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Applications of Imaging Detectors

Kai Vetter
Ross Barnowski, Andy Haefner, Tenzing Joshi, Brian Quiter, Ryan Pavlovsky

Department of Nuclear Engineering, UC Berkeley
Applied Nuclear Physics Program, LBNL
Institute for Resilient Communities

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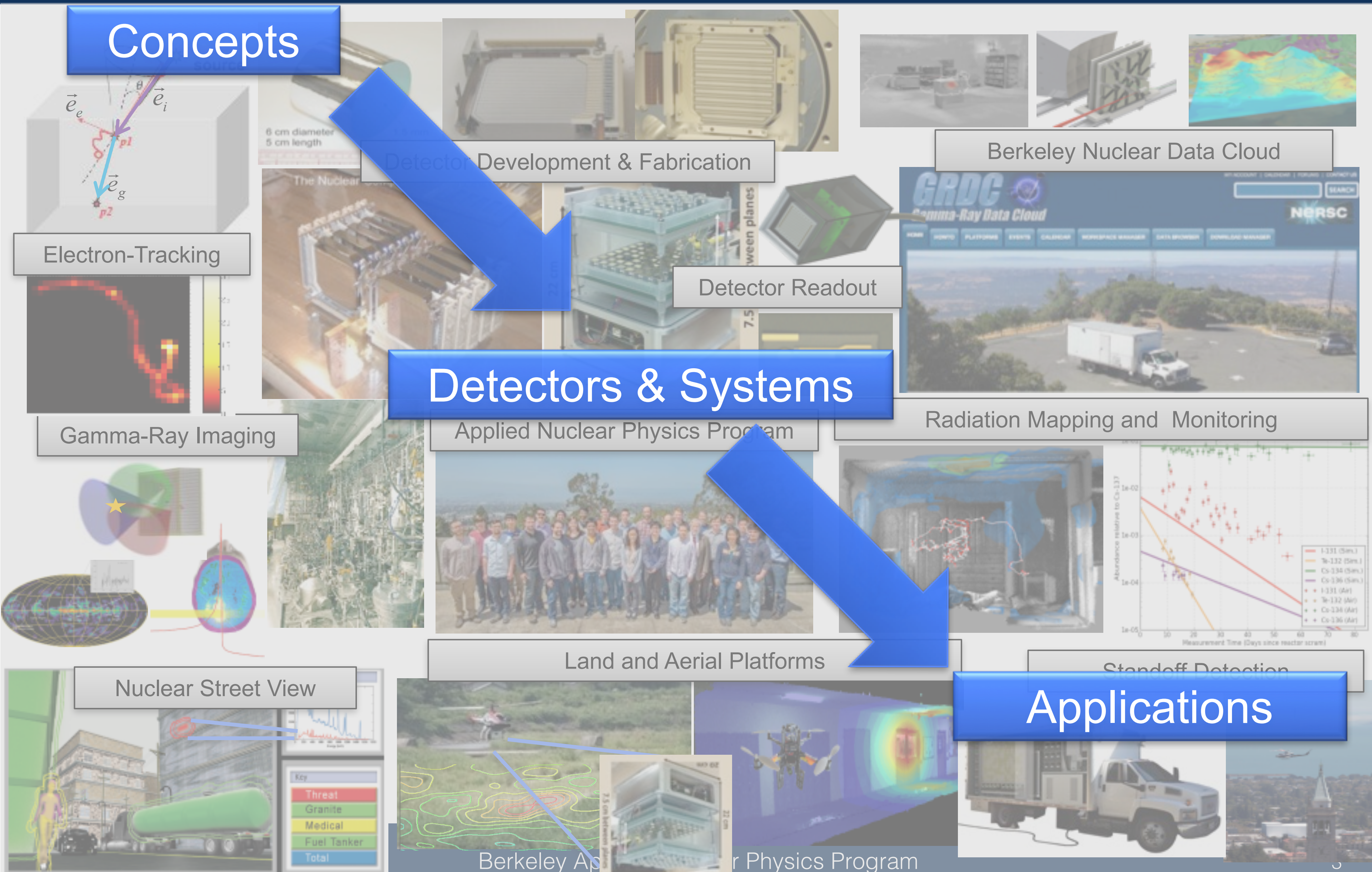
Applications of Imaging Detectors

- The Applied Nuclear Physics Program – Mapping technological advances to challenges in science, security, and society (and vice versa)
- "Conventional" 2-D and 3-D gamma-ray imaging
- The 3-D Scene-Data Fusion concept: "Seeing" gamma radiation in 3-D (in color and real time)
- Conclusions

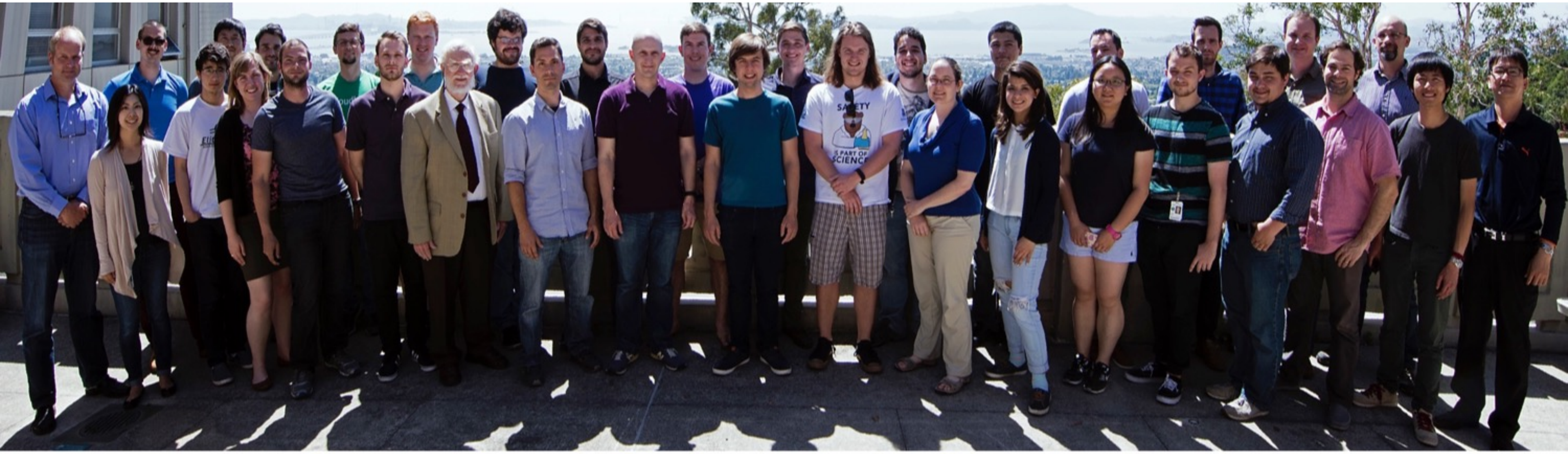
Applied Nuclear Physics

DEPARTMENT OF
Nuclear Engineering
UNIVERSITY OF CALIFORNIA, BERKELEY

The Berkeley Applied Nuclear Physics Program
- at a glance -



Our Team

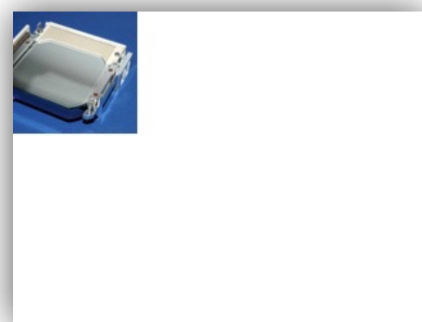


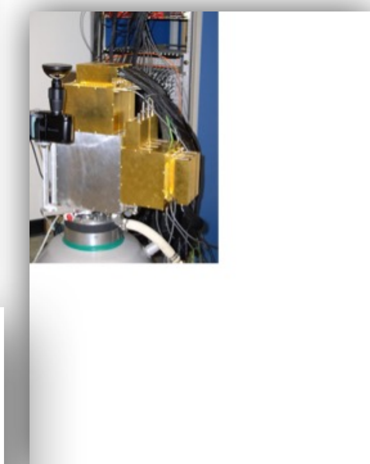
12 graduate students, ~10 undergraduate students, 4 postdocs, 16 scientists and engineers

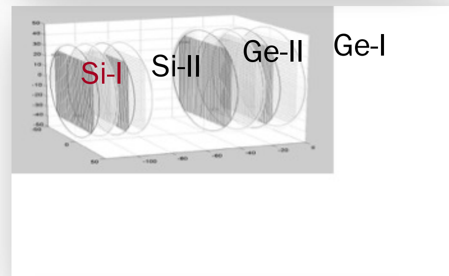
Located in B50C and B70A (… at the "heart" of LBNL)

Gamma-Ray Imaging – Semiconductor-based Instruments

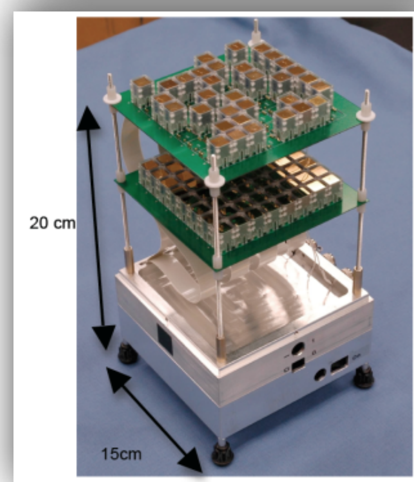
- **“Compact” Compton Imager CCI**
  - 2 HPGe +2 Si(Li) large DSSD detectors in two cryostats & SIS DAQ
    - Si(Li): Each 32+32 strips w/ 2 mm pitch size; 10 mm thickness; 1.9 keV at 60 keV
    - HPGe: Each 37+37 strips w/ 2 mm pitch size; 15 mm thickness; 1.7 keV at 60 keV
    - Can be operated as Compton imager or in combination with passive collimators or apertures

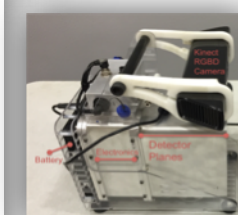






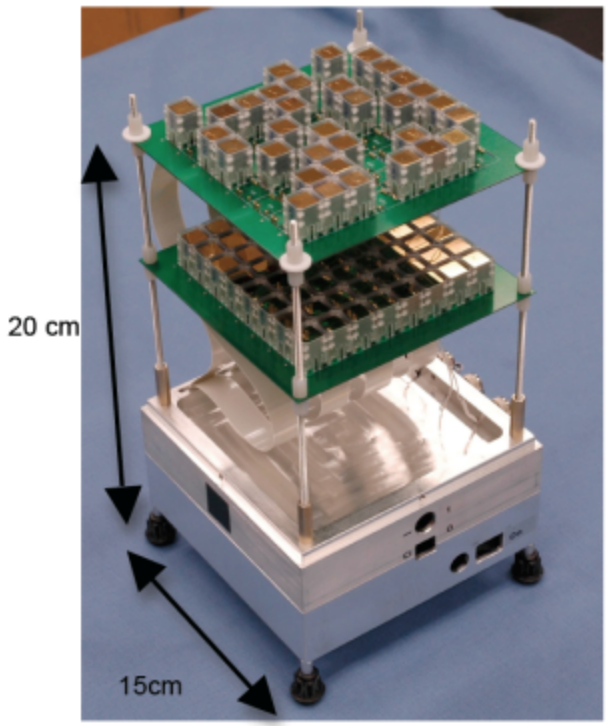
- **High-Efficiency Multimode Imager HEMI**
  - Modular, Coplanar Grid (CPG) CdZnTe (CZT) based detector array:
    - 32+64 CPG CZT detectors arranged in two layers.
    - Front layer as active coded aperture mask or as Compton scatter detector.
    - Simple, room-temperature, and scalable detection and imaging system.

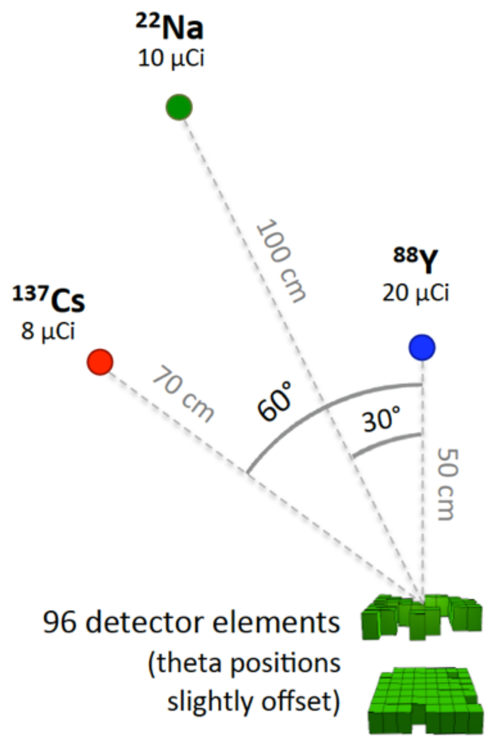


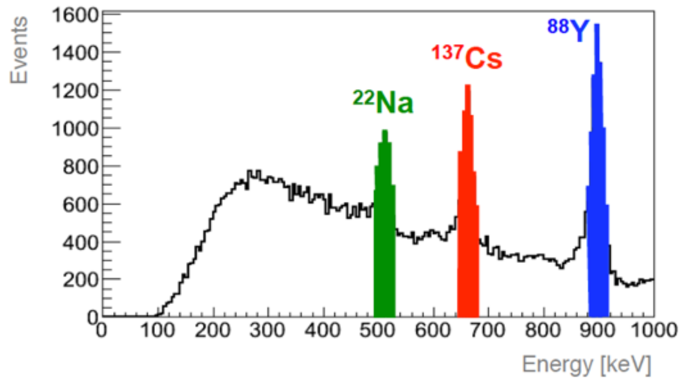


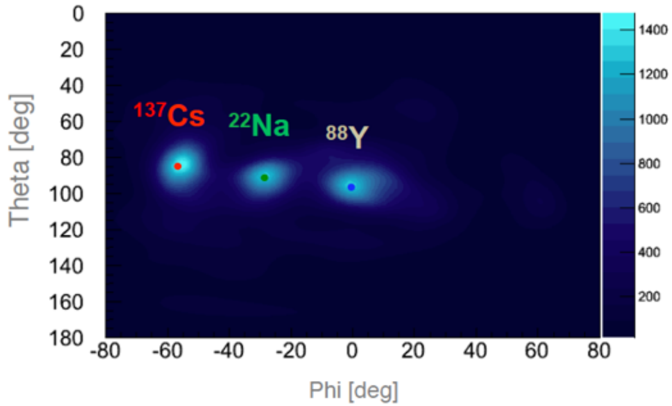
"Conventional" 2-D Imaging with HEMI

Multi-mode, spectroscopic gamma-ray imaging: **Compton Imaging**





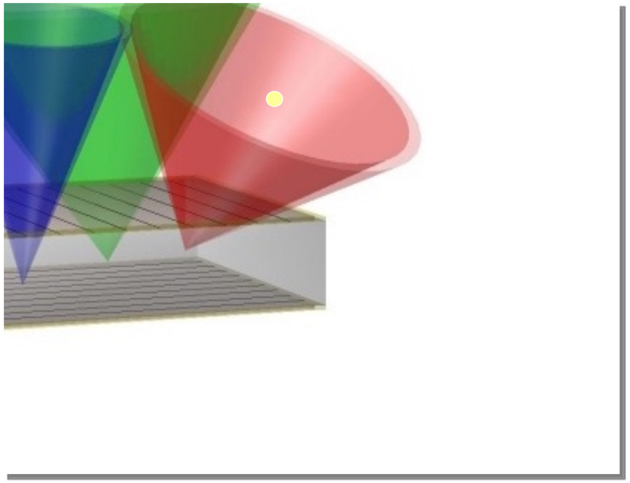


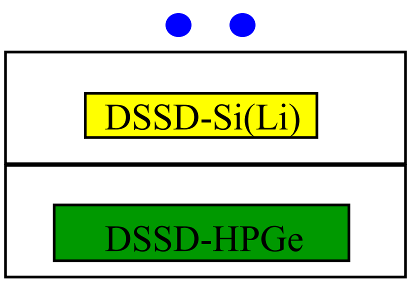


- Compact (15x15x20 cm^3), low power (<10W), modular, and easily scalable Gamma-Ray Imager w/ excellent detector-to-instrument weight ratio.
- $\Delta E/E \sim 2.5\%$ at 662 keV
- $\Delta\theta \sim 9°$ from 80 keV to 1000 keV (coded aperture and Compton imaging modes)

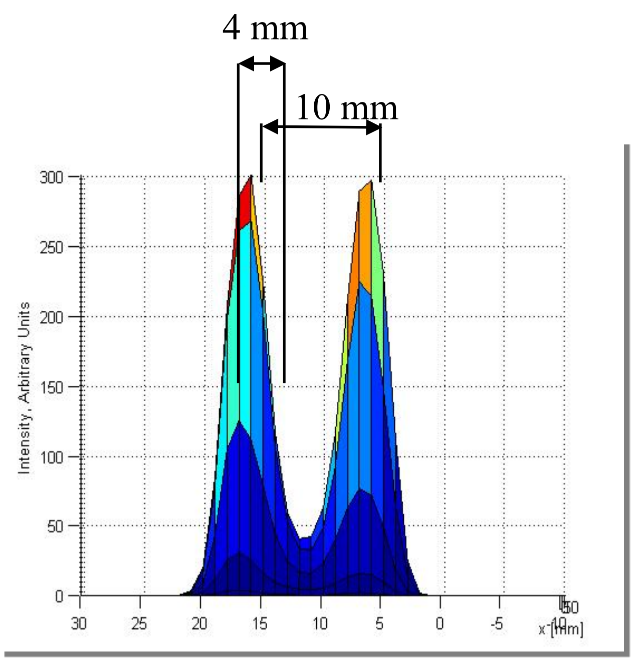
"Conventional" 3-D Imaging with CCI

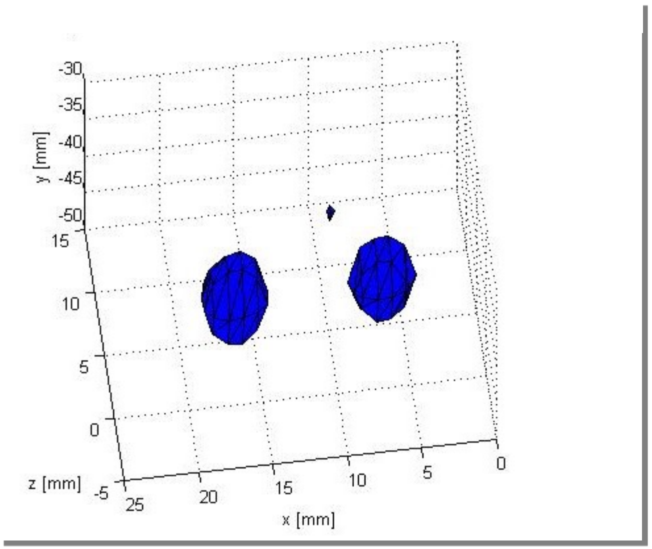
- Demonstration of near-field imaging using CCI and ML-EM image reconstruction:
  - 2 spherical ^{113}Sn sources (391 keV):
  - Diameter: Each 4 mm
  - Distance: 10 mm





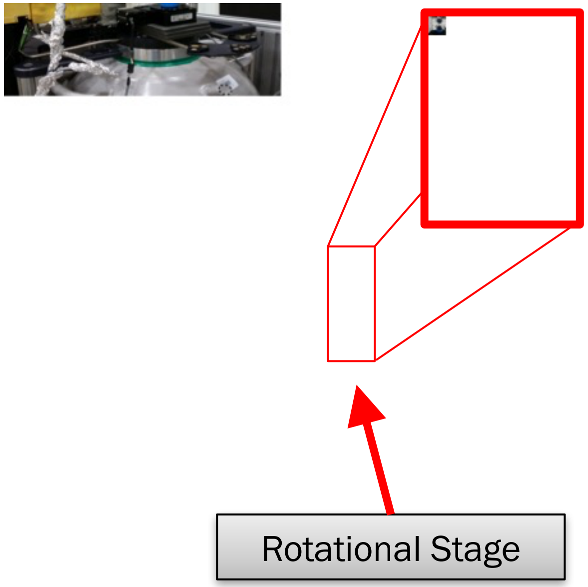
CCI-1

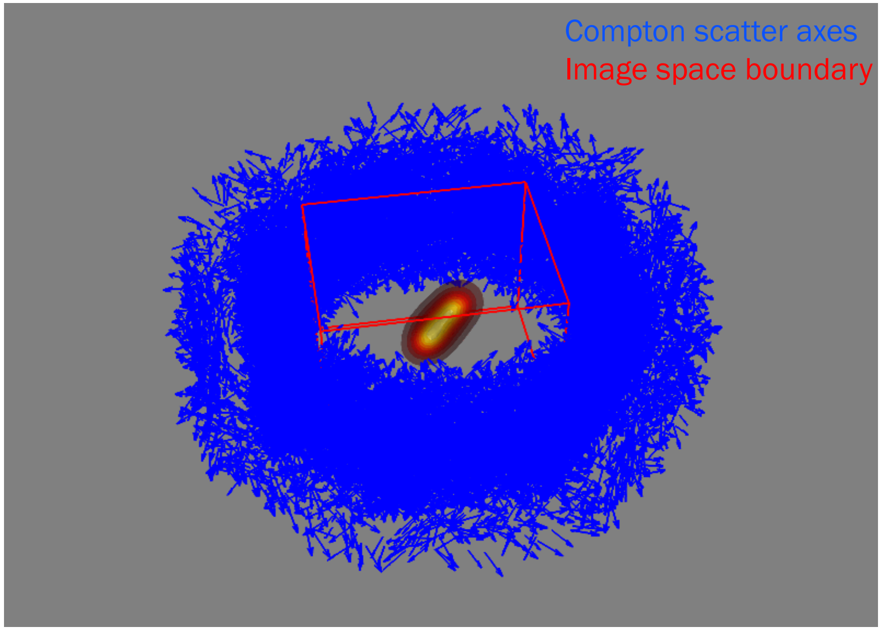


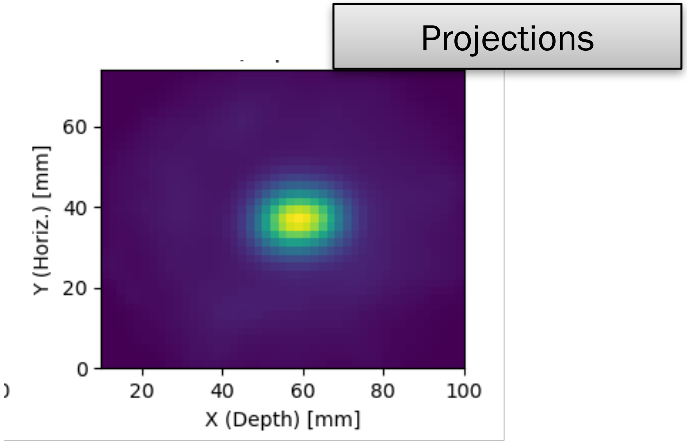


"Conventional" 3-D Imaging with CCI

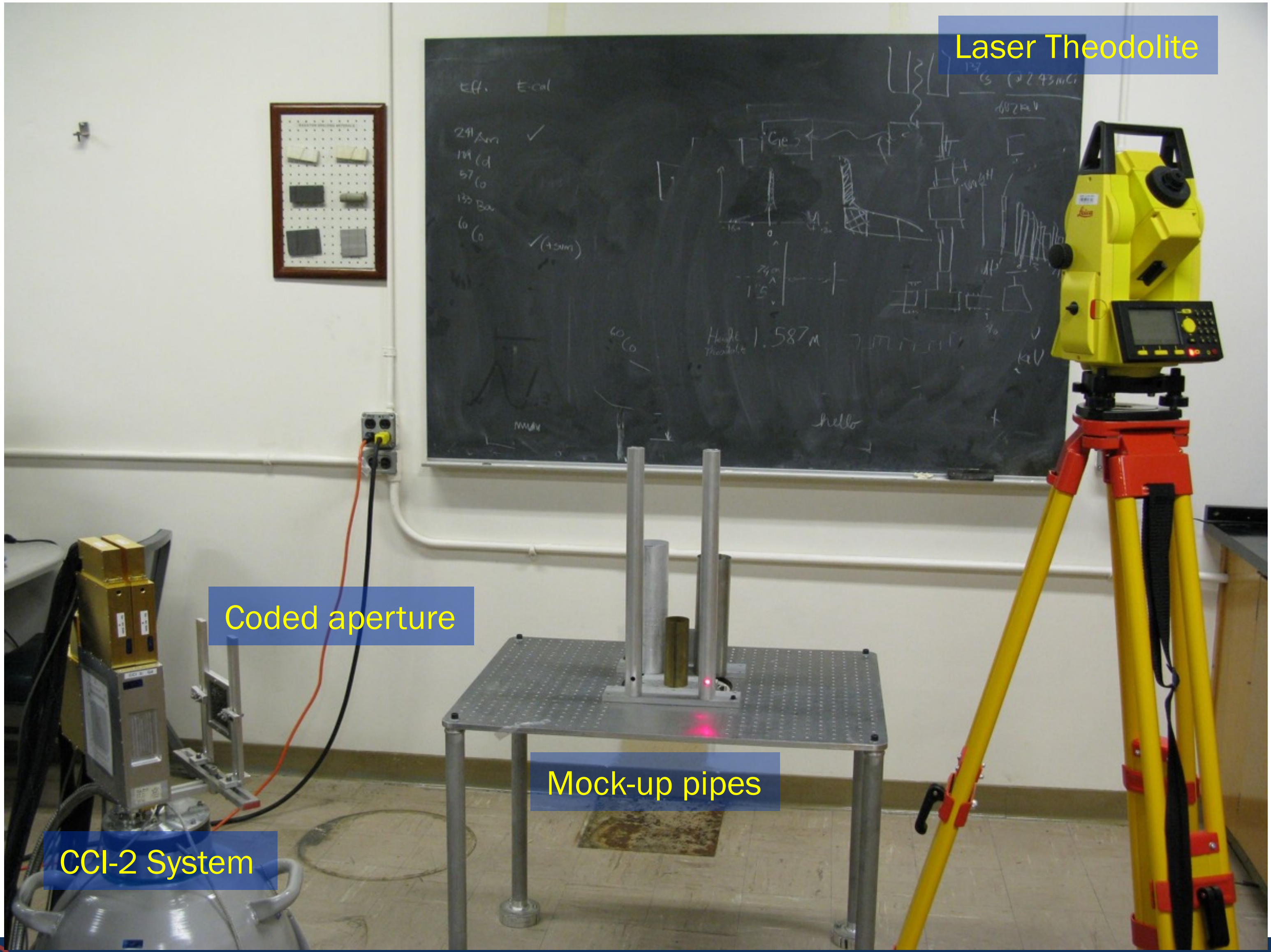
- Demonstration of near-field imaging with 8 projections and LM-MLEM
  - ^{137}Cs line source, 10 uCi
  - 50mm long, 2.35mm diameter
  - 60mm minimum standoff
  - Mounted on rotational stage
  - 8 projections @ 45° increments, 2 min/projection



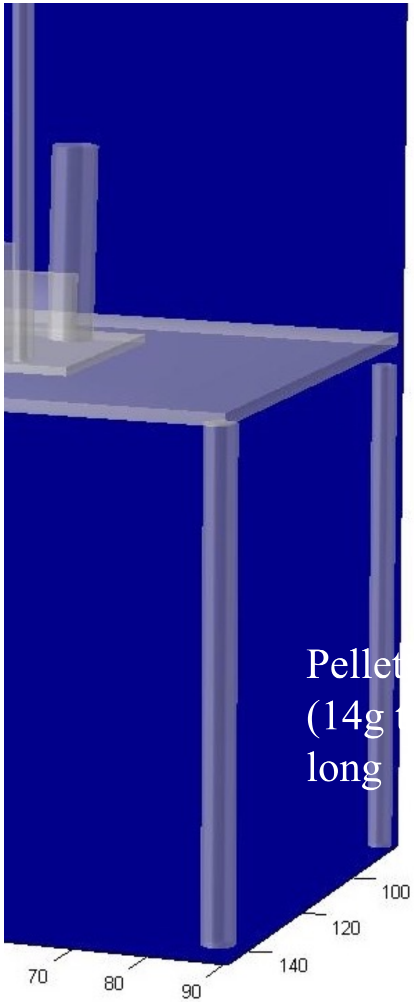




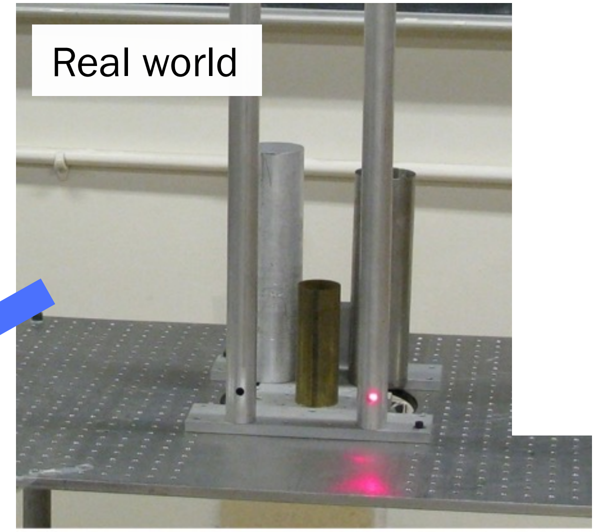
“Conventional” 3-D Imaging with CCI – from “standoff” distances
Towards Scene-Data Fusion

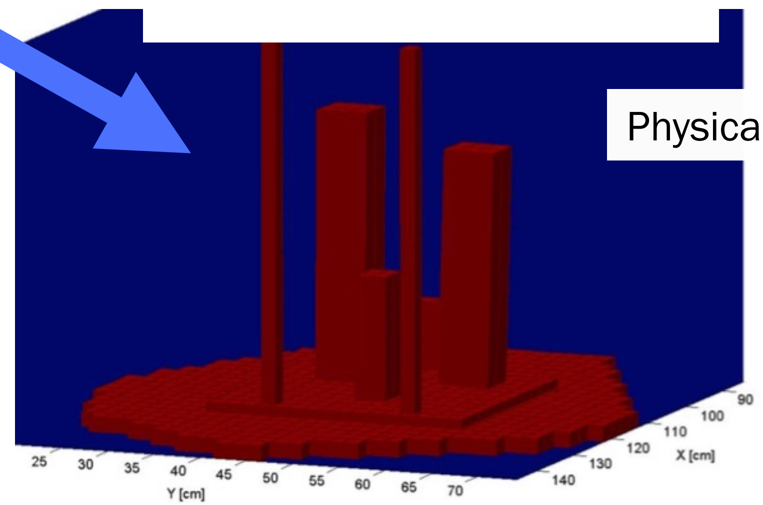


Voxelization for 3D imaging
Towards Scene-Data Fusion



CAD Model

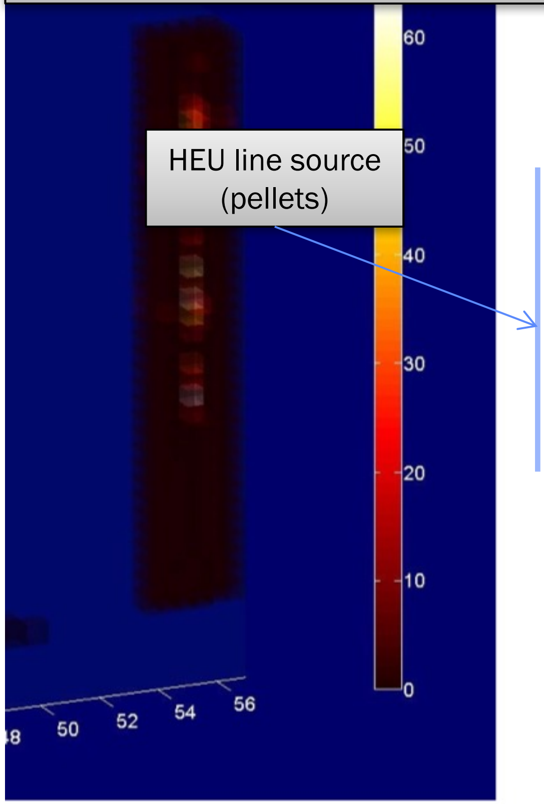




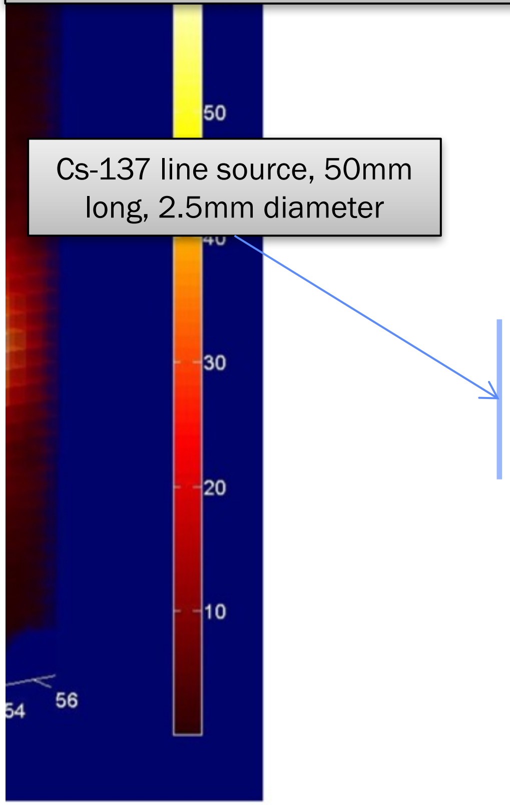
Reconstruction in voxelized 3-D Space Towards Scene-Data Fusion

- 3 locations at 1.5 m away from source configuration; Each location and orientation measured by hand/ theodolite

Coded aperture imaging at 186 keV



Compton imaging at 662 keV

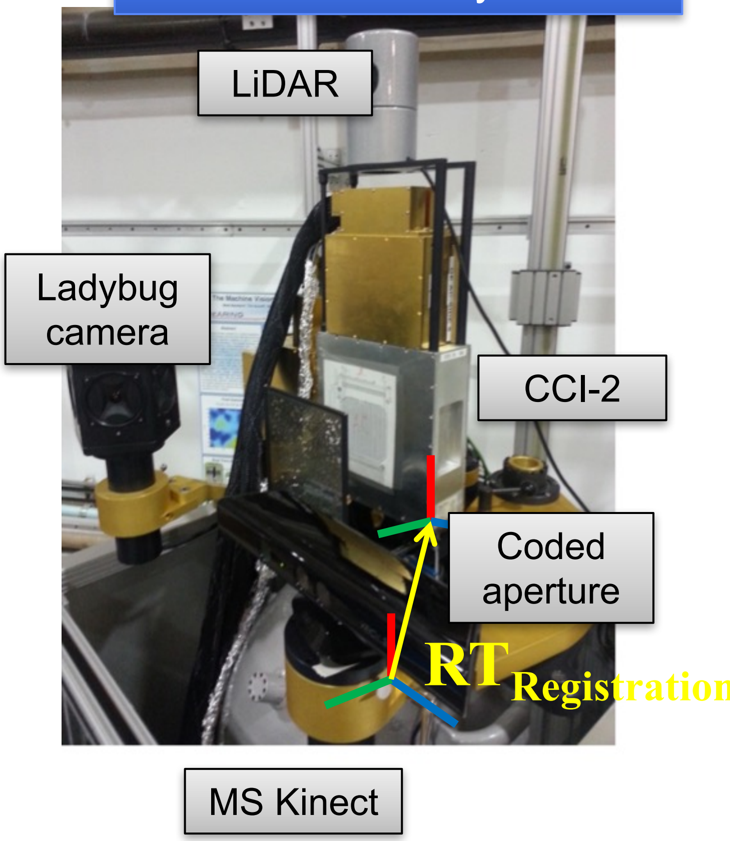


Scene-Data Fusion

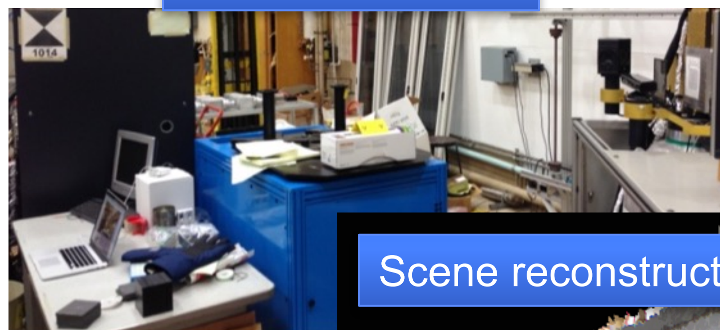
Adding "contextual" sensors to enable mapping and tracking

From conventional static 2D imaging to dynamic 3D volumetric imaging

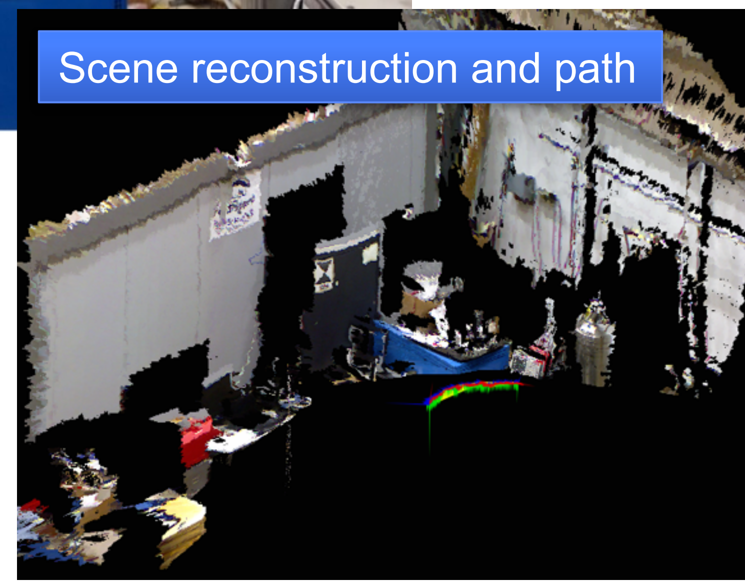
Multi-sensor system



"Cluttered" Scene



Scene reconstruction and path



- RGB Images
- Depth Images

➡ SLAM ➡

- Cumulative Global model
- Sensor trajectory

- Simultaneous localization and mapping (SLAM)
  - Provides detector tracking and 3D scene/ map reconstruction

Scene-Data Fusion

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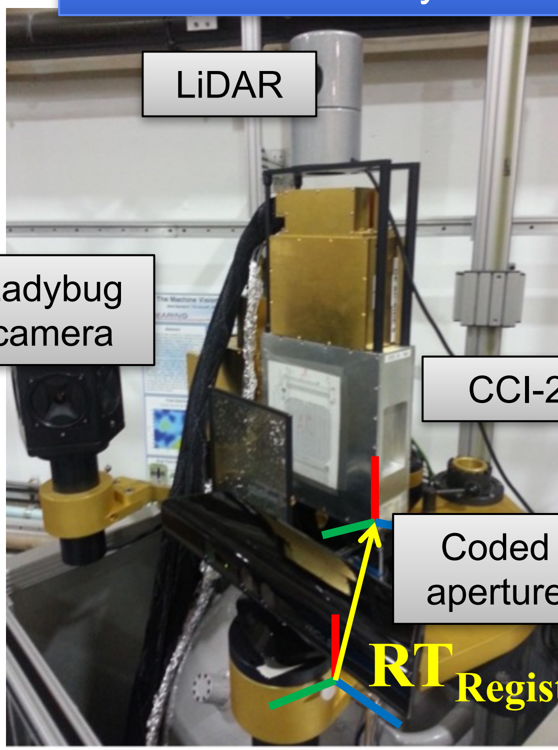
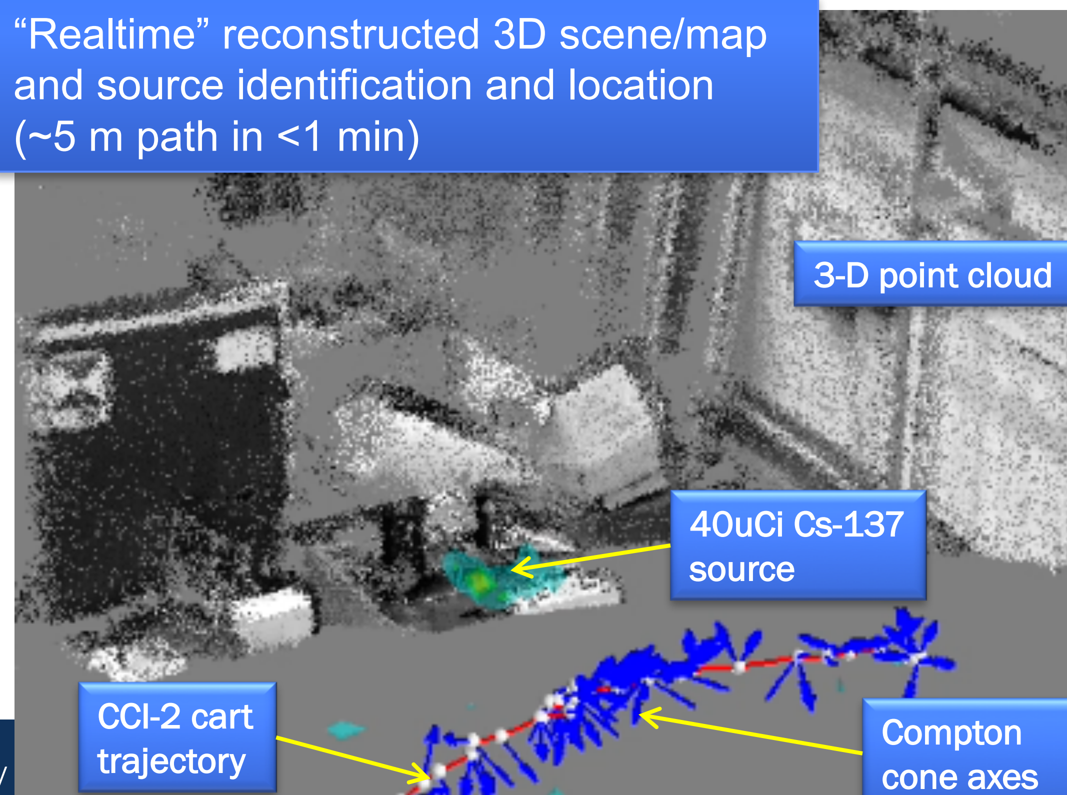
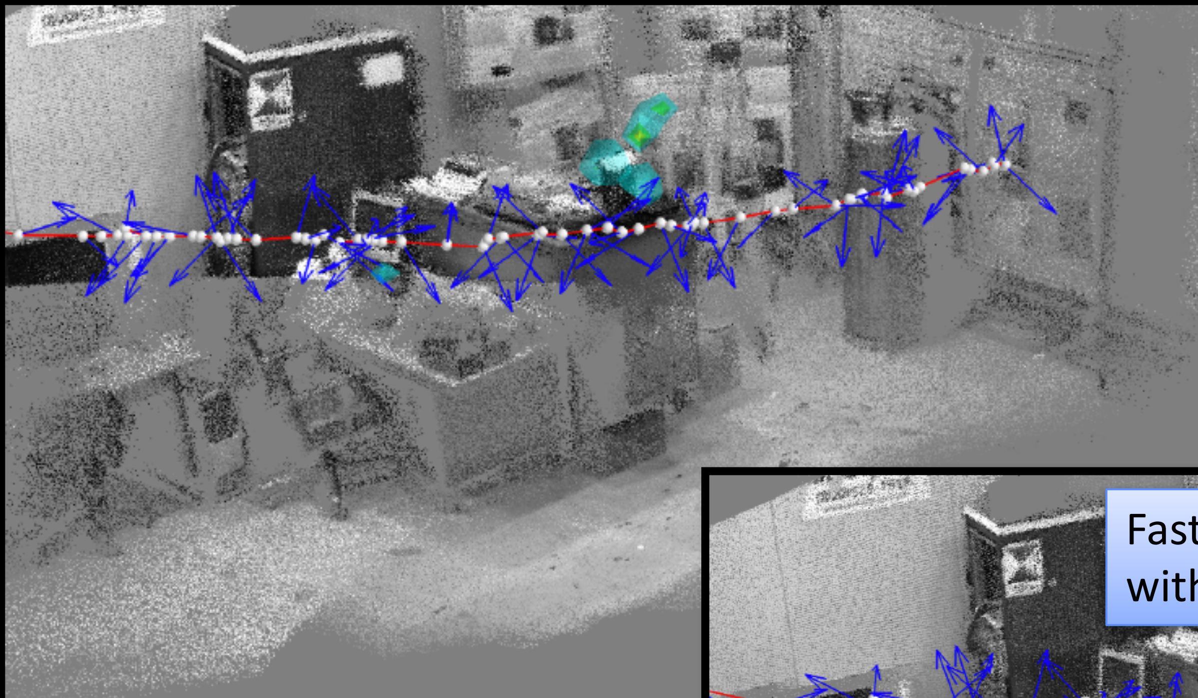


“Cluttered” Scene

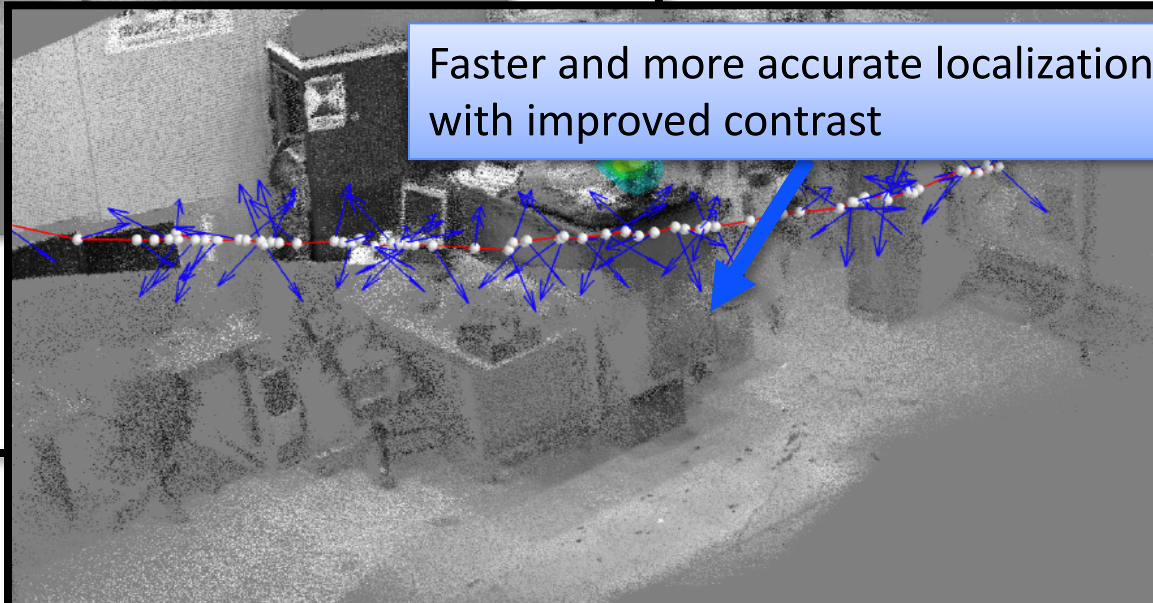
“Realtime” reconstructed 3D scene/map and source identification and location (~5 m path in <1 min)



Fused Scene Data



3D volumetric reconstruction without constraints



Faster and more accurate localization with improved contrast

3D volumetric reconstruction with constraints

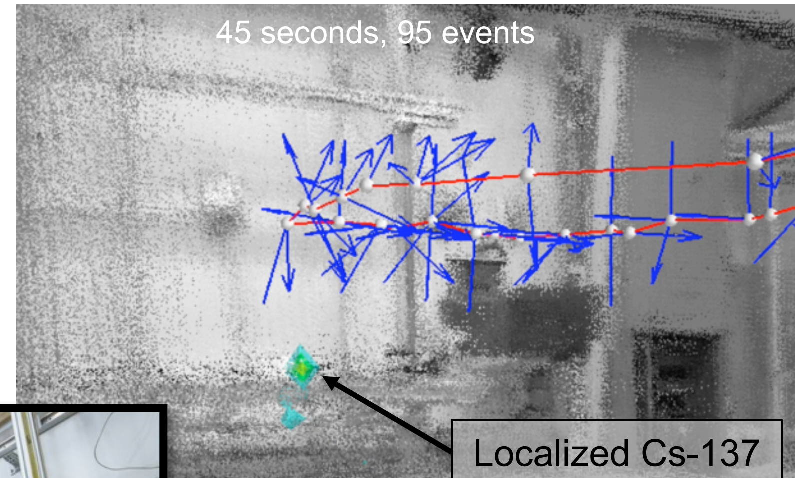
HEMI Demonstration – Mapping Application

Scene-Data Fusion – Demonstrations

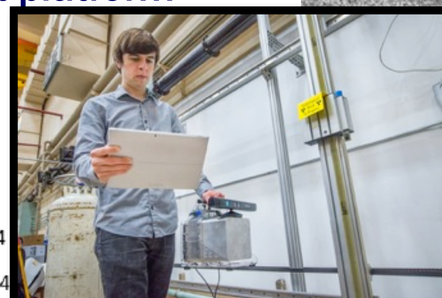
Mapping and Visualizing nuclear radiation in 3D, color, and real time

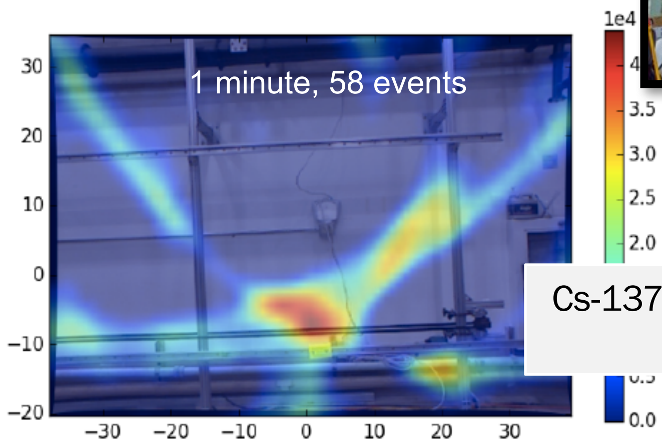
- **Power of Scene Data Fusion**
  - Integrating contextual sensors to estimate position and orientation of systems for detection, localization and mapping
  - Simultaneous, real-time 3D localization and mapping of radiological materials with freely moving detector
- **Greater mobility of imager**
- **Higher efficiency and accuracy**
- **Measurement time < 1 minute**
- **Independent of detector or deployment platform**
- **Remote operation and real time display**
- **All 3-D data available for re-analysis**

HEMI & MS Kinect

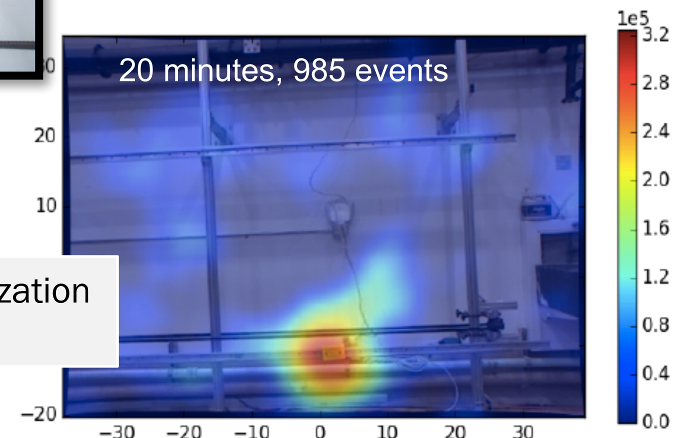


Cs-137 detection and 3D-localization w/ freely moving HEMI





Cs-137 detection and 2D-localization w/ static HEMI



Scene-Data Fusion - Demonstrations

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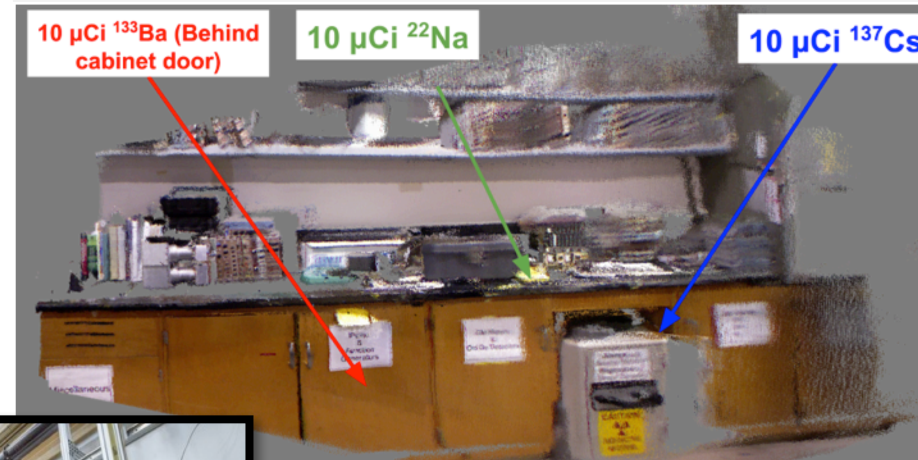
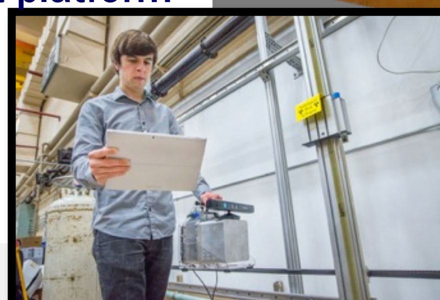
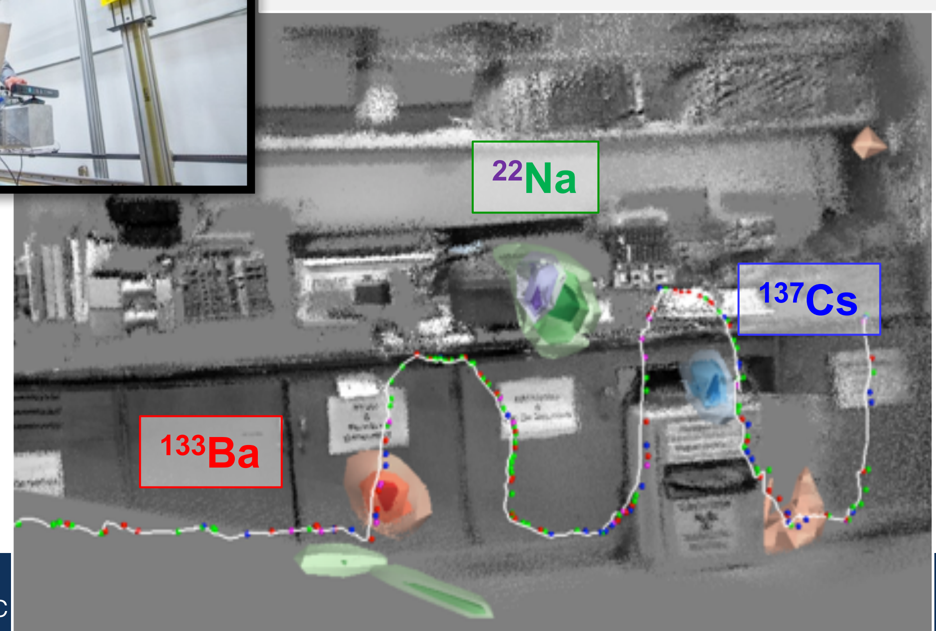
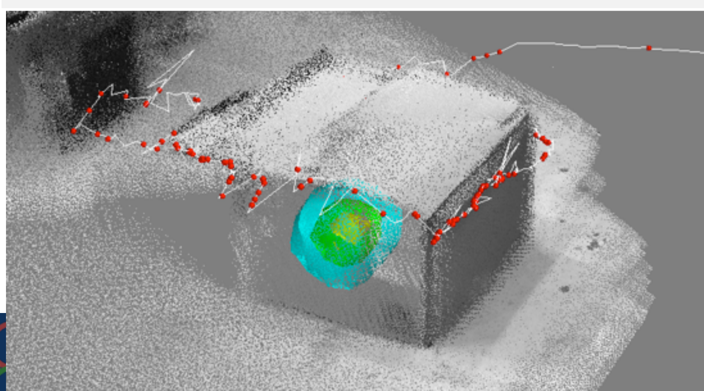




Volumetric Reconstruction



Cs-137 in a box
Tomography w/ freely moving HEMI



Scene-Data Fusion - Demonstrations

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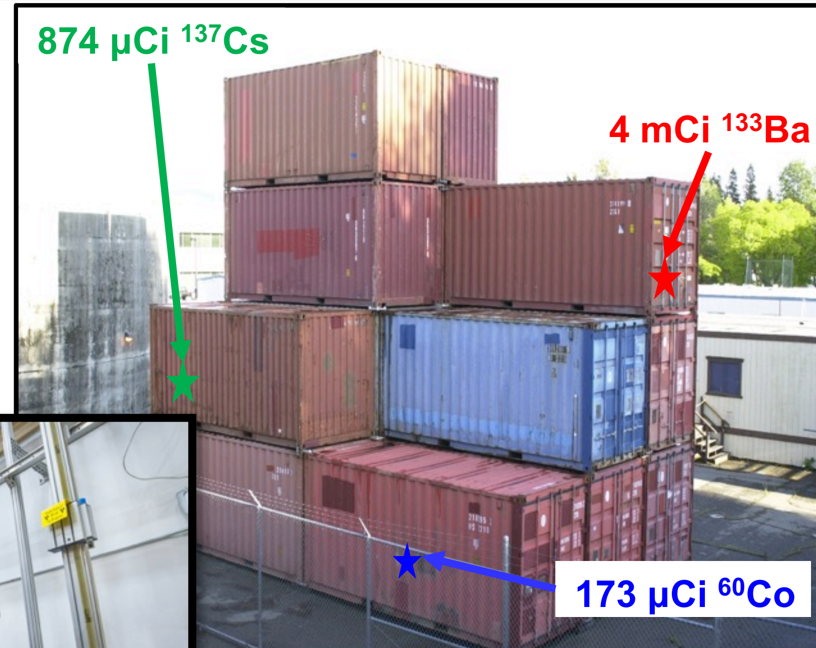
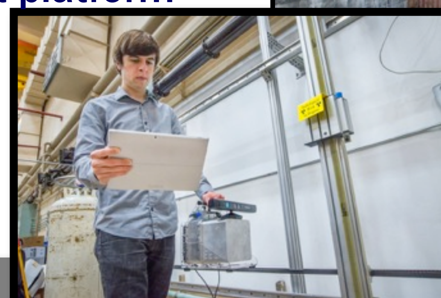
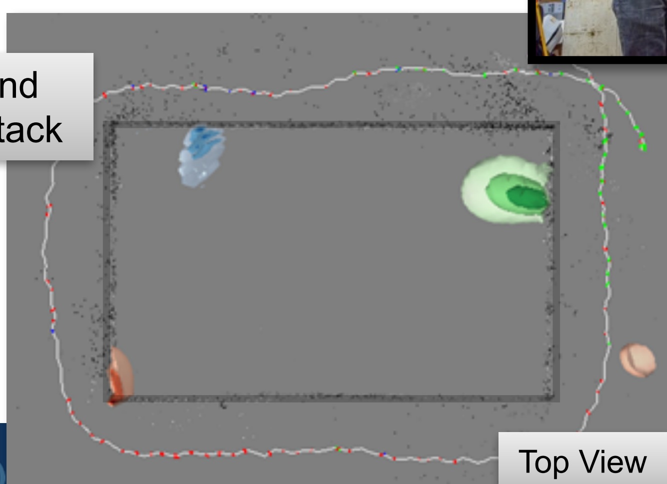
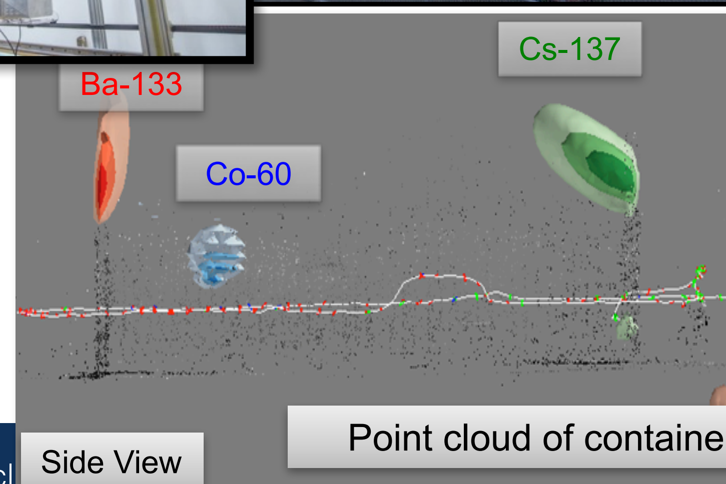
HEMI & LiDAR & Visual Camera





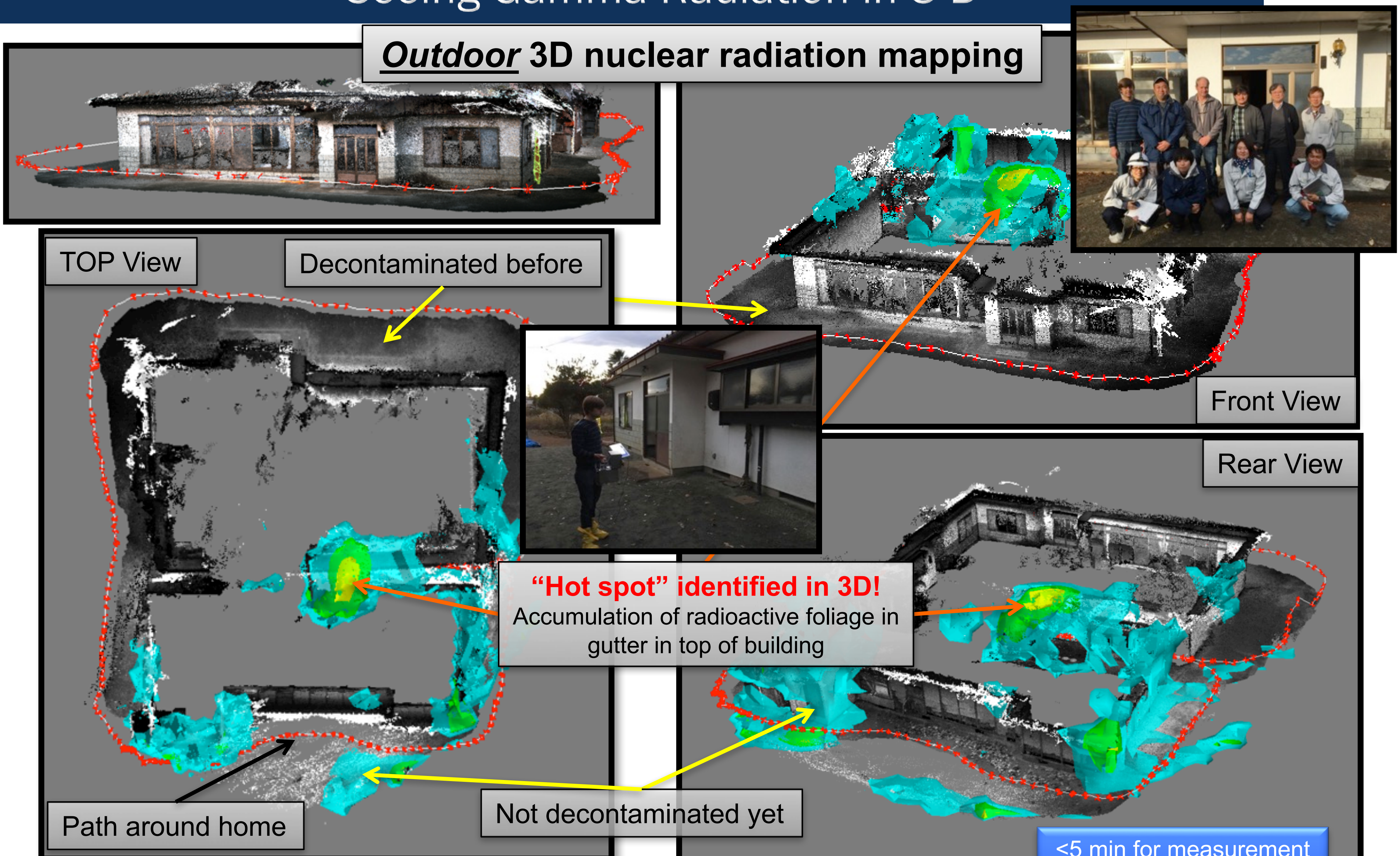
Path around container stack





Point cloud of containers

Contamination Map of Evacuated Home in Fukushima
"Seeing Gamma Radiation in 3-D"



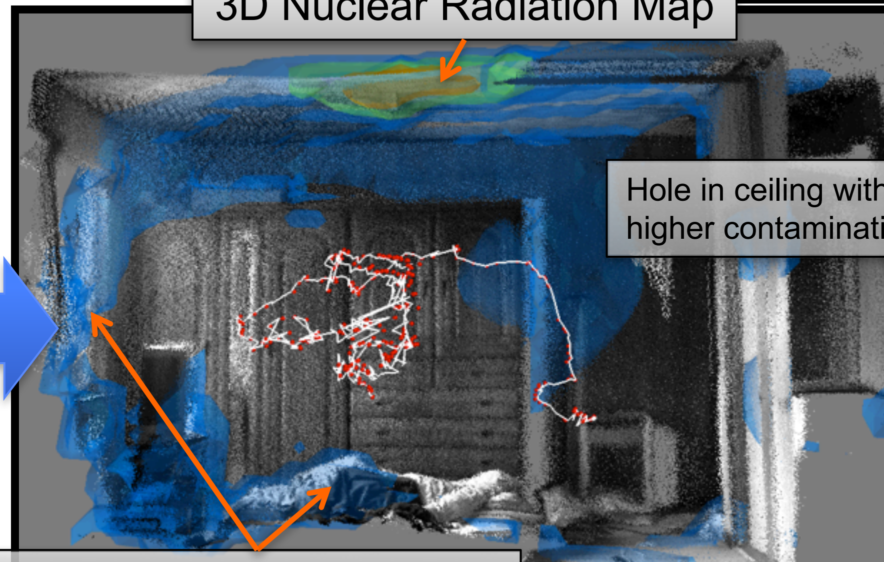
<5 min for measurement and reconstruction!

Contamination Mapping of Evacuated Home in Fukushima
"Seeing Gamma Radiation in 3-D"

Indoor **3D nuclear radiation mapping**

3D colorized reconstructed bedroom

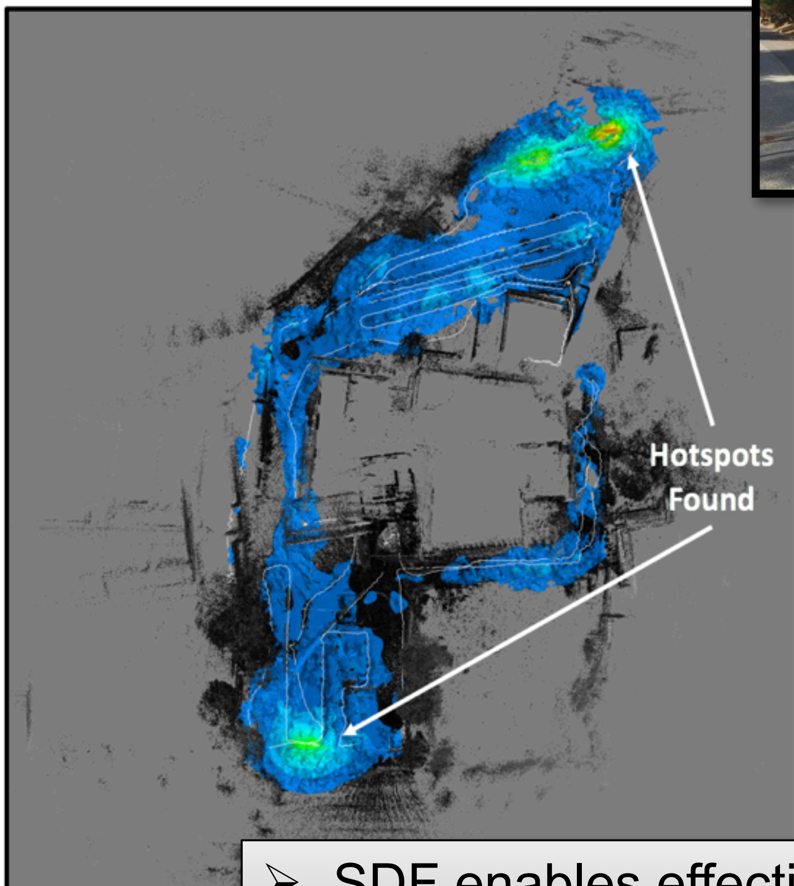
3D Nuclear Radiation Map

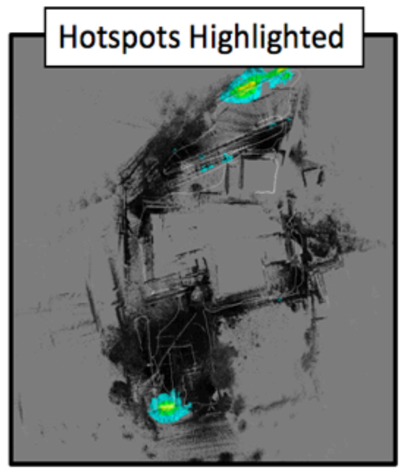


<5 min for measurement and reconstruction!

- SDF enables effective, fast, and accurate mapping in 3D, even years after event

Contamination Mapping of Buildings in Fukushima "Seeing Gamma Radiation in 3-D"

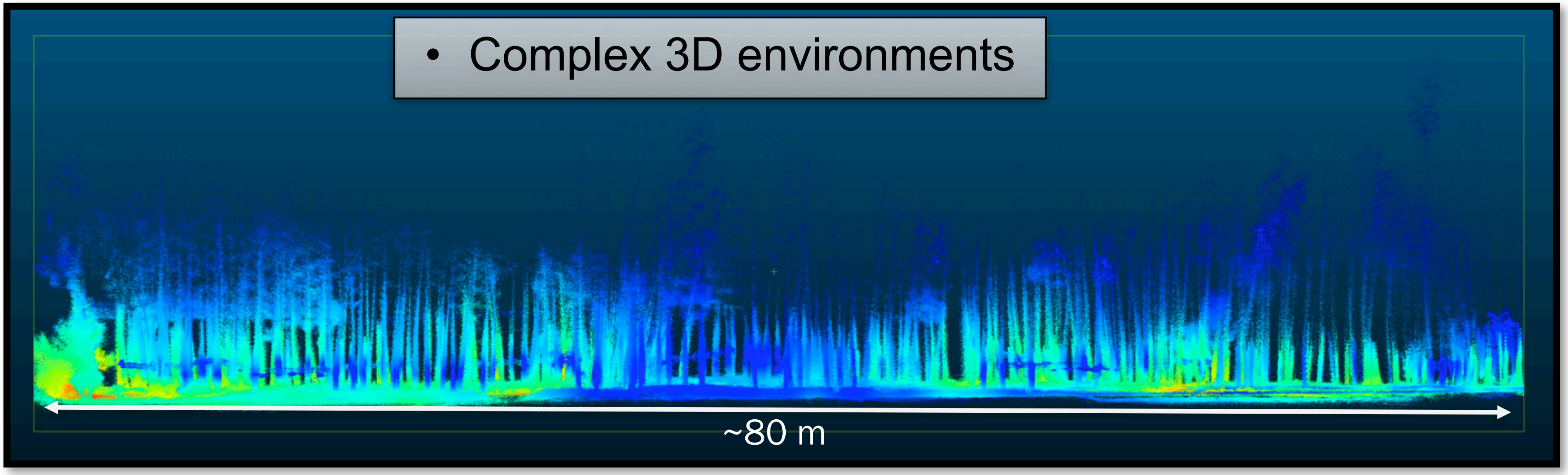


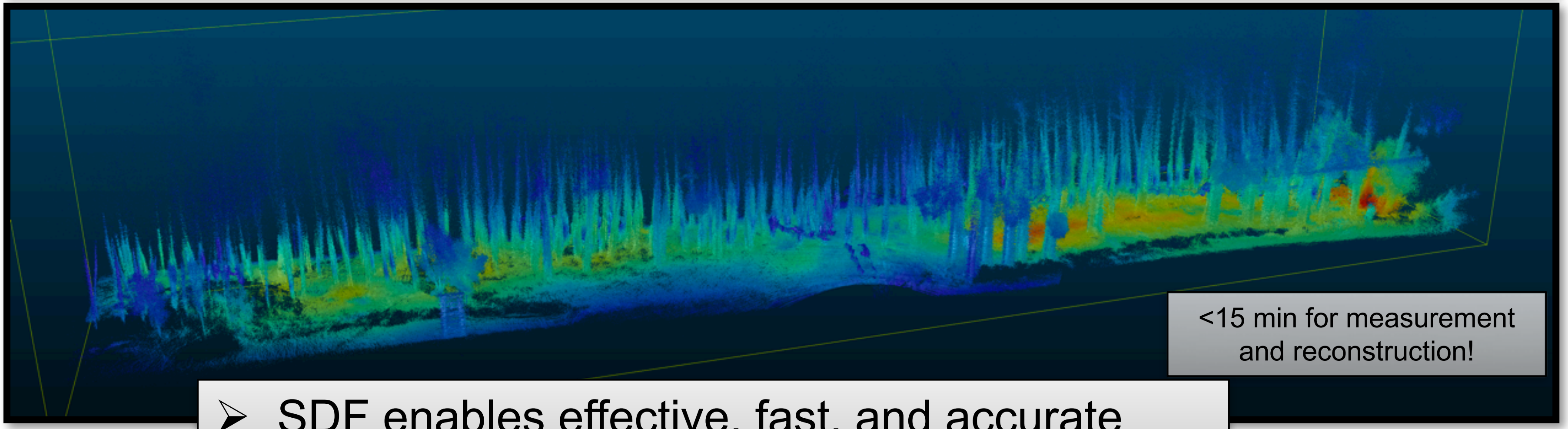


24 min for measurement and reconstruction!

- SDF enables effective, fast, and accurate mapping in 3D, even years after event

Contamination Mapping in Bamboo Forest w/ HEMI



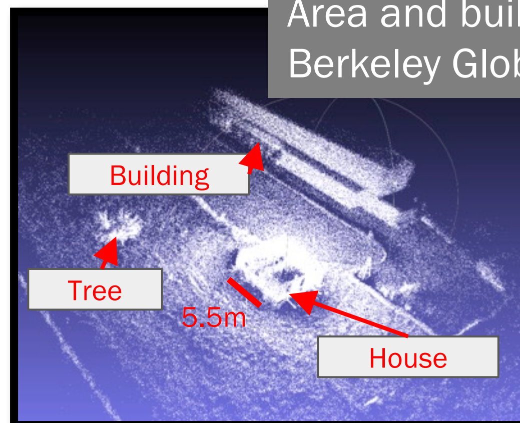


➢ SDF enables effective, fast, and accurate mapping in 3D, even years after event

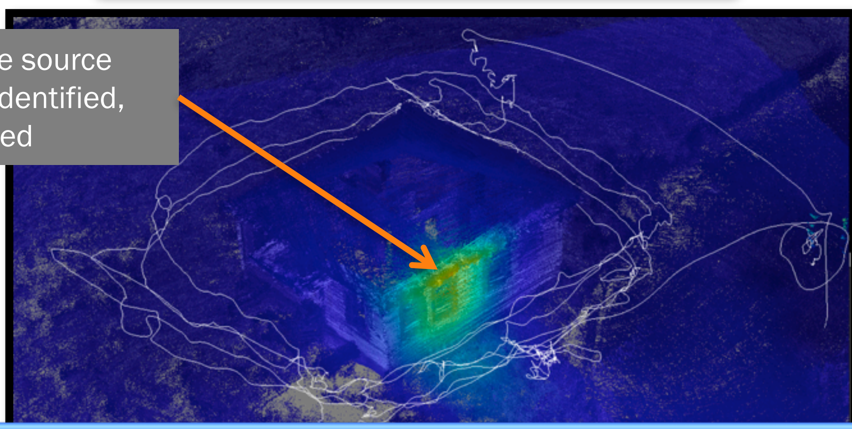
Mapping from Aerial Platforms
“Gamma-Ray Eyes in the Sky”

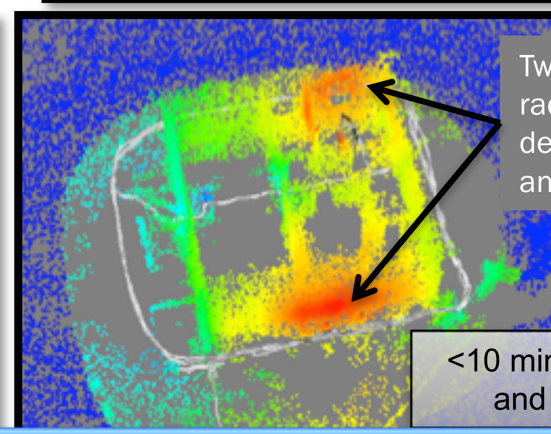
- ➢ Detection and mapping of radiological materials from small unmanned aerial systems (UAS) or drones – Enormous advances in autonomous systems provide unparalleled capabilities for in-accessible or hazardous areas

Area and buildings of Berkeley Global Campus



Radioactive source detected, identified, and localized





Two different radioactive sources detected, identified, and localized

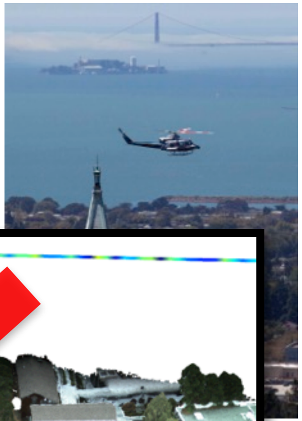
<10 min for measurement and reconstruction!

➢ Mapping and reconstruction in near-real time!

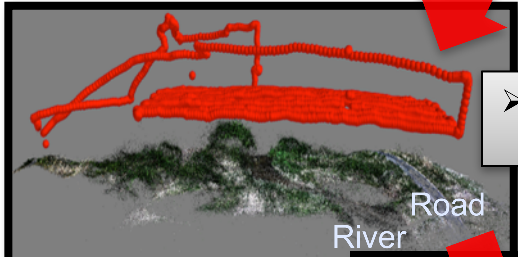
Data reconstruction done on the platform, only data products are transferred.

Mapping from Aerial Platforms "Gamma-Ray Eyes in the Sky"

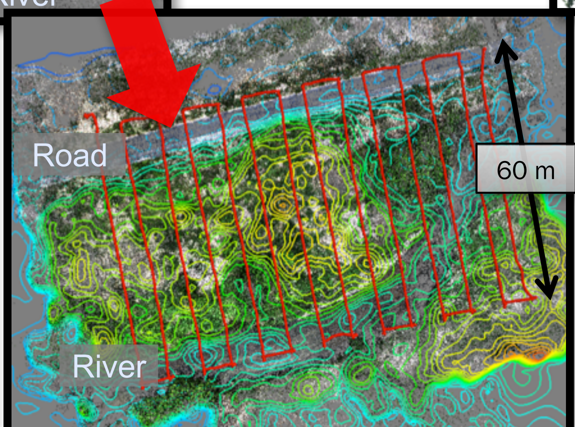
- **Power of Scene Data Fusion on larger aerial platforms**
  - From remote-controlled RMAX to manned Bell helicopter



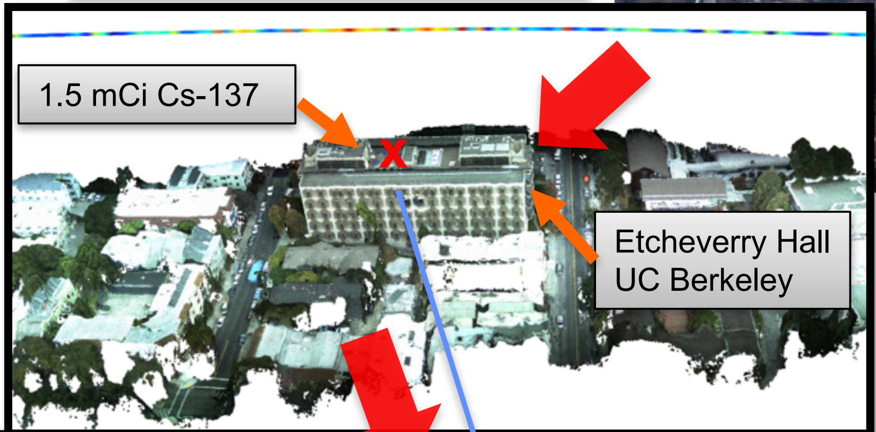
Flight path and scene reconstructed from visual images

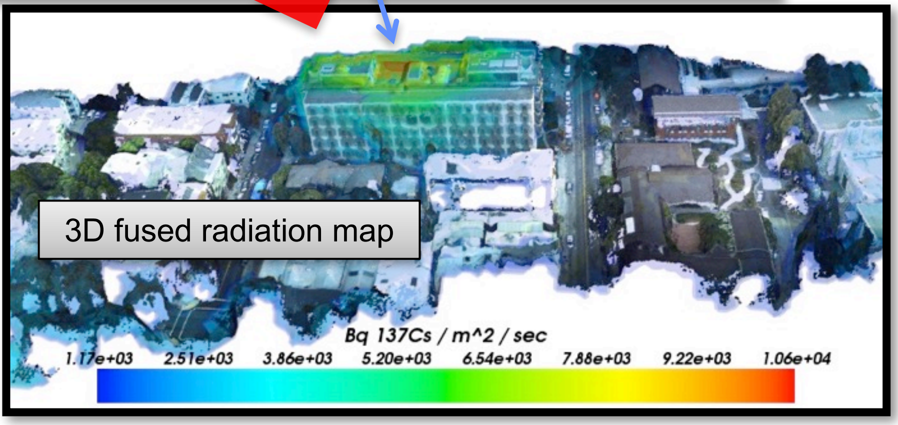


➢ Reconstructed 3D surface and flight path



- ➢ <30 min for measurement and reconstruction!
- ➢ Accurate radiation maps (~m resolution) with "cold" road and river
- ➢ No "hot spots" as seen by conventional means





Conclusions

- Gamma-ray imaging has evolved as an important tool not only in biomedical imaging and astrophysics but also in nuclear security and safety.
- The recently developed Scene-Data Fusion concept provides
  - Ability to visualize gamma radiation in arbitrary and unconstrained environments and operations;
  - New capabilities to map and visualize even complex radiation fields in 3-D and in real time with information available immediately critical for the effective assessment and response;
  - Enormous gains in detection sensitivity and accuracy;
  - Detection platform and modality independent capabilities with broad applicability;

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Thank you !