

# Real-time Free-moving Volumetric Coded Aperture Gamma-ray Imaging in PRISM

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# Outline

- 3D gamma-ray imaging and scene data fusion
- PRISM development
- Real-time 3D coded aperture imaging
- Preliminary depth-of-interaction

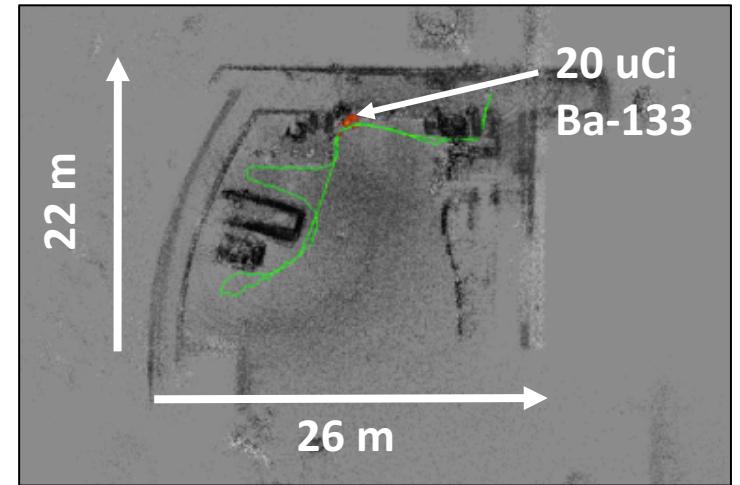
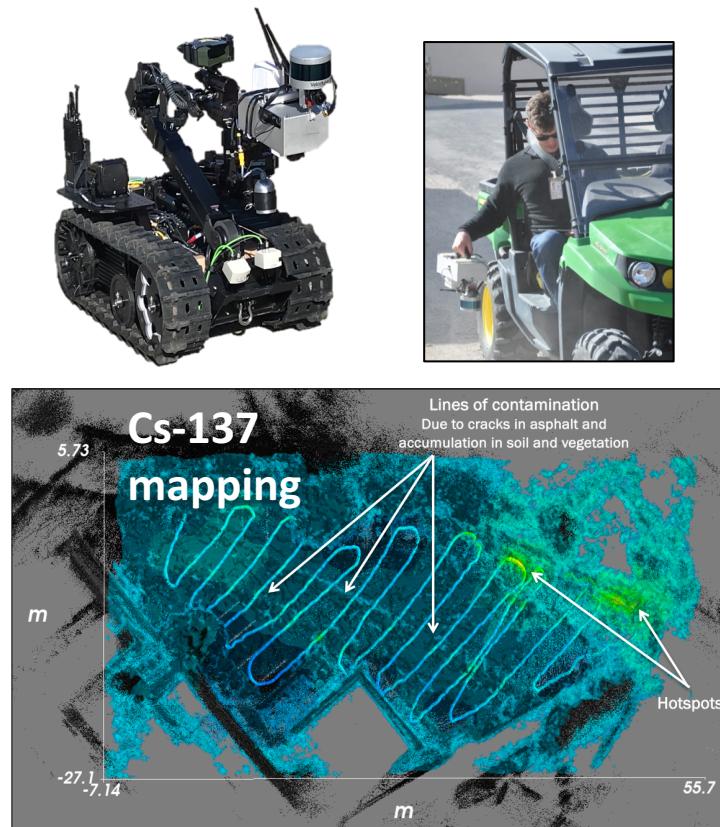
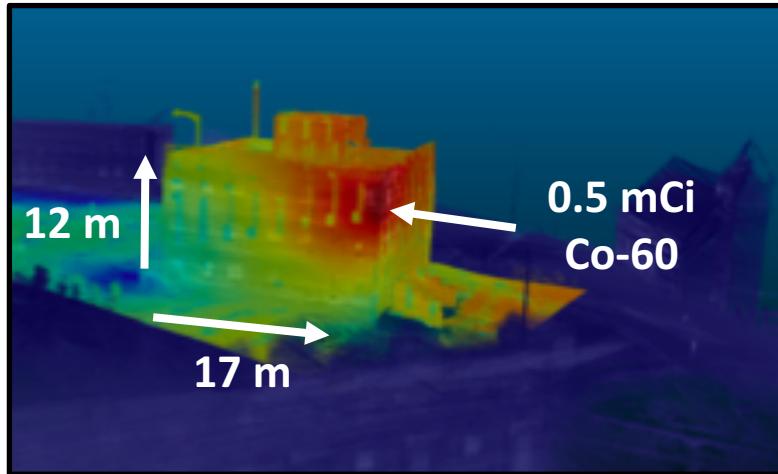
# Goals of this work

To improve our capabilities in radiation detection and imaging for a wide variety of areas including nuclear security, proliferation detection, consequence management and nuclear contamination remediation.

Source detection, characterization, identification, quantification and localization/mapping in 2D/3D in real-time with a variety of mobile systems (e.g. hand-held, UAVs, vehicles).

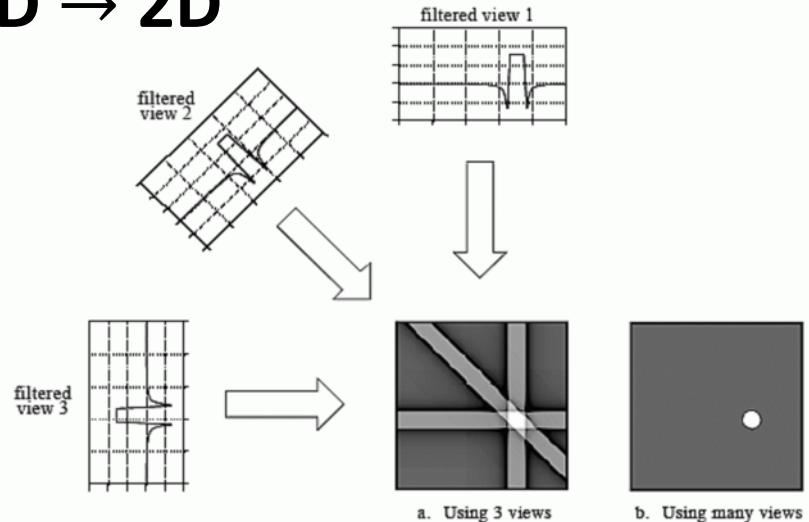
# Approach

Fuse contextual sensors (such as visual cameras and LiDAR) with mobile gamma-ray imaging systems to facilitate real-time 3D proximity, coded aperture, and Compton imaging and mapping over a broad energy range

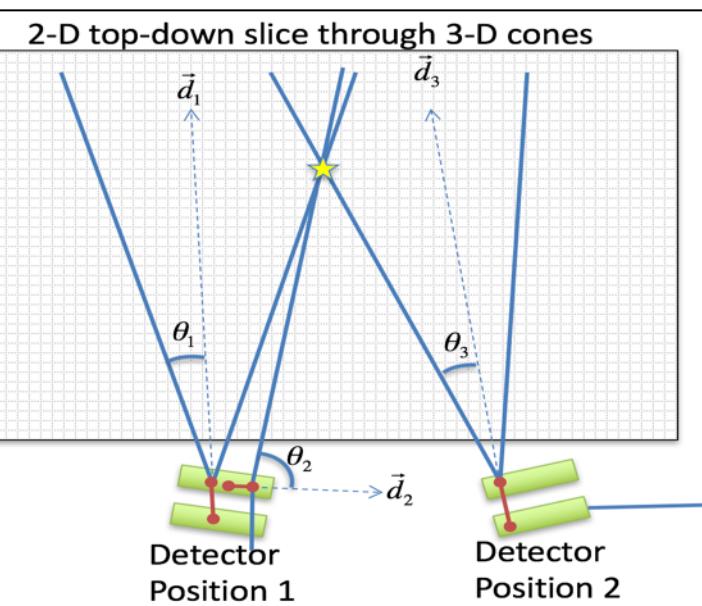
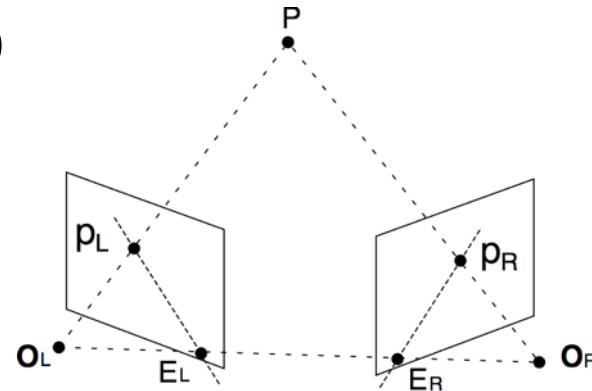


# $\{N\}D \rightarrow \{N + 1\}D$ Imaging

**1D → 2D**



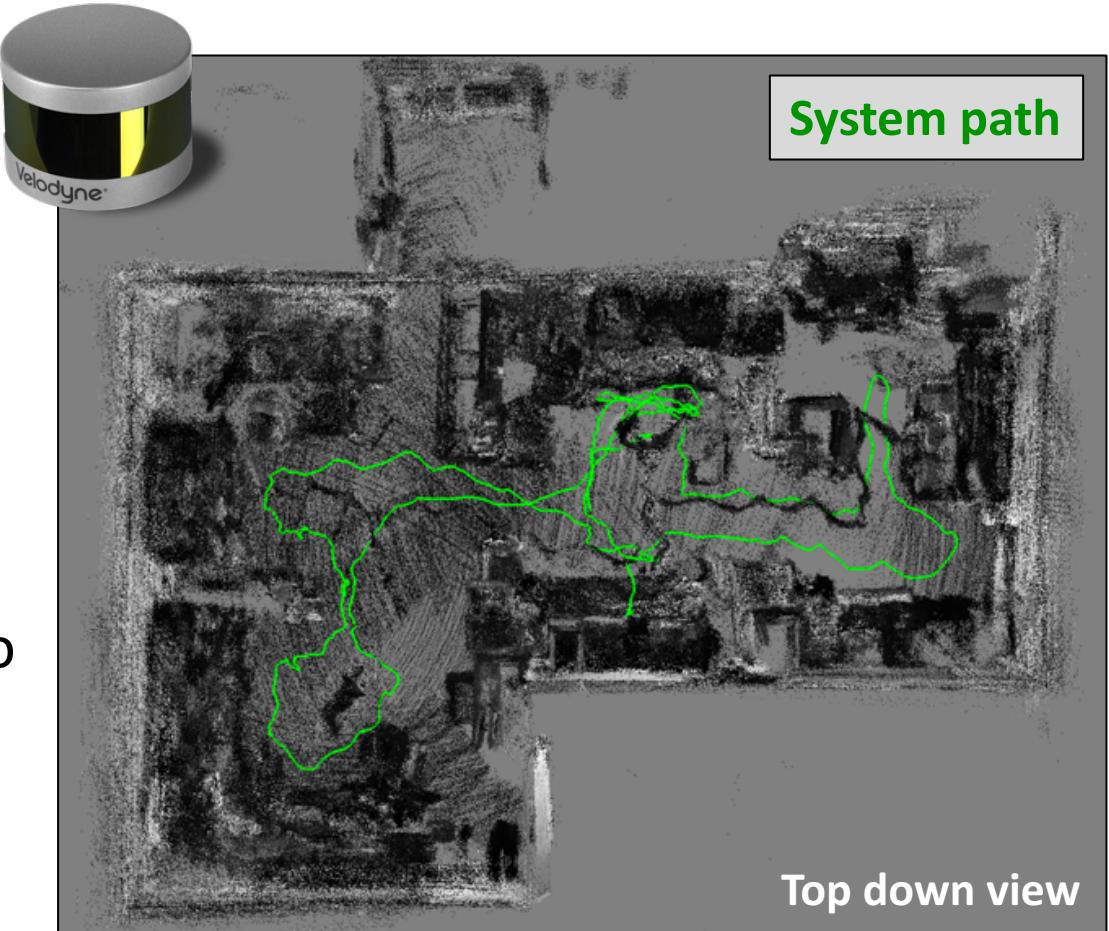
**2D → 3D**



Voxelize 3D space (dynamically)  
 Accurately track pose (free-moving)

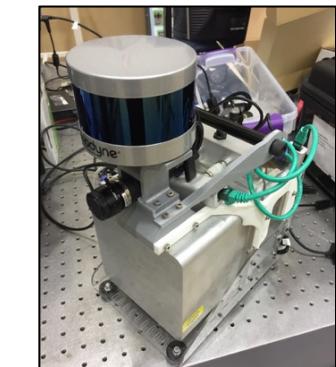
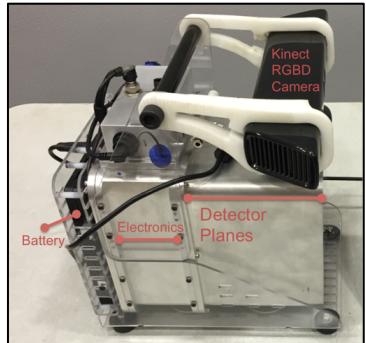
# Scene Data Fusion

- Auxiliary **contextual sensors** (visual camera, LiDAR, IMU) used with **Simultaneously Localization and Mapping (SLAM)** algorithms to map the 3D scene and track the **position and orientation** of the system as it moves freely through an environment
- 3D scene model fused with 3D radiation image to
  - provide visual context
  - increase image accuracy
  - reduce noise
  - decrease reconstruction time



# Platform Agnostic

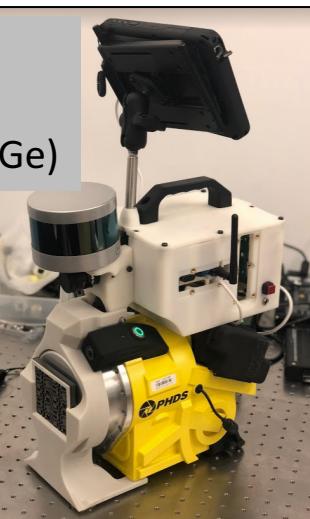
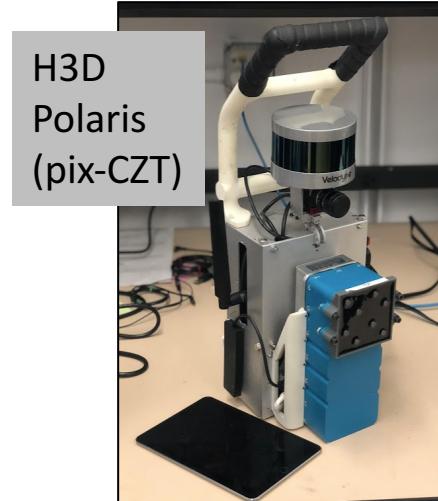
HEMI (CPG-CZT)



LAMP (CsI)



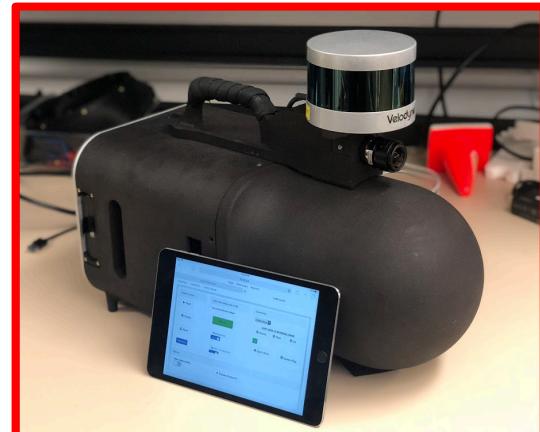
Commercial



miniPRISM (CPG-CZT)

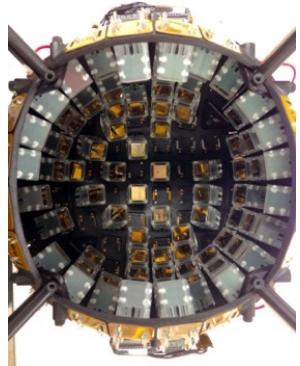


PRISM (CPG-CZT)

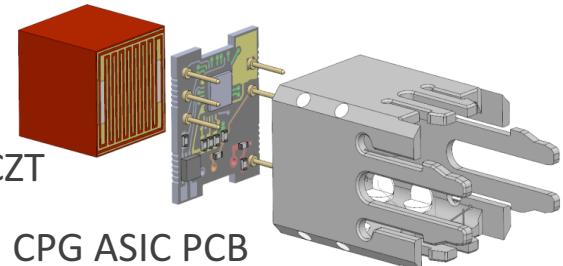


# Portable Radiation Imaging Spectroscopy and Mapping

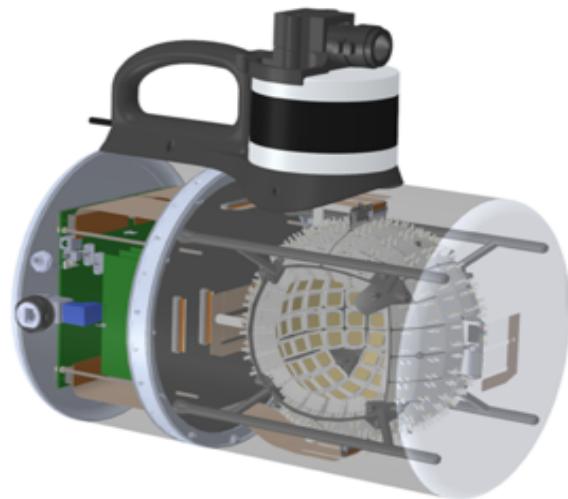
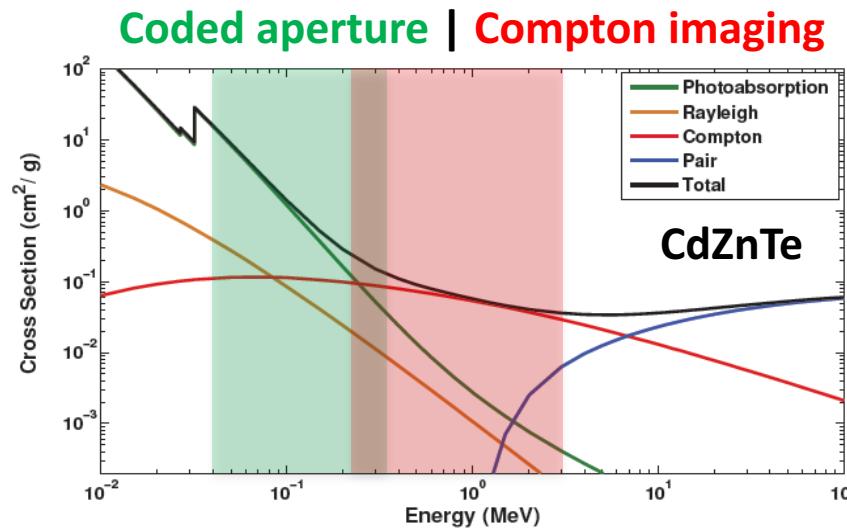
- Hand-held, free-moving,  $1 \text{ cm}^3$  CPG-CZT
- 192 total available detector locations
- Spherical active coded aperture → omnidirectional dual mode imaging



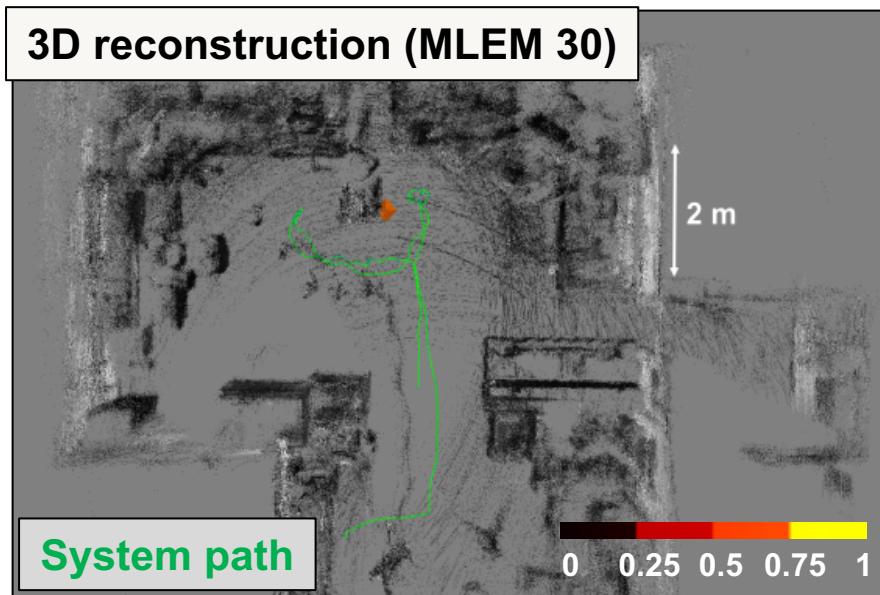
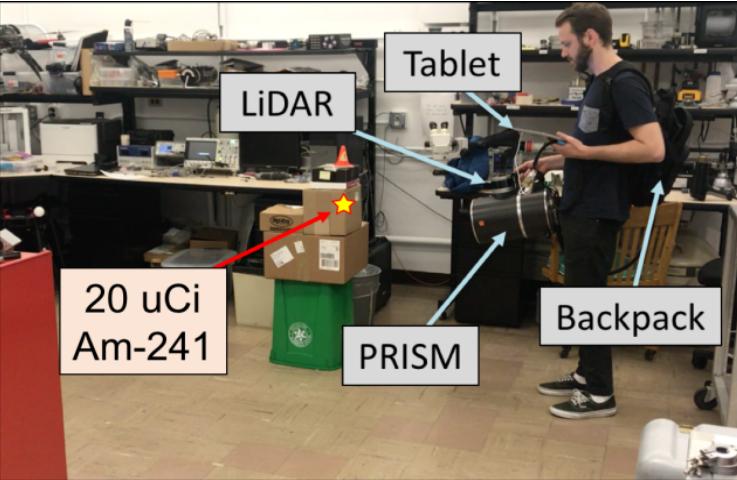
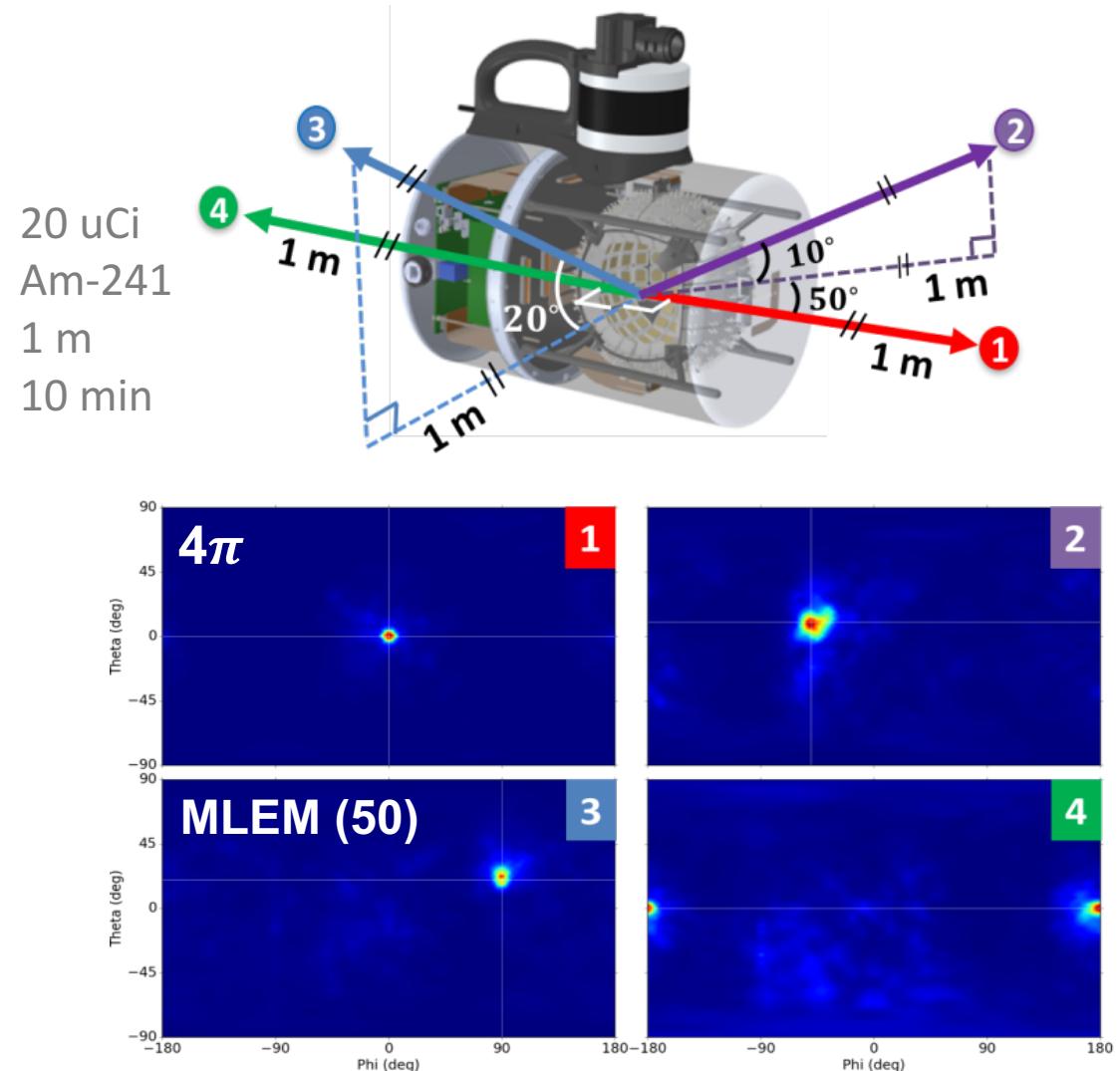
$1 \text{ cm}^3$  CPG CZT  
(Kromek)



Plastic snap-in housing



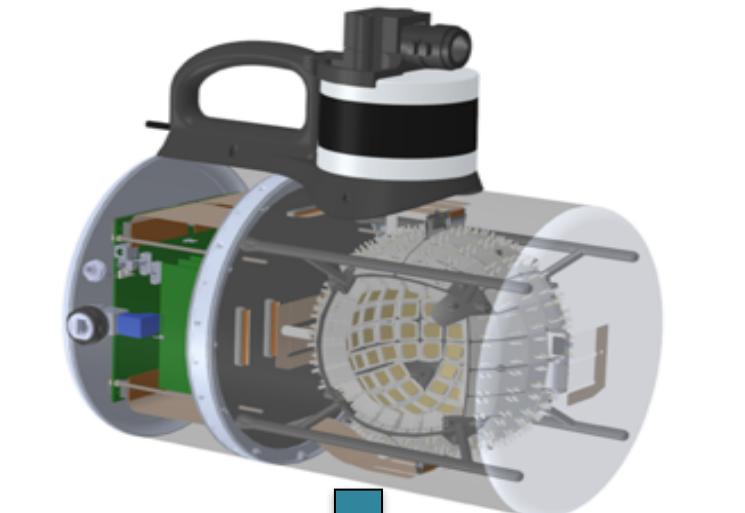
# 2D/3D Coded Aperture



20 uCi Am-241  
34,000 voxels  
10 cm voxels  
900 poses  
2 min

D. Hellfeld, P. Barton, A. Haefner, D. Gunter, L. Mihailescu, K. Vetter, "Omnidirectional 3D Gamma-ray Imaging with a Free-moving Spherical Active Coded Aperture", in Proc. IEEE NSS-MIC, Atlanta, GA, Oct. 2017.  
D. Hellfeld, P. Barton, D. Gunter, L. Mihailescu, K. Vetter, "A Spherical Active Coded Aperture for 4 $\pi$  Gamma-ray Imaging", IEEE Trans. Nucl. Sci., vol. 64, no. 11, pp. 2837-2842, 2017.

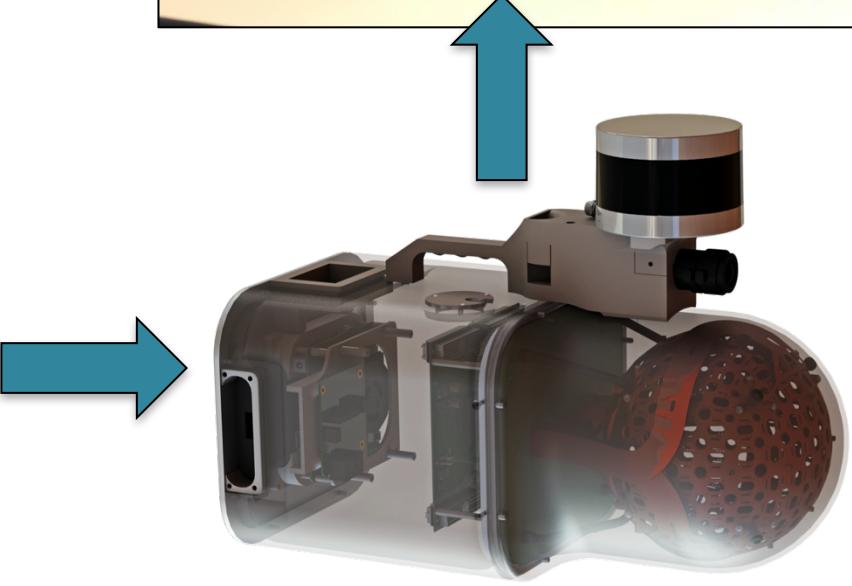
# Improvements to PRISM: V0 → V1



10 lbs (4.54 kg)  
+ backpack



14 lbs (6.35 kg)  
w/ battery



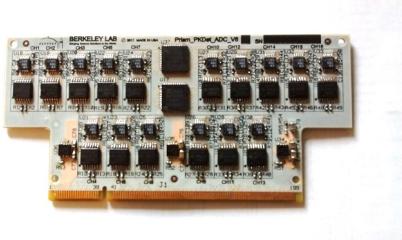
- Integrated battery and processing
- Cathode readout for depth-of-interaction
- Structural improvements
- Weight reduction
- Low power DAQ

# PRISM V1 - Components

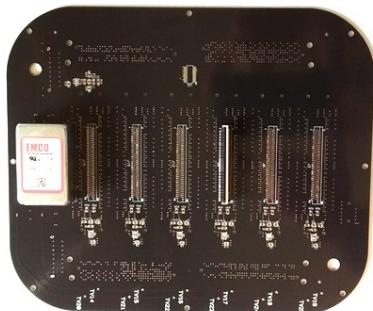


Board computer  
and power  
distribution

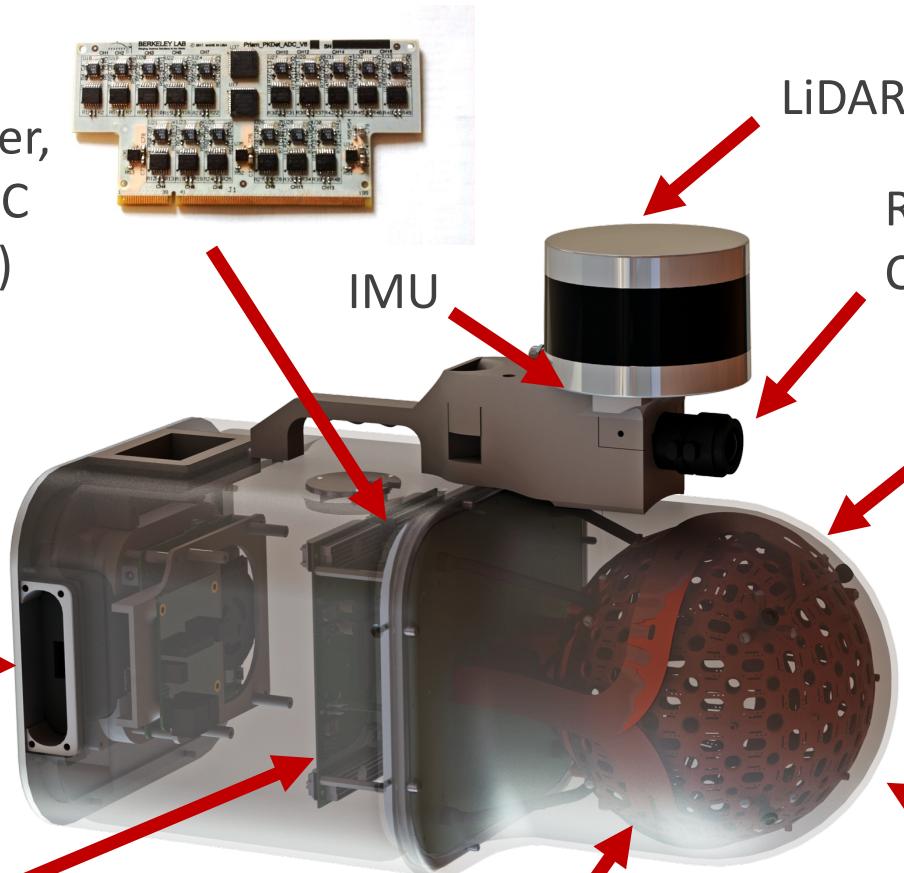
Improved,  
lower-power,  
smaller ADC  
boards (12)



Single battery



Redesigned smaller  
motherboard with 2x  
number of channels



Lighter detector  
support shell

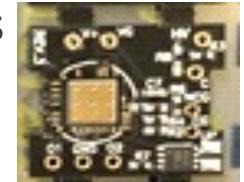


RGB  
Camera

LiDAR

Tighter enclosure  
for near-field and  
carry-on travel

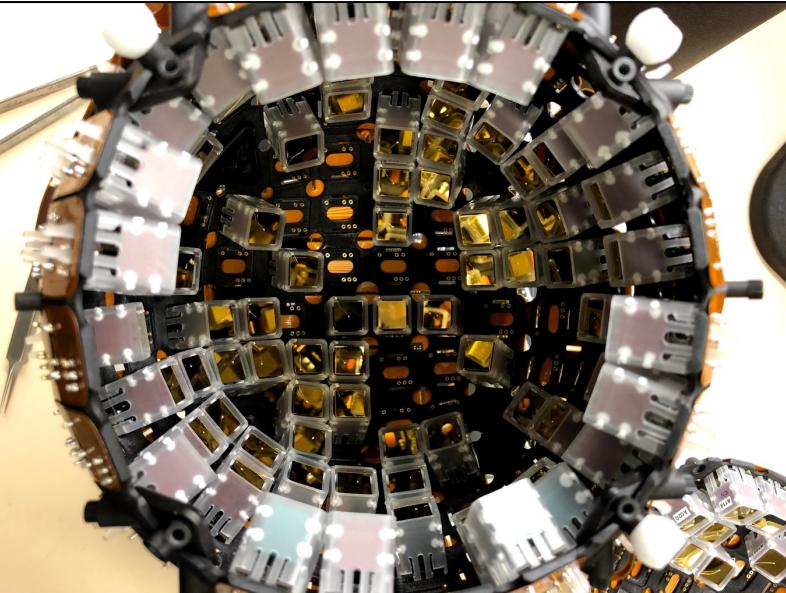
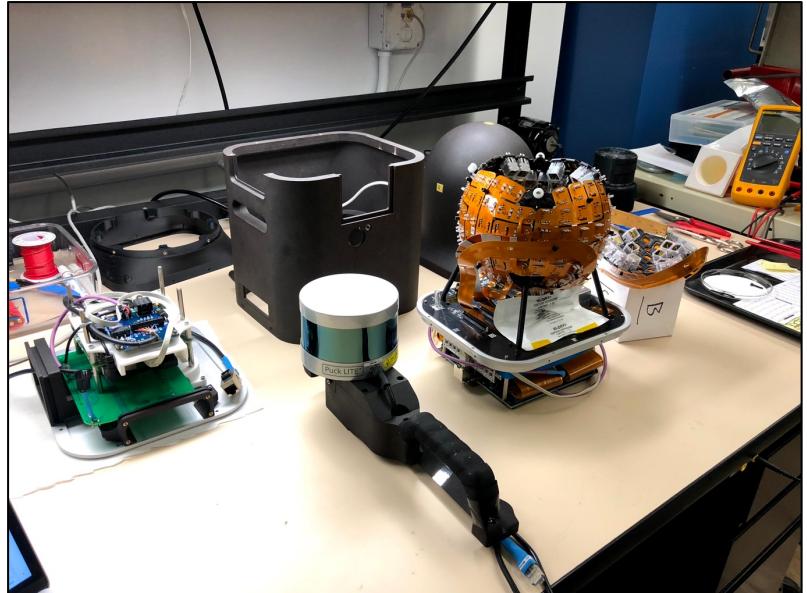
DOI detectors  
with new ASIC  
boards



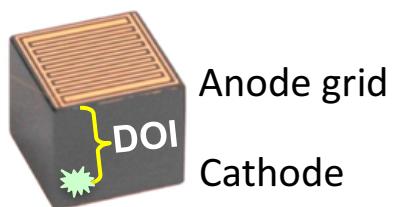
Single flex  
assembly



# PRISM V1 – Putting it together

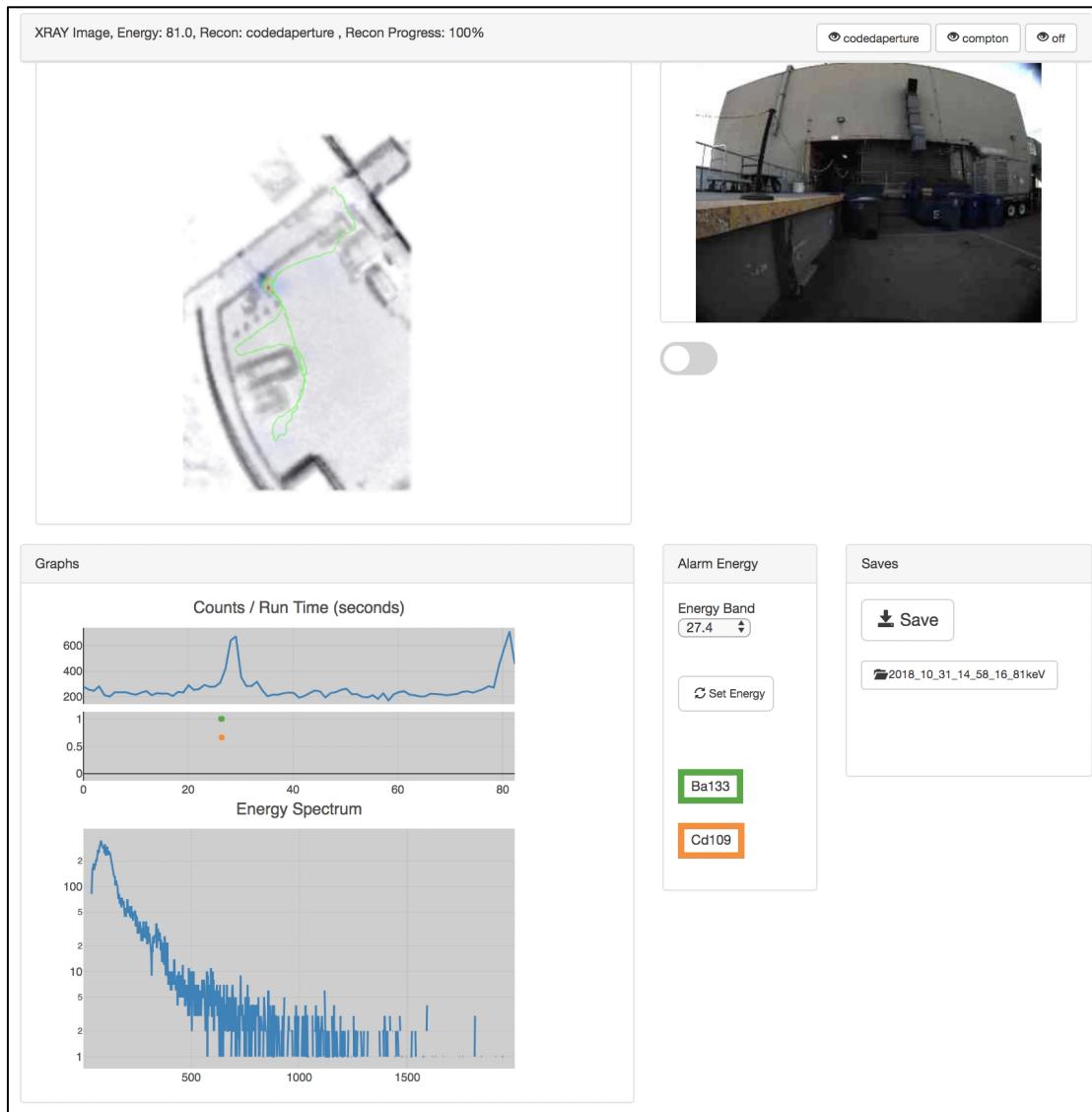


- 100 CPG-CZT detector modules loaded in optimal coded configuration
- 52 modules with cathode readouts – **depth of interaction**
- iPad used for remote control and real-time visualization



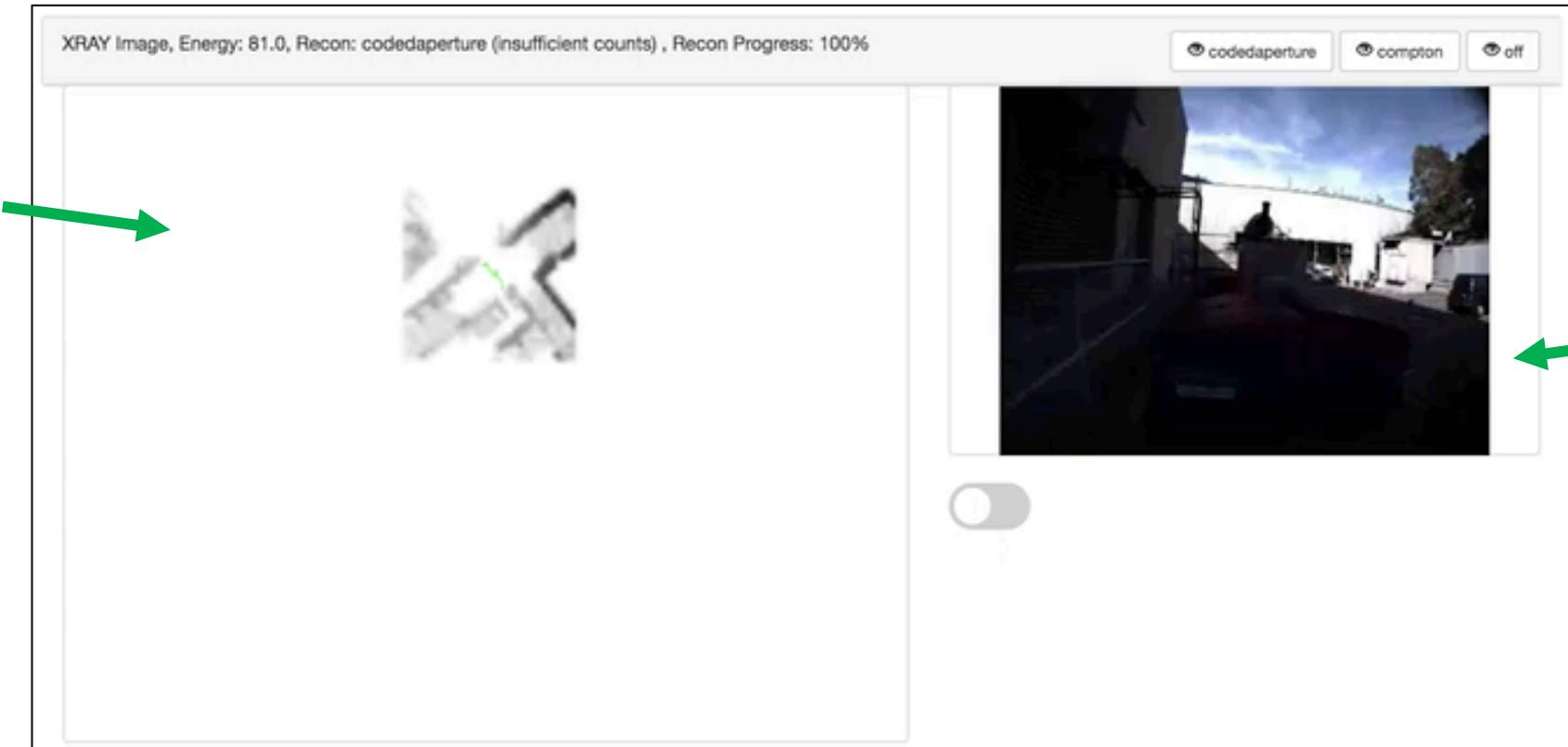
# Scalable and Real-time Image Reconstruction

- **3D list-mode MLEM** on single board computer integrated **GPU**
- **< 1 sec / iteration**  
 $10^2$  detectors,  $10^2$  poses,  $10^4$  voxels,  $10^3$  counts
- Online reconstruction during measurement and shown to user in real-time
- Current work:
  - OSEM on counts, poses, and voxels
  - Voxelization: octree, adaptive mesh
  - System matrix change of basis



# Scalable and Real-time Image Reconstruction

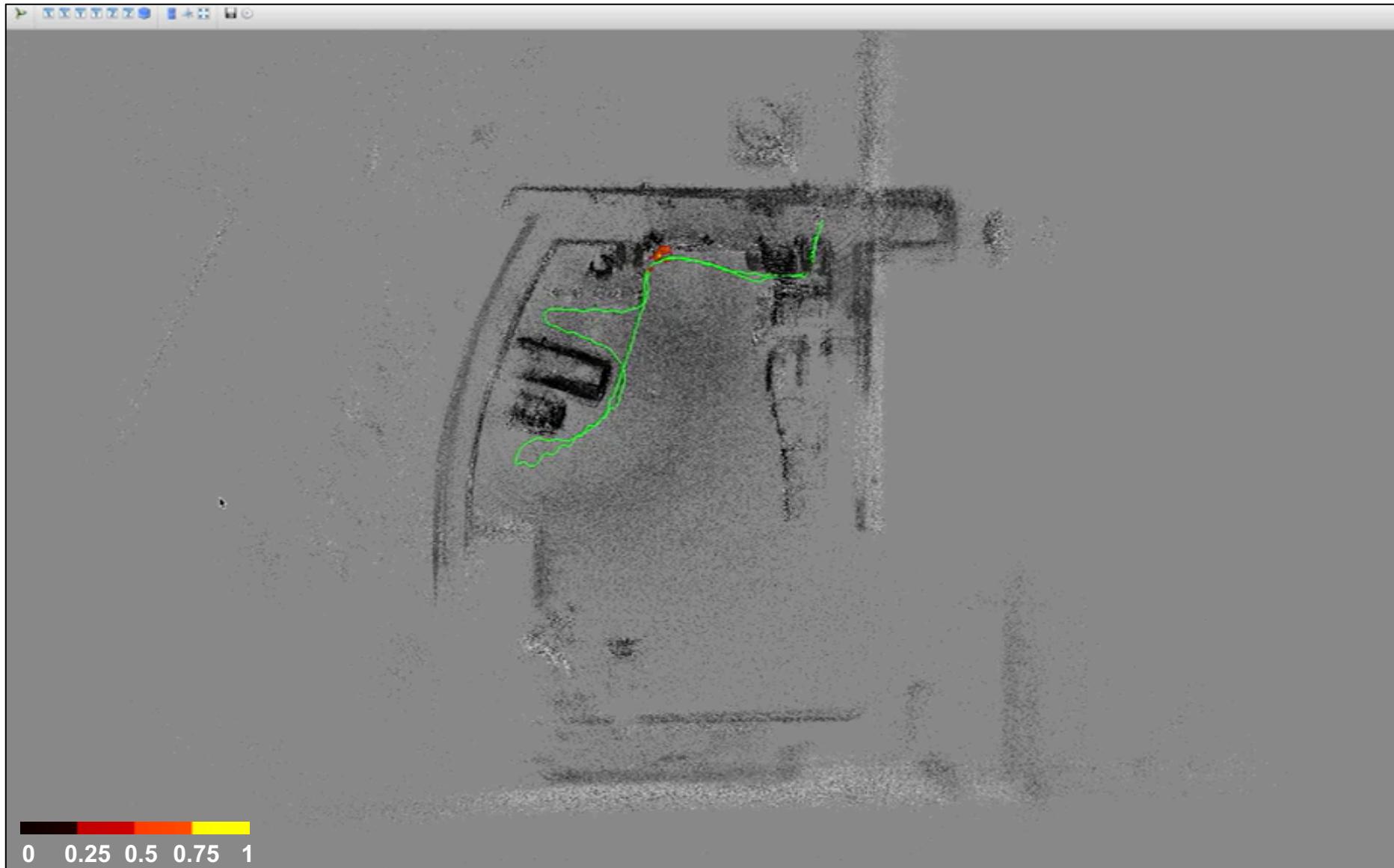
Top down  
projection  
of 3D image



RGB image w/  
**augmented  
overlay**



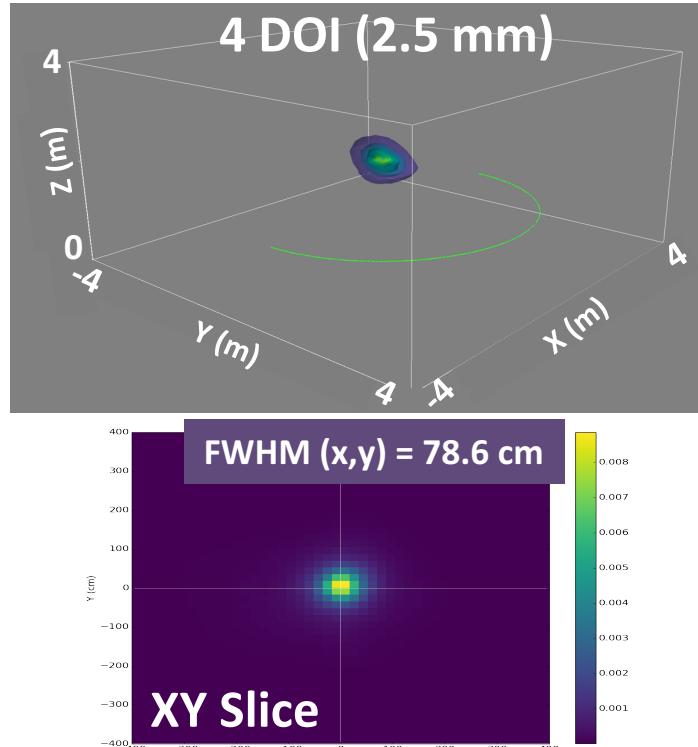
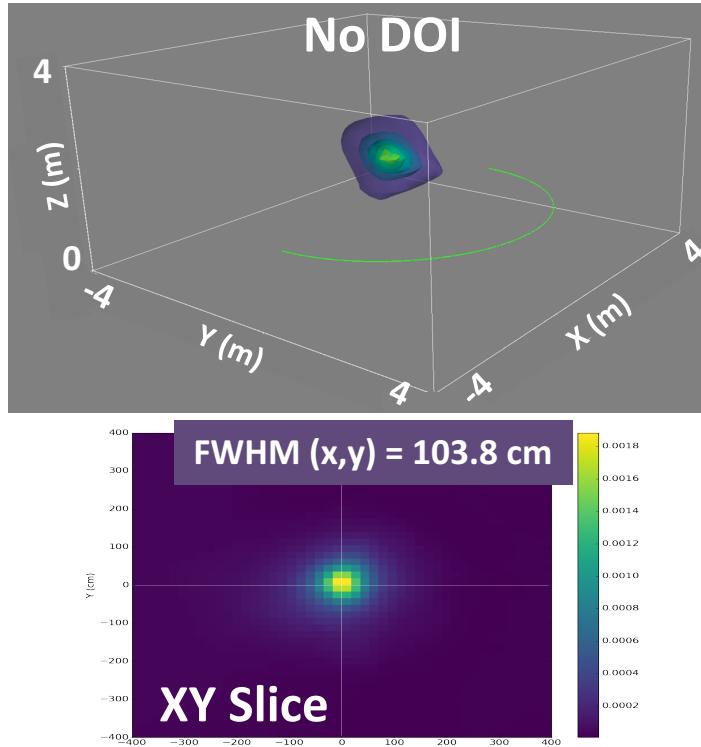
# 3D Image



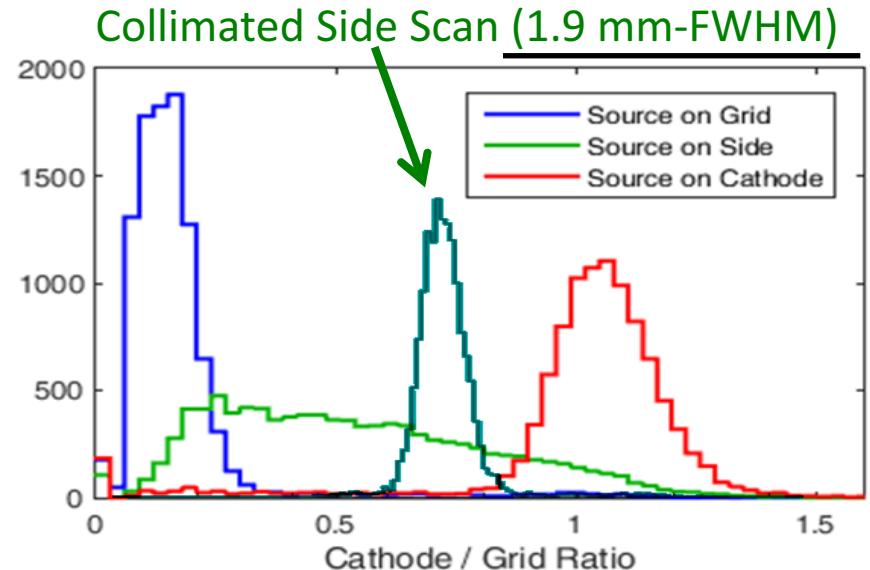
# Depth-of-interaction and CAI

- DOI = cathode / anode grid
- Increase in information density should improve angular and spatial resolution
- Depth-dependent energy losses already corrected for with CPG

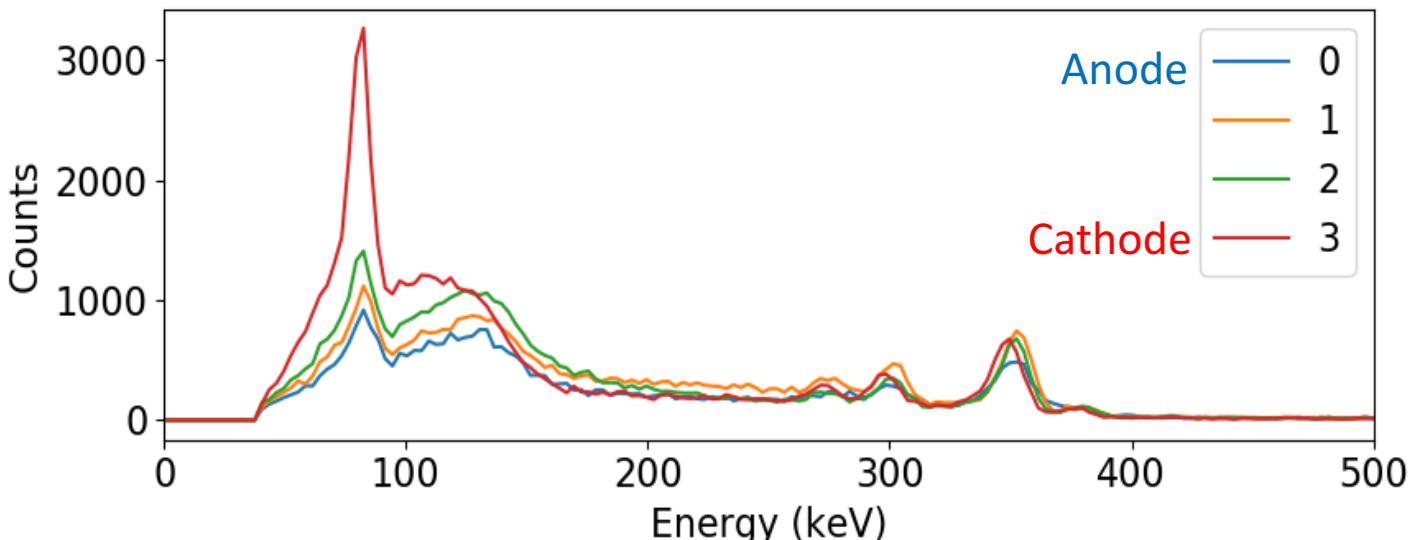
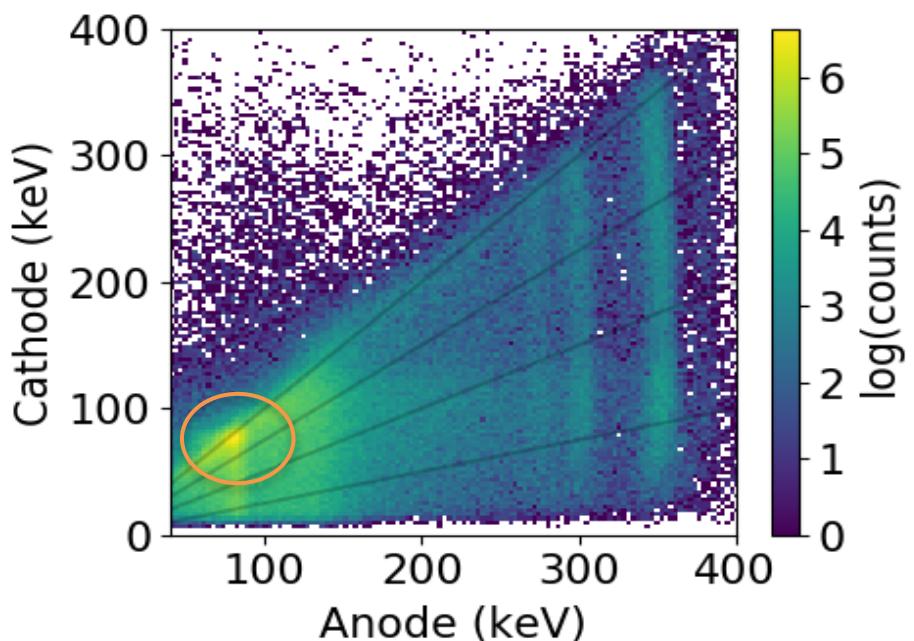
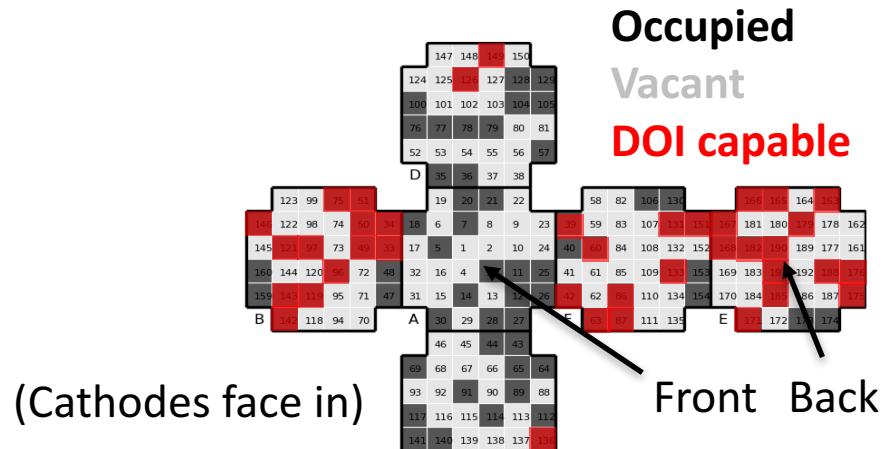
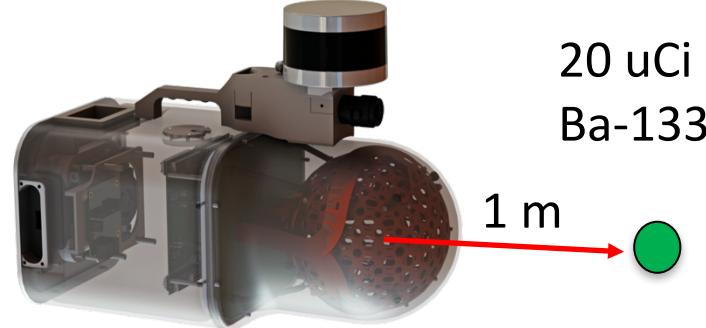
## 3D Simulations



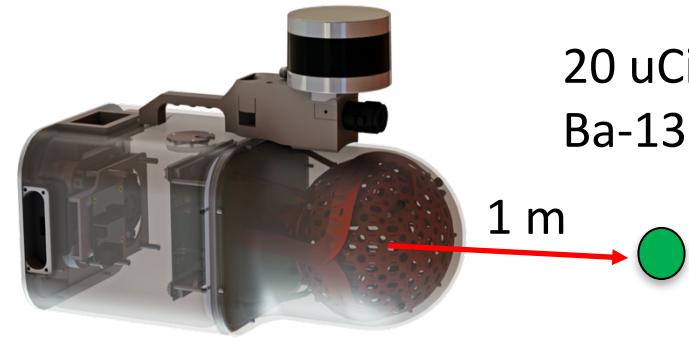
## Measured DOI resolution



# Depth-of-interaction characterization

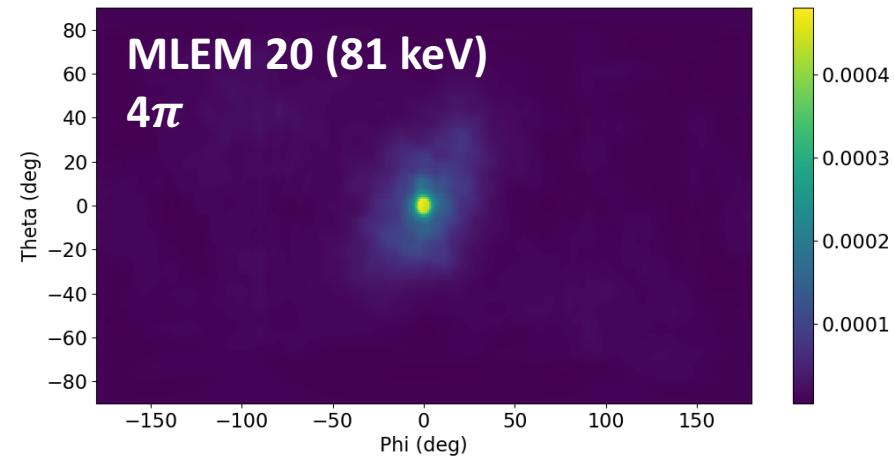


# 2D Imaging Improvement (simulated)

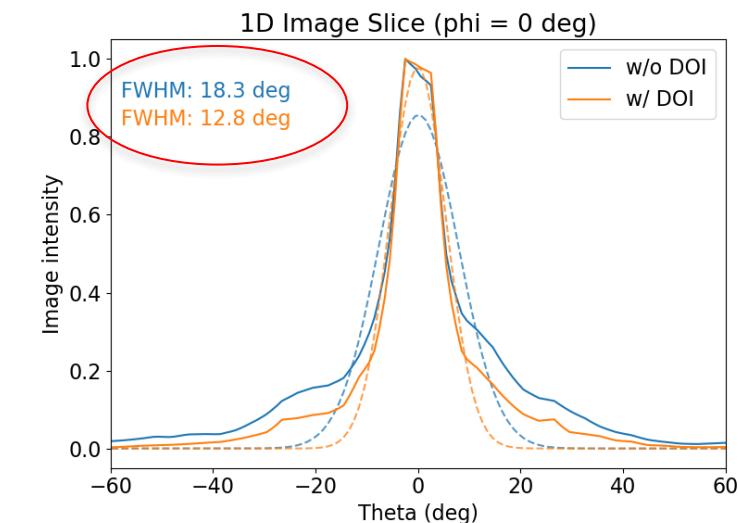
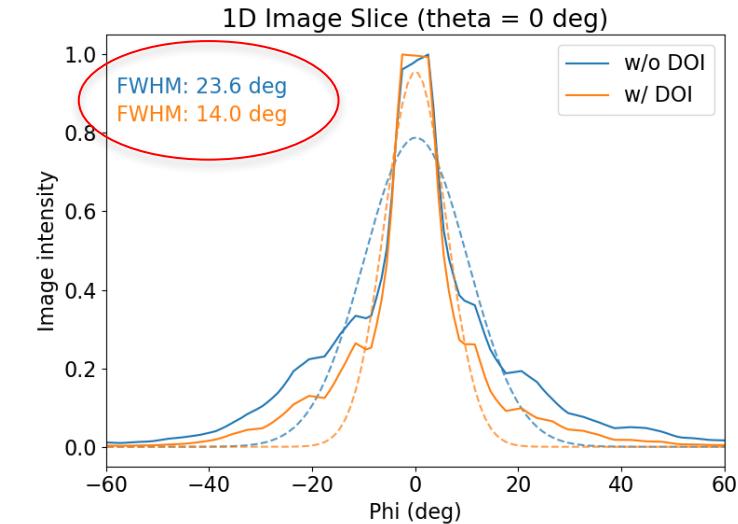
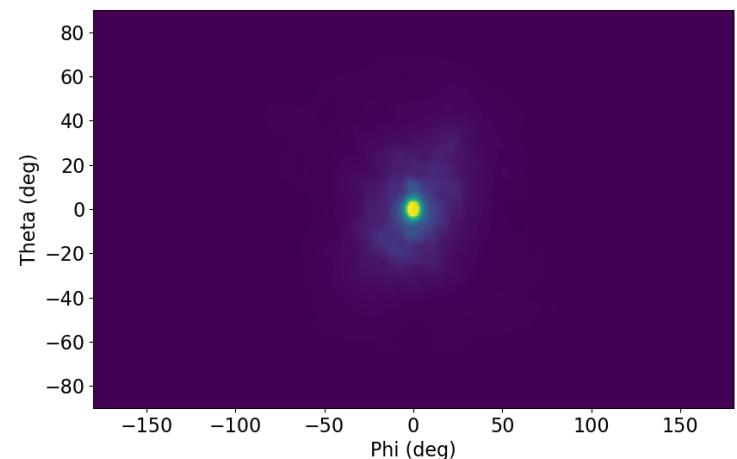


20 min  
89 detectors  
39 cathodes

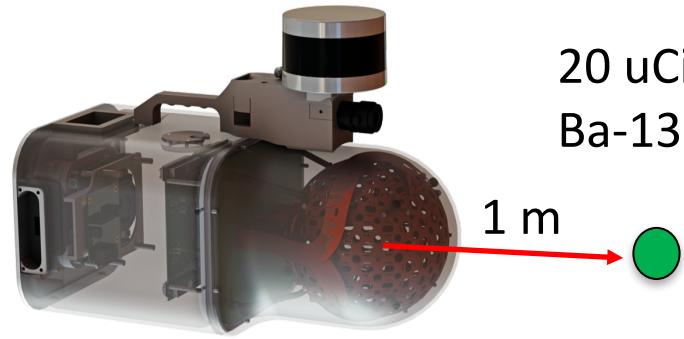
No DOI



With 4 DOI

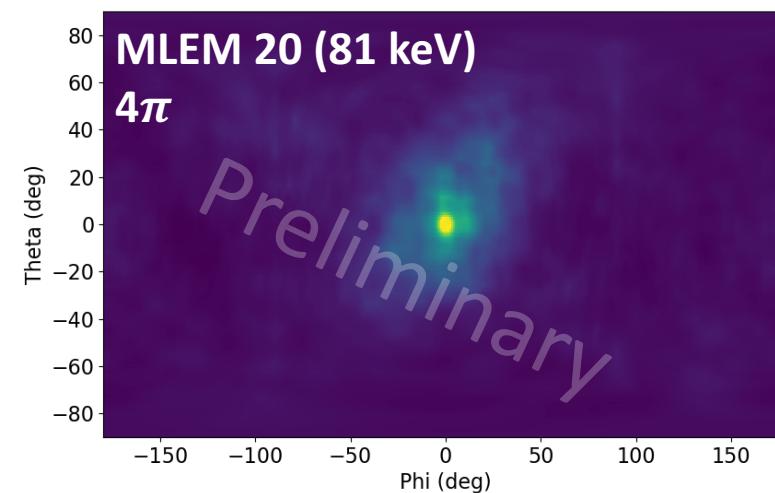


# 2D Imaging Improvement (measured)

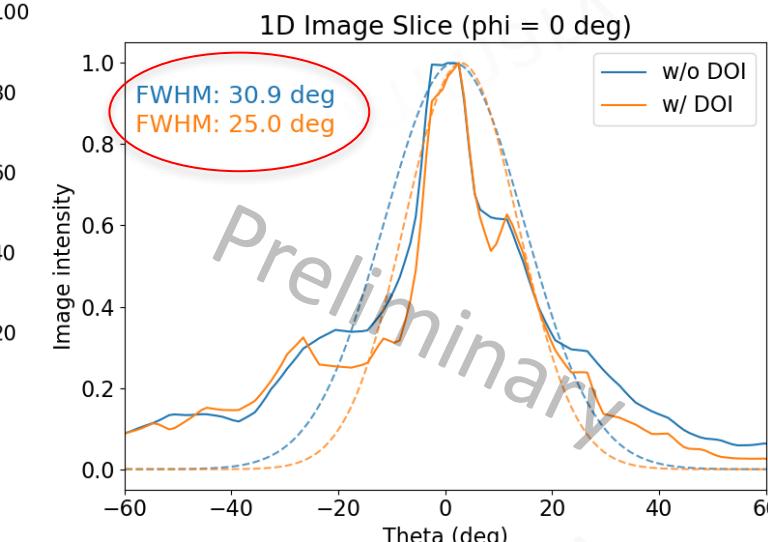
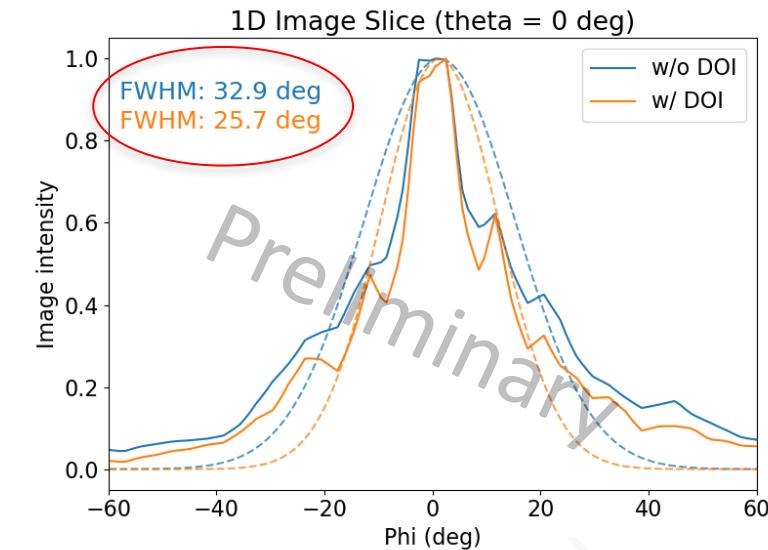
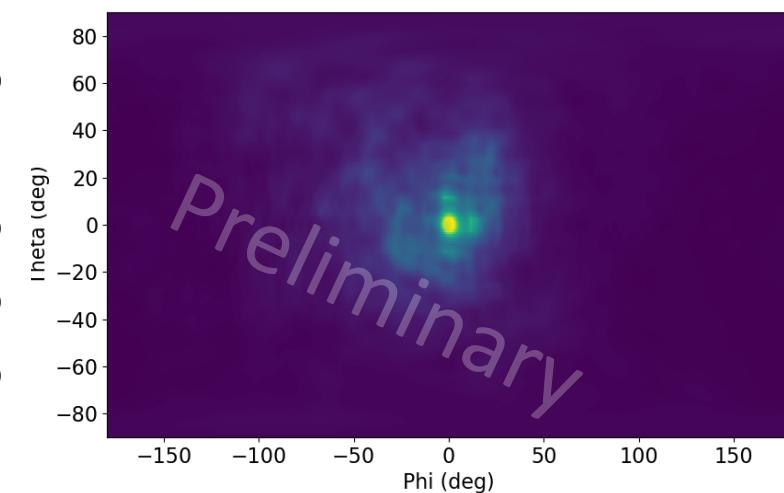


20 min  
89 detectors  
39 cathodes

No DOI

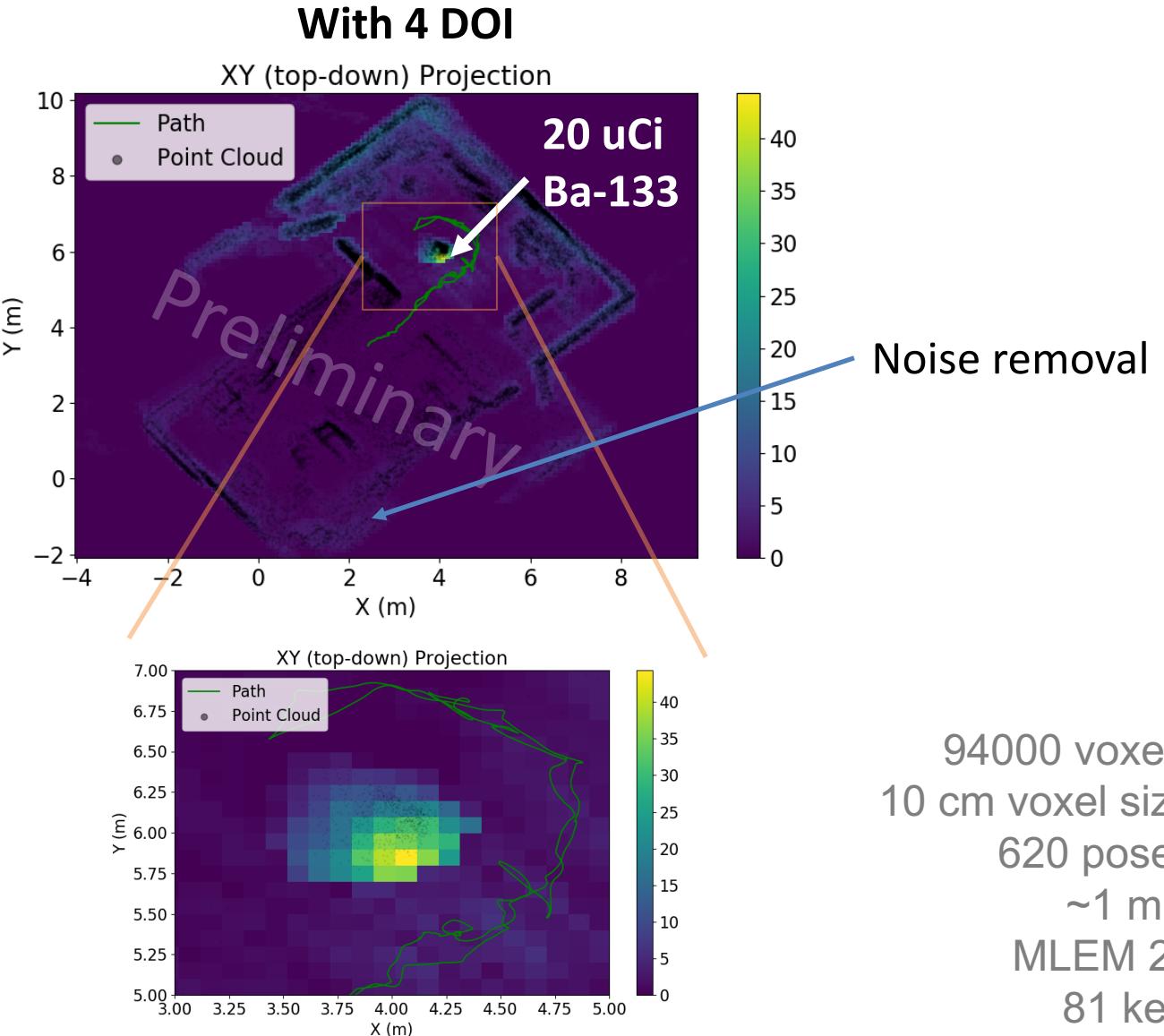
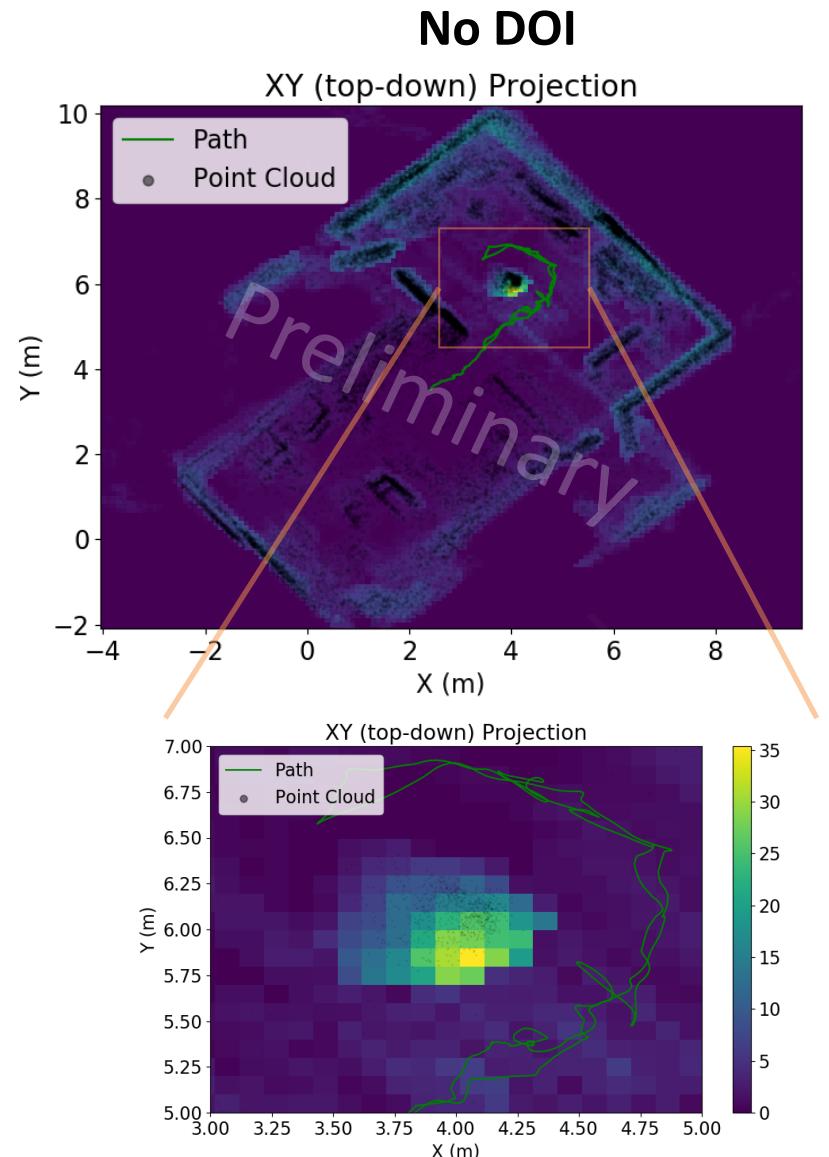


With 4 DOI



\* Simplified system response

# 3D Imaging



# Summary

- Free-moving, multimodal, hand-portable, CPG-CZT-based, 3D gamma-ray imager with scene data fusion
- Improved design with integrated electronics and battery, cathode readouts
- Real-time, on-line, coded aperture and Compton imaging and 3D scene mapping
- Preliminary coded aperture image reconstruction with DOI in CPG-CZT

## Future Work

- Fabricate and integrate more DOI capable detector modules
- Detailed depth-of-interaction characterization and continue to improve image quality
- Continue development of reconstruction acceleration techniques and voxelization schemes for scalable reconstruction

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Thank you for your attention

Questions?