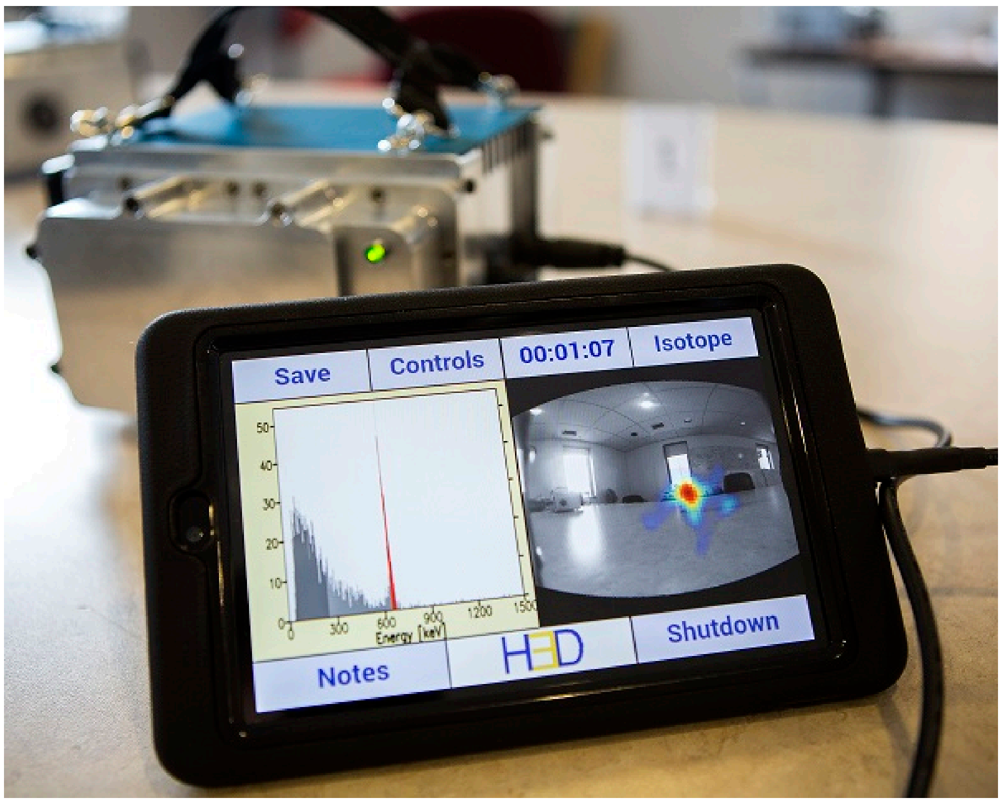
Today and Tomorrow

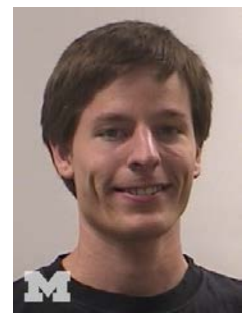


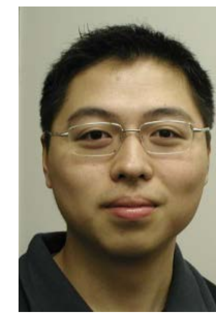
Univ. of Michigan Polaris Technology

↓ **Licensed to**

H3D, Inc.



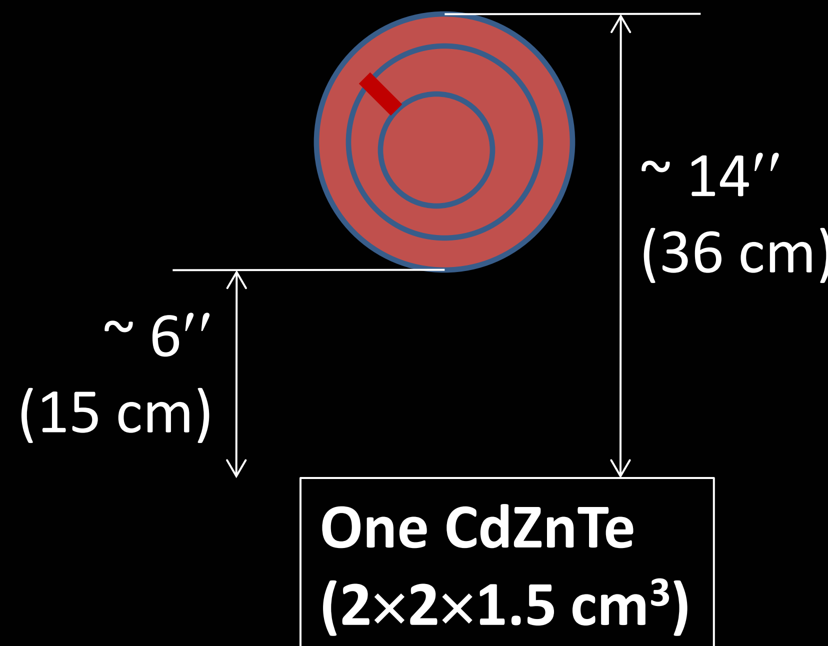




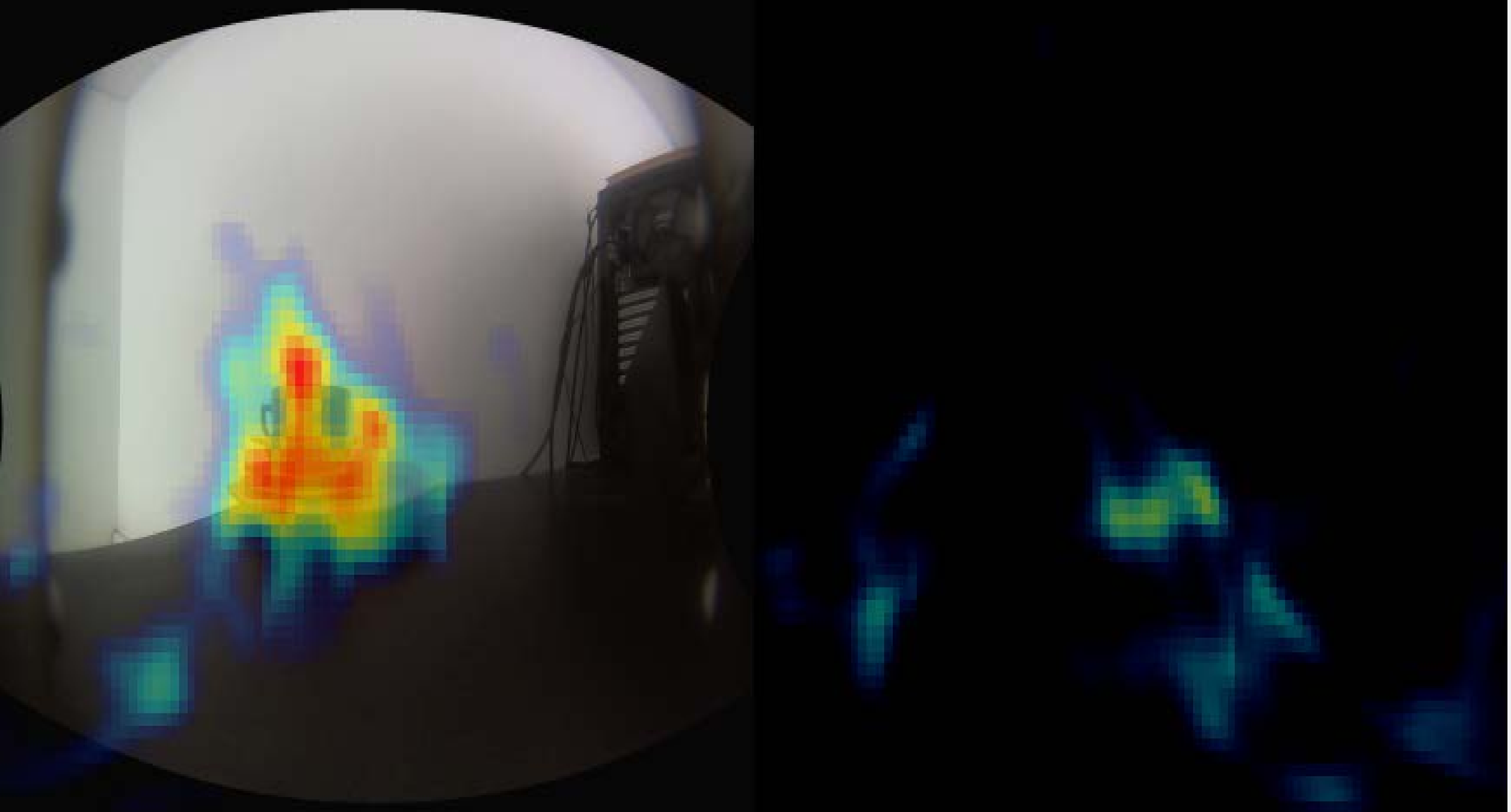
Fiestaware

Compiled by Dr. Chris Wahl of H3D Inc.

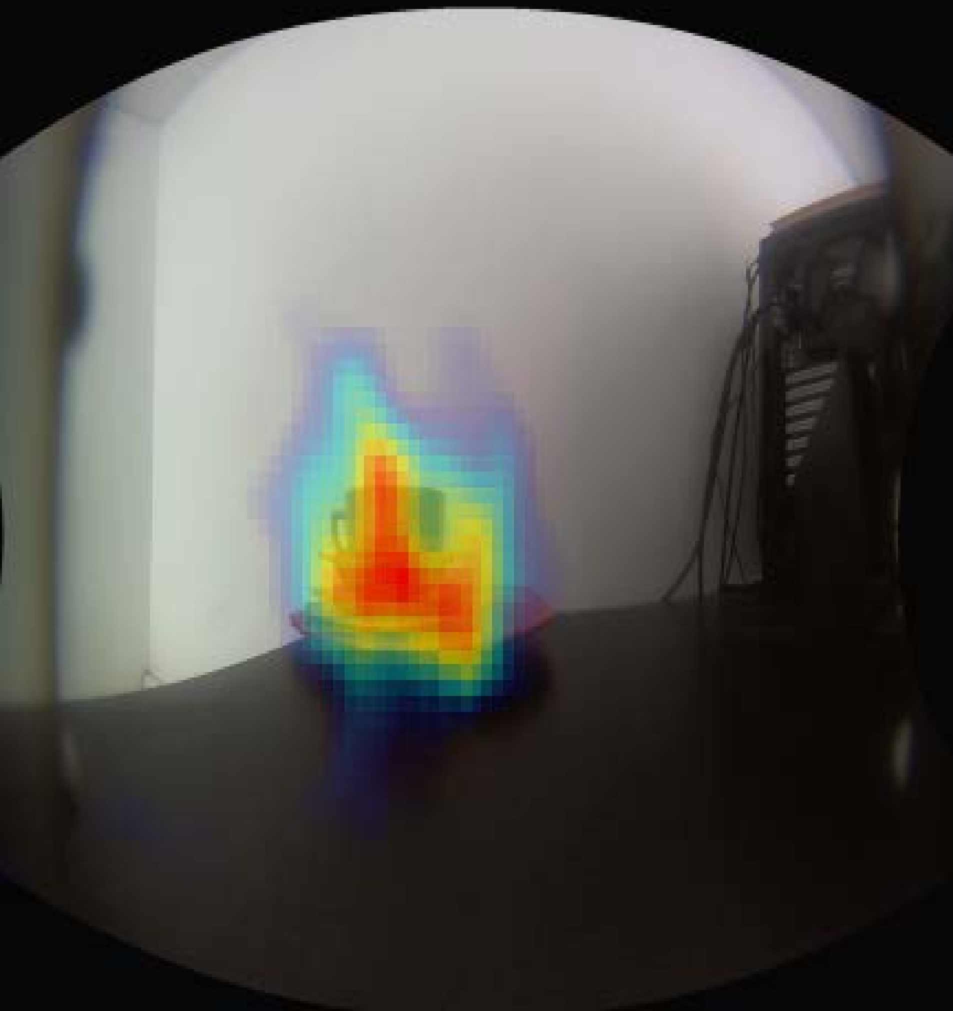
Distance:



6 hours (367 counts, imaging 766 and 1000 keV lines)

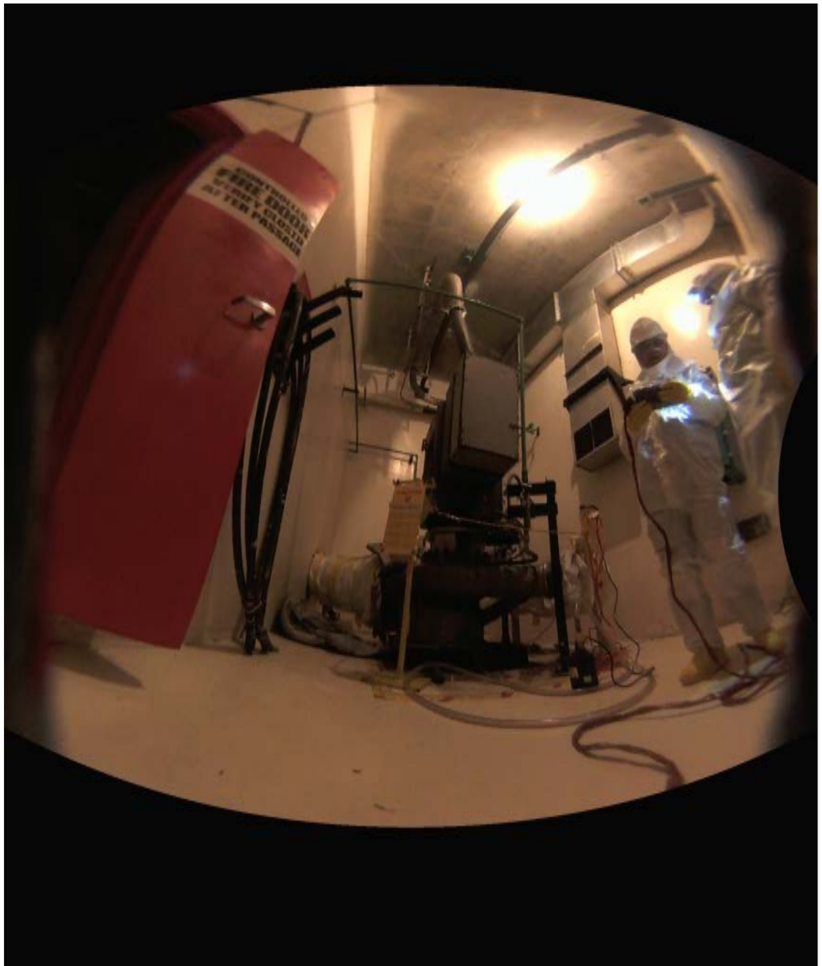


12 hours (786 counts, imaging 766 and 1000 keV lines)

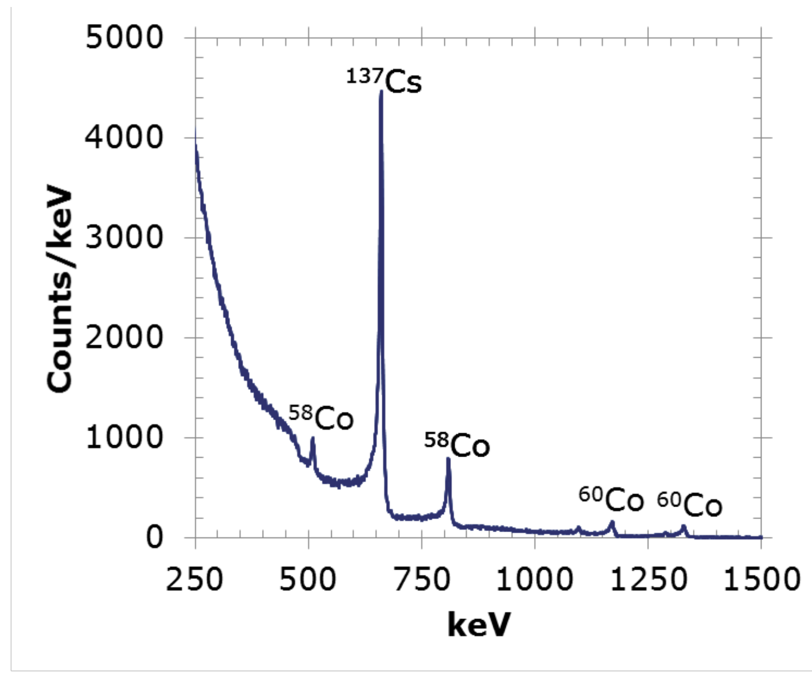


Shape of fiestaware start to appear – what you can see from an overnight measurement

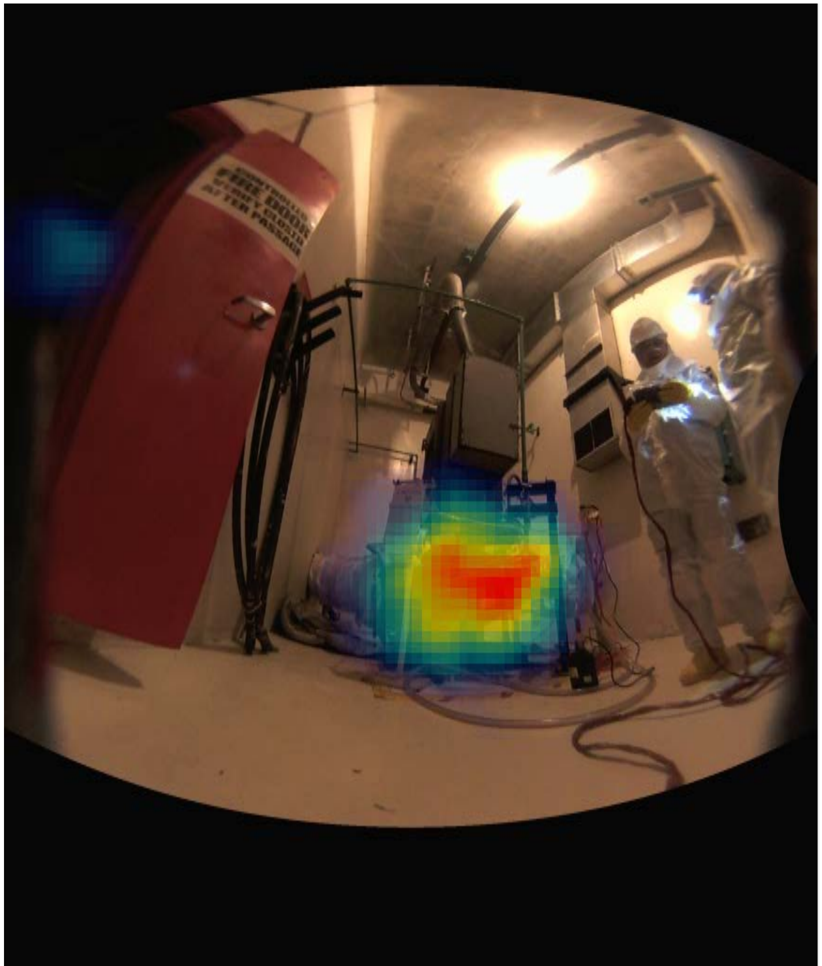
Residual Heat Remover (RHR) Pump Room



10.2 minutes
2.3 x 10^6 counts
~0.4 mrem/hr

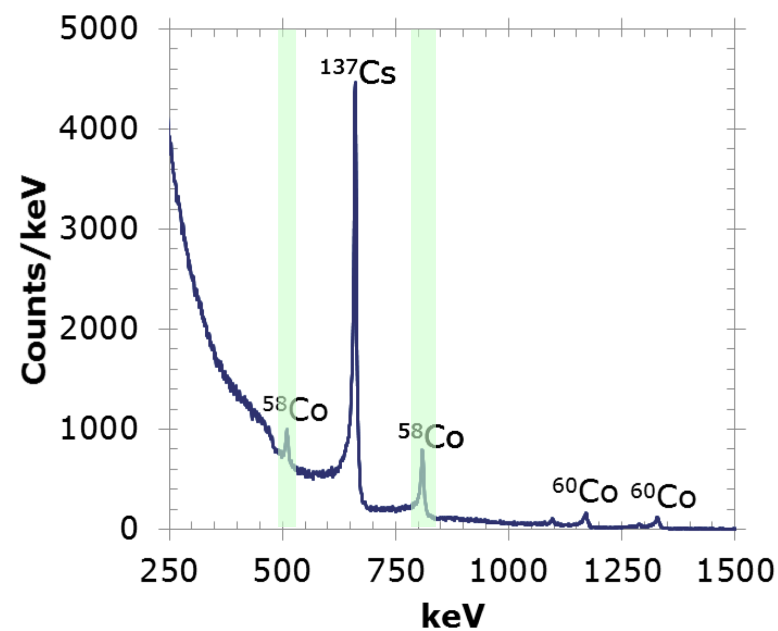


RHR Pump Room – ^{58}Co

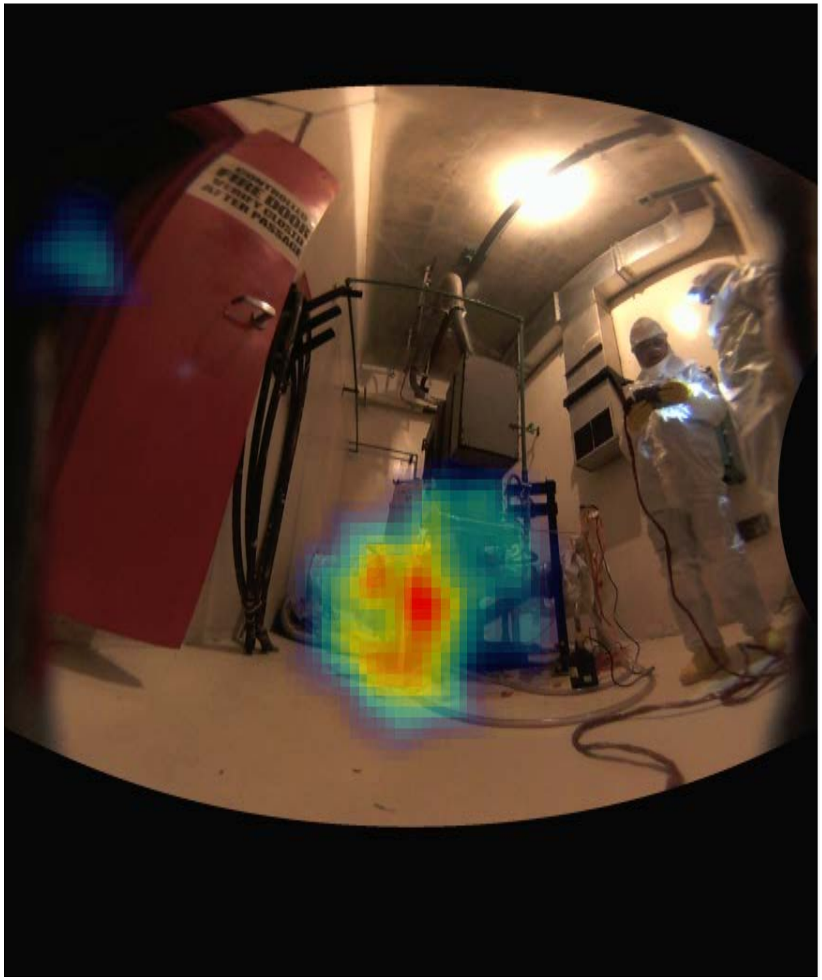


Area source found on pump.

2.1 x 10^4 counts in ROI
(23% of those imageable)

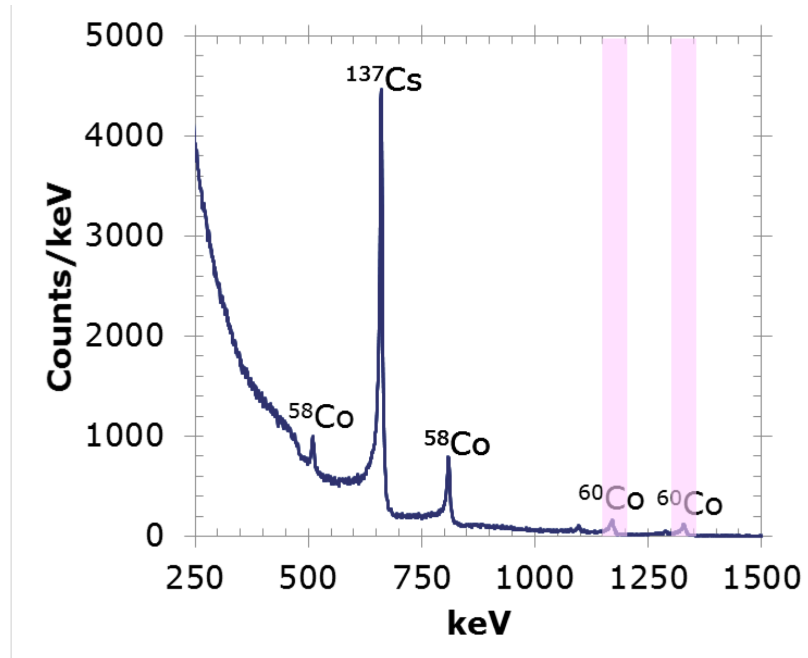


RHR Pump Room – ^{60}Co

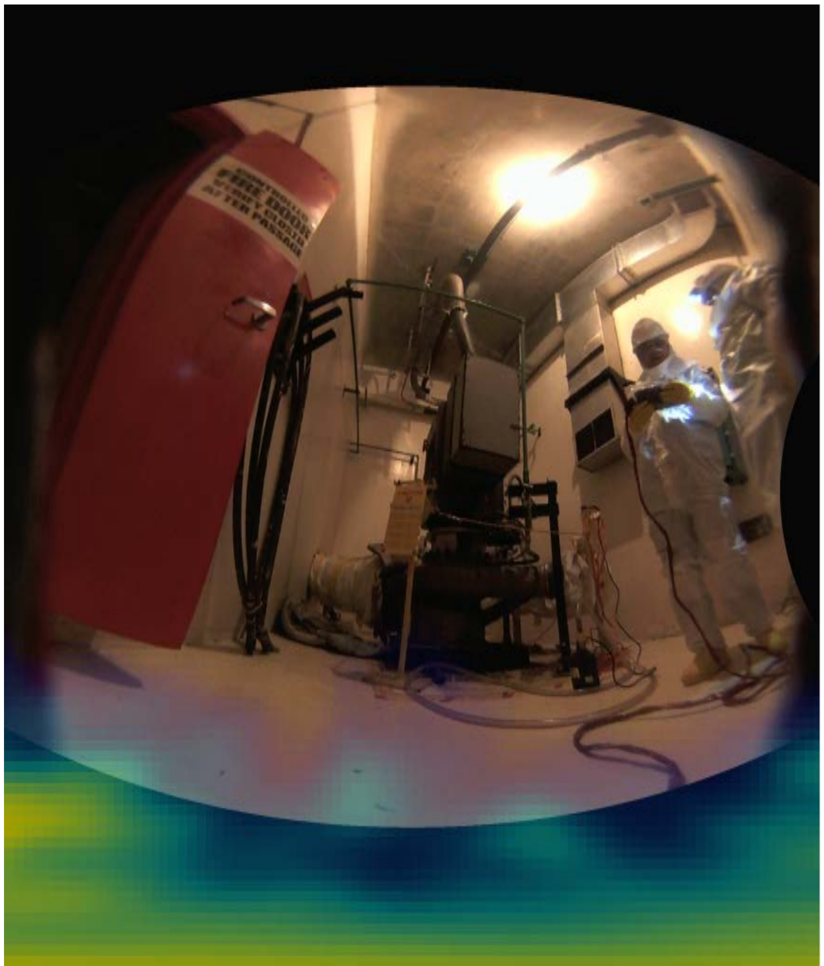


^{60}Co and ^{58}Co are in different regions of pump.

3.7 x 10^3 counts in ROI (34% of those imageable)

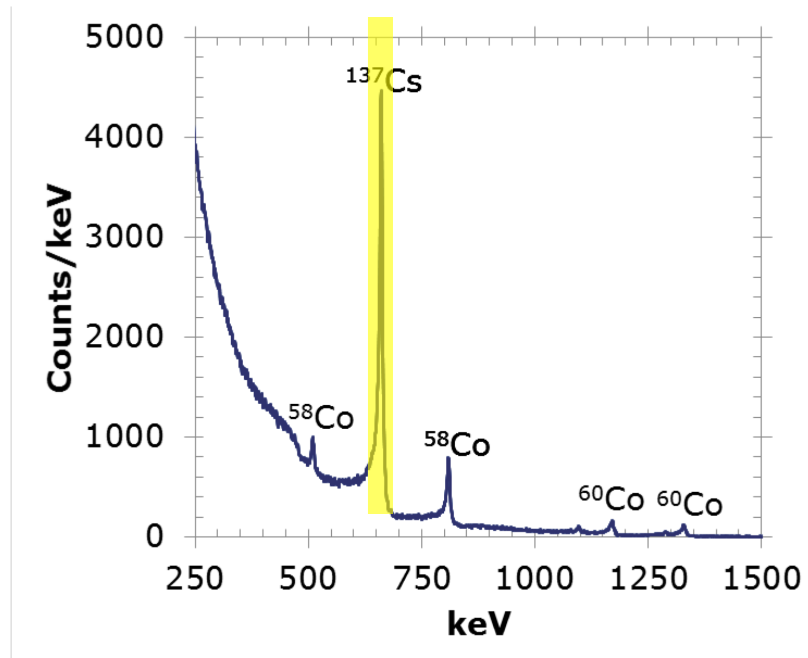


RHR Pump Room – ^{137}Cs

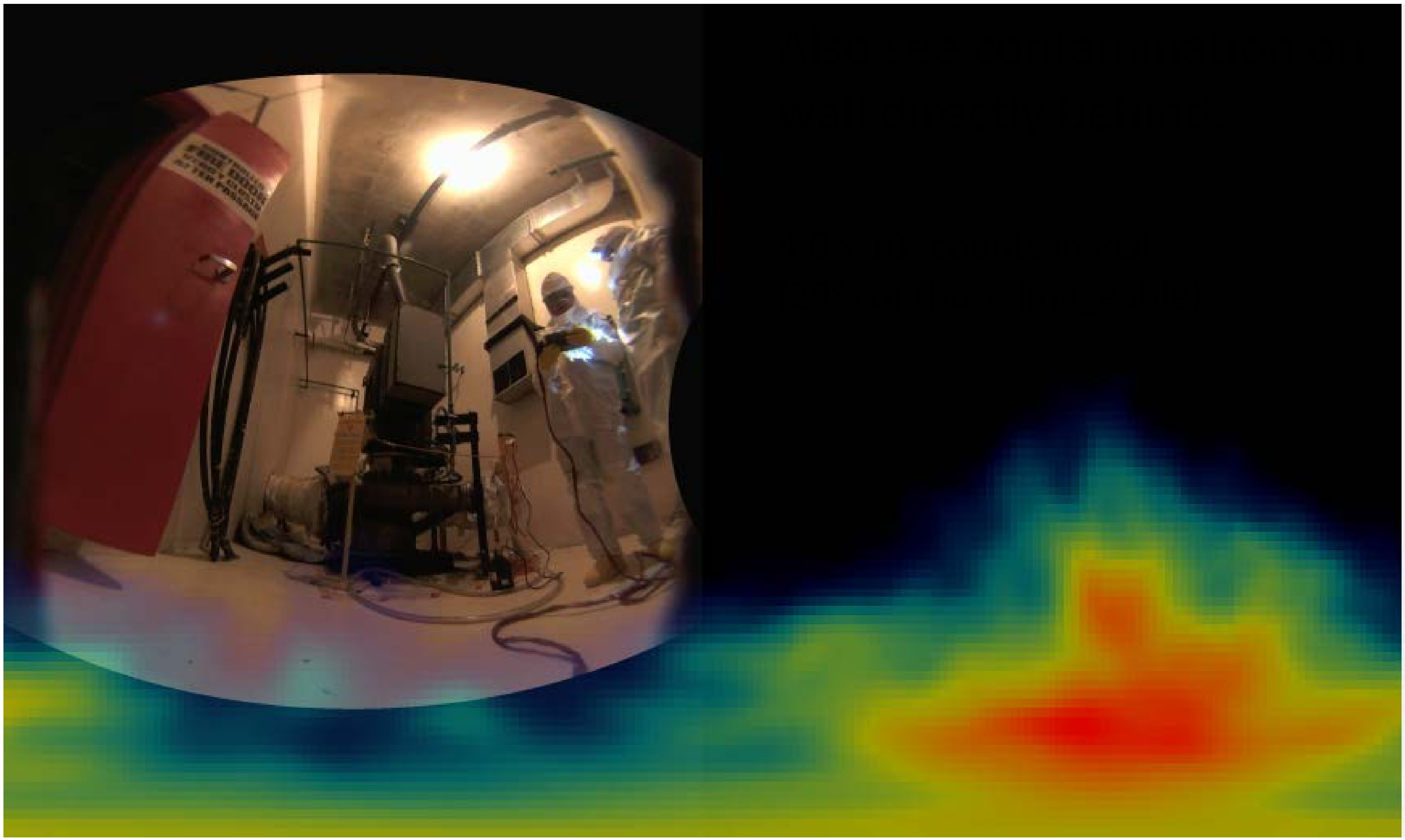


See contamination on floor from prior flood. Nearer areas appear hotter.

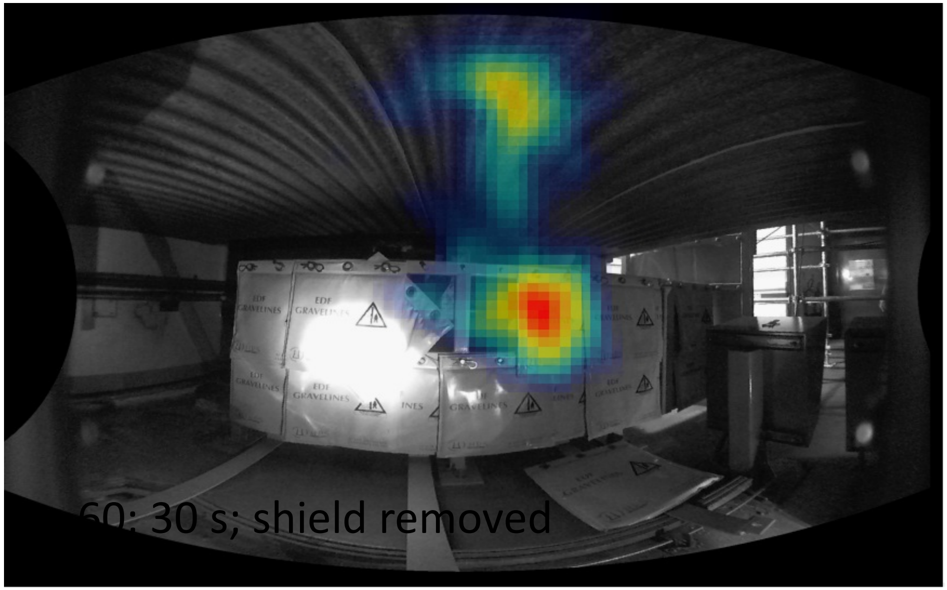
4.0 x 10^4 counts in ROI
(29% of those imageable)

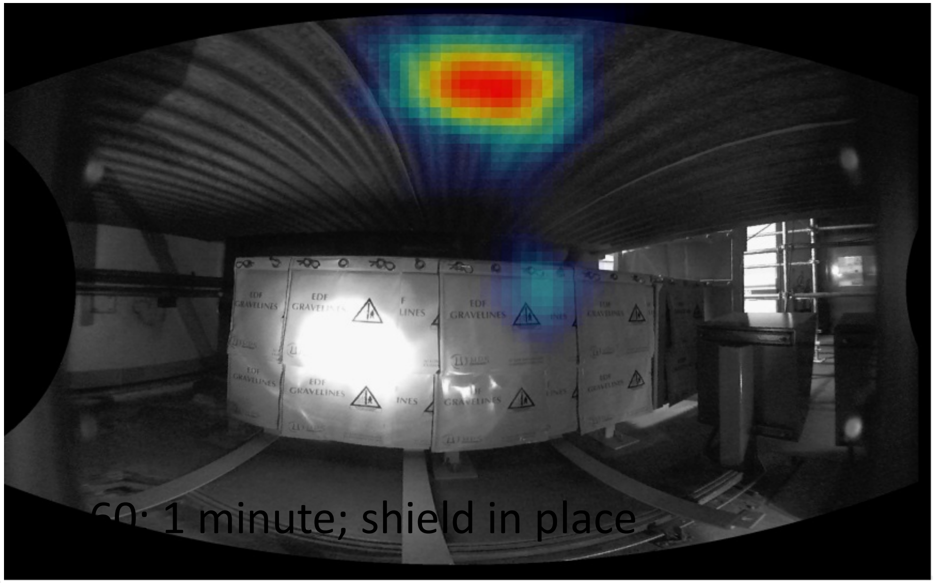


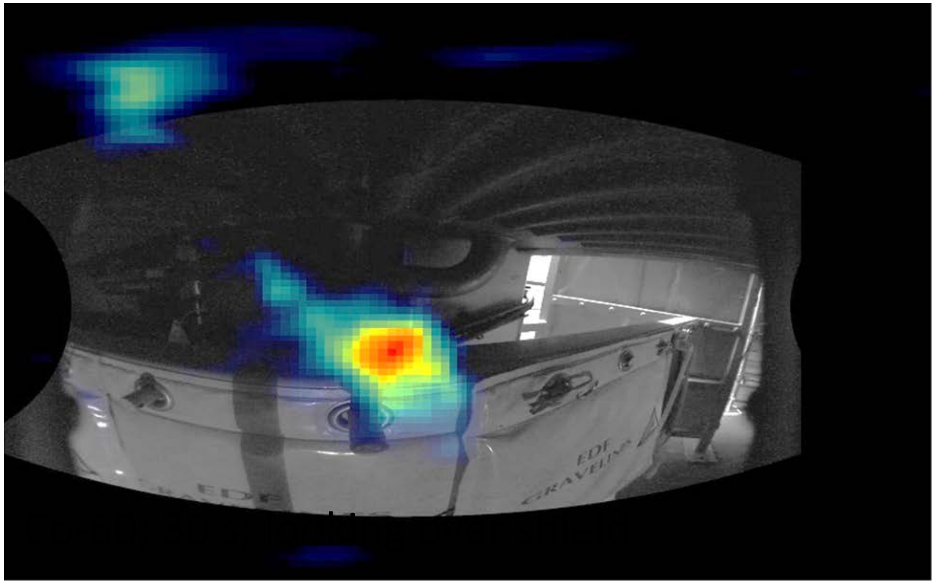
RHR Pump Room – ^{137}Cs

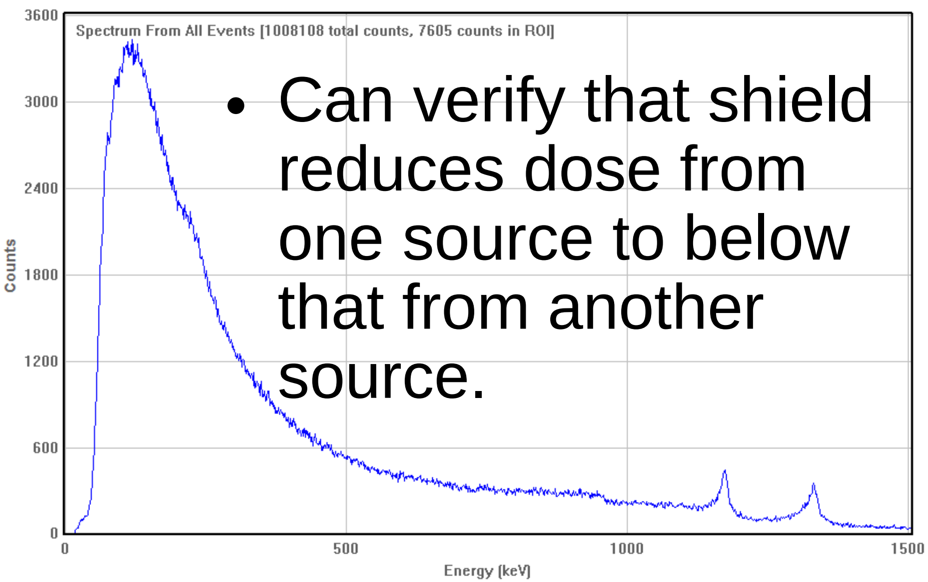


Shielding Verification



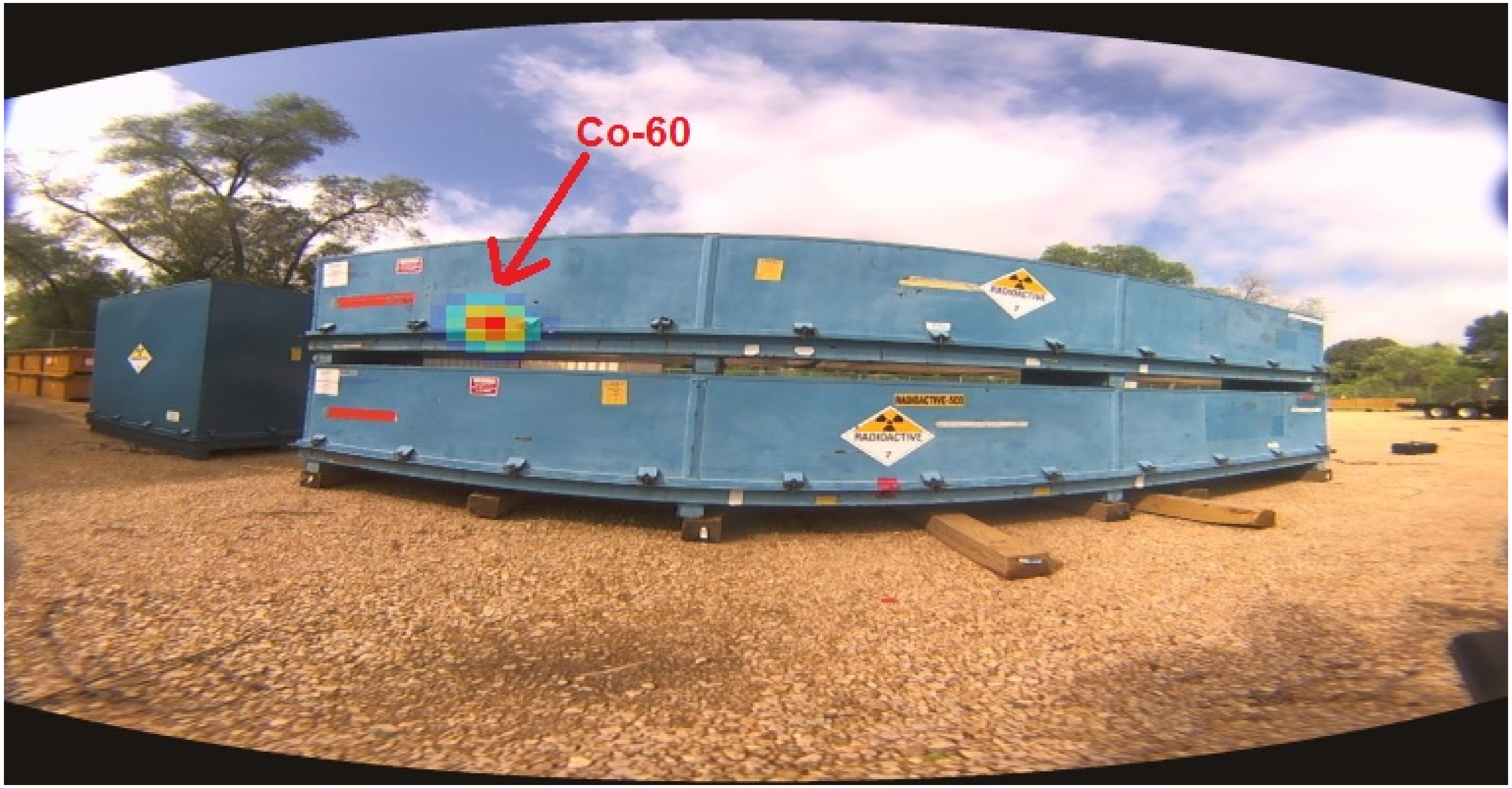






- Can verify that shield reduces dose from one source to below that from another source.

Locating Isotopes in Shipping Containers

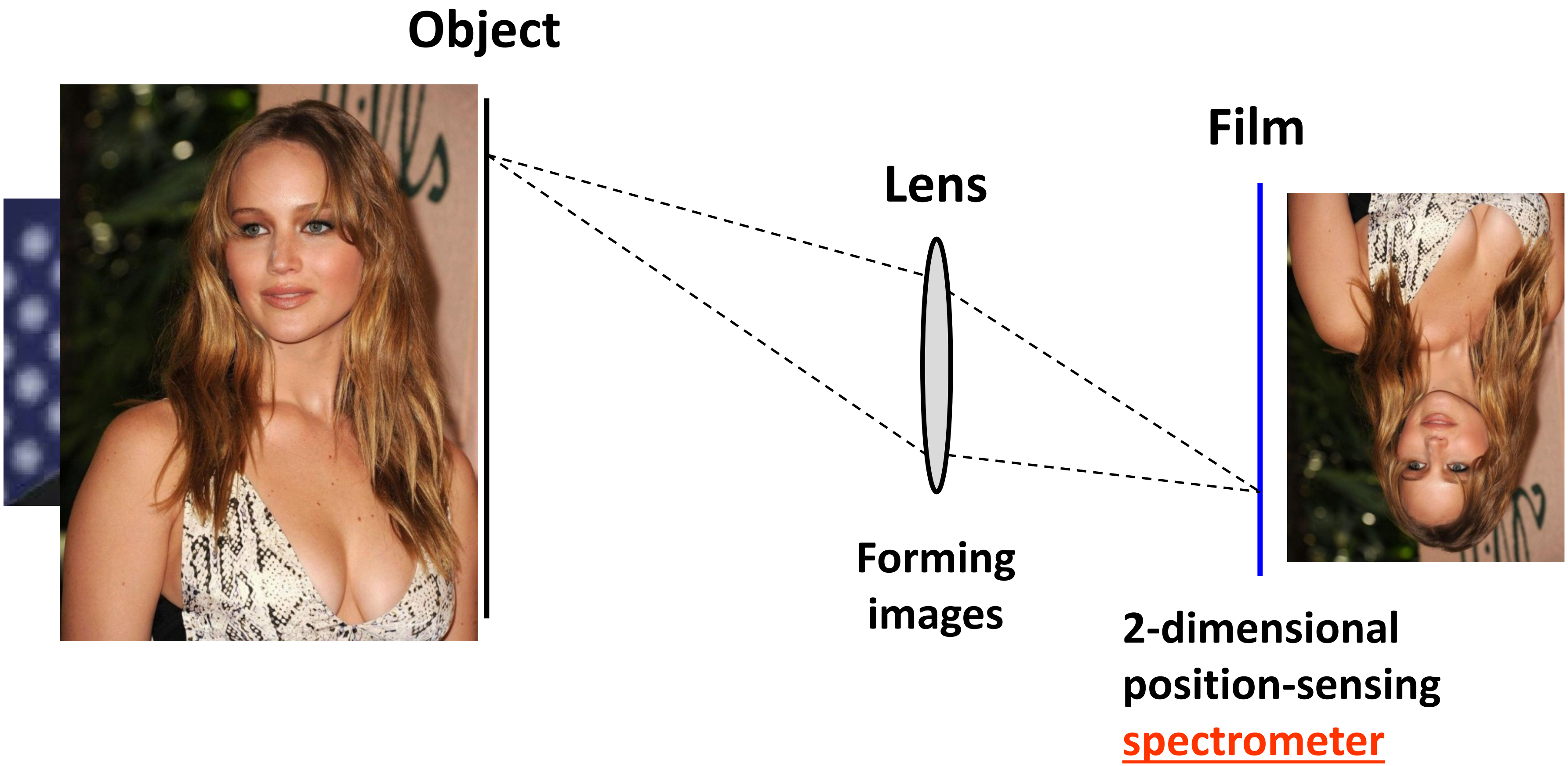


Co-60; 17 min.

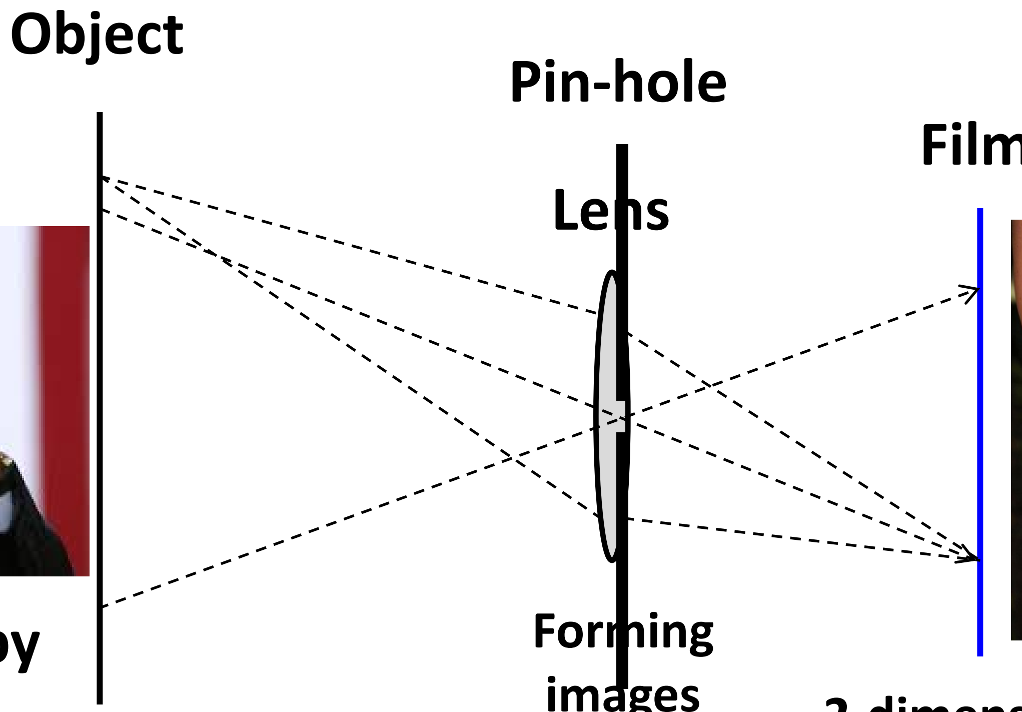
Applications

- National security, homeland security and international nuclear non-proliferation
- Nuclear power (dose reduction, clean-up and inspection)
- Medical imaging (proton cancer therapy)
- Planetary sciences & astrophysics (NASA)
- Safeguard (IAEA)
- Fundamental Physics
- Environmental monitoring

How does an optical camera work?



Principle of a low-energy gamma camera
(< 250 keV)



No spectroscopy
No isotope ID

2-dimensional
position-sensing
Spectrometer?

Note: Identity of isotopes are determined by γ-ray spectroscopy

Principle of Polaris technology for higher energy (> 250 keV, ^{137}Cs, ^{58}Co, ^{60}Co) γ-rays