



Position Sensitivity within a Bar of Stilbene Coupled to Silicon Photomultipliers

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Introduction

Motivation

Human-portable systems are needed to locate special nuclear material (SNM) and identify warheads for:

- Safeguards
- Treaty verification
- Emergency response

SNM geometry is an indication of a nuclear weapon. SNM emits neutrons and gamma rays spontaneously or when interrogated.

A handheld dual particle imager (H²DPI) can exploit these two signatures to identify nuclear warheads.



Handheld Dual Particle Imager (H²DPI) Design

- Exploits recent advances in silicon photomultiplier (SiPM) technology to achieve compact form factor
- Utilizes the crystalline organic scintillator, stilbene, for sensitivity to, and discrimination between, neutrons and gamma rays
- **Double-ended pillar readout improves position resolution using fewer electronic channels than would otherwise be required.**



Figure 1: (a) 2D and (b) 3D sketches of proposed H²DPI design.

$$n_{top} = PDE \varepsilon_{top}(z) \left(\frac{n_{photons}}{E} \right) E$$

$$z = f(n_{top}/n_{bottom})$$

$$n_{bottom} = PDE \varepsilon_{bottom}(z) \left(\frac{n_{photons}}{E} \right) E$$

Figure 2: Diagram of vertical position sensitivity technique.

Previous Experimental Results

Pulse Shape Discrimination

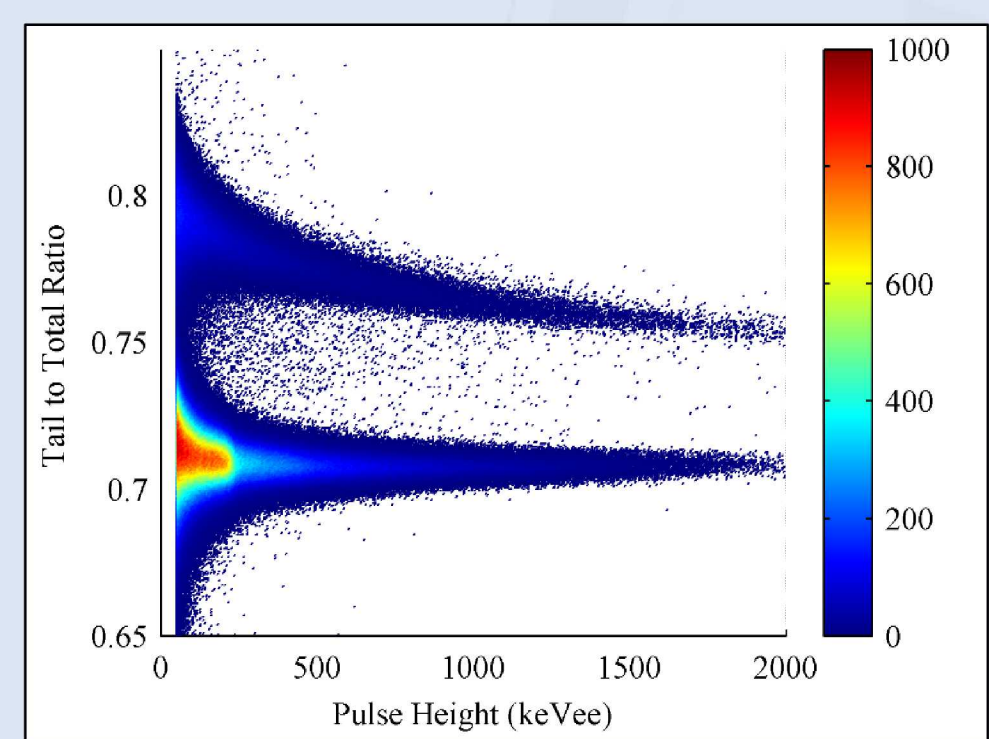


Fig. 3. Previously achieved pulse shape discrimination result of stilbene coupled to MicroFC-600035 SiPM. Reproduced from Ruch et al., Nucl. Inst. & Meth. A, 2015.

Time Resolution

- Measured time resolution of stilbene/SiPM system
- Coincident annihilation photons Na-22 source
- CAEN DT5730 digitizer (500 MS/s)
- SensL C-Series SiPM
- SiPM standard output: 0.28 ns σ
- SiPM fast output: 0.23 ns σ
- Fast PMT: 0.32 ns σ

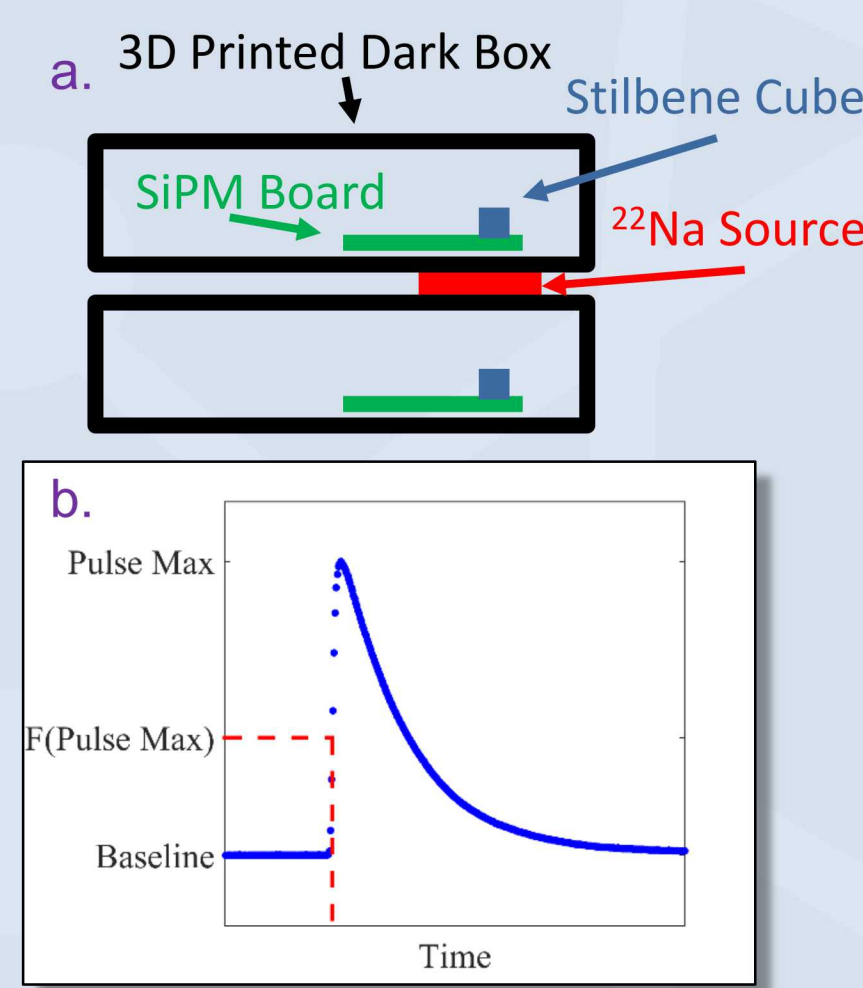


Figure 4: (a) Setup and (b) algorithm depiction for time resolution experiment.

Method

Experimental Setup

- Measured position sensitivity within a bar of stilbene with a SiPM on either end
 - 0.6 cm x 0.6 cm x 5.0 cm
- Collimated Na-22 source
- Measured at 5 positions along bar
- Repeated experiment with uncoated and PTFE-wrapped stilbene crystal

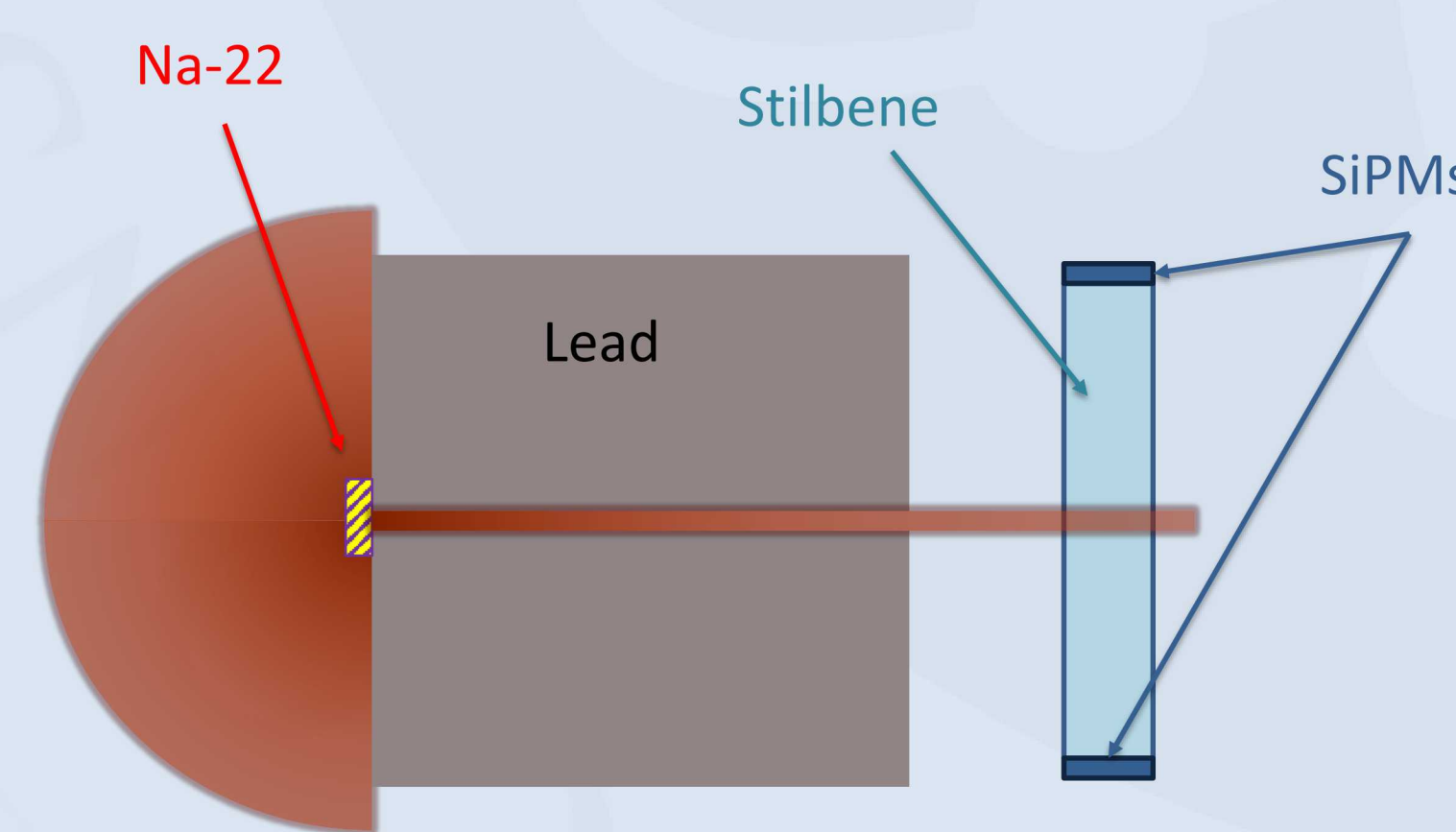


Figure 5: Diagram of position sensitivity experiment.

Results

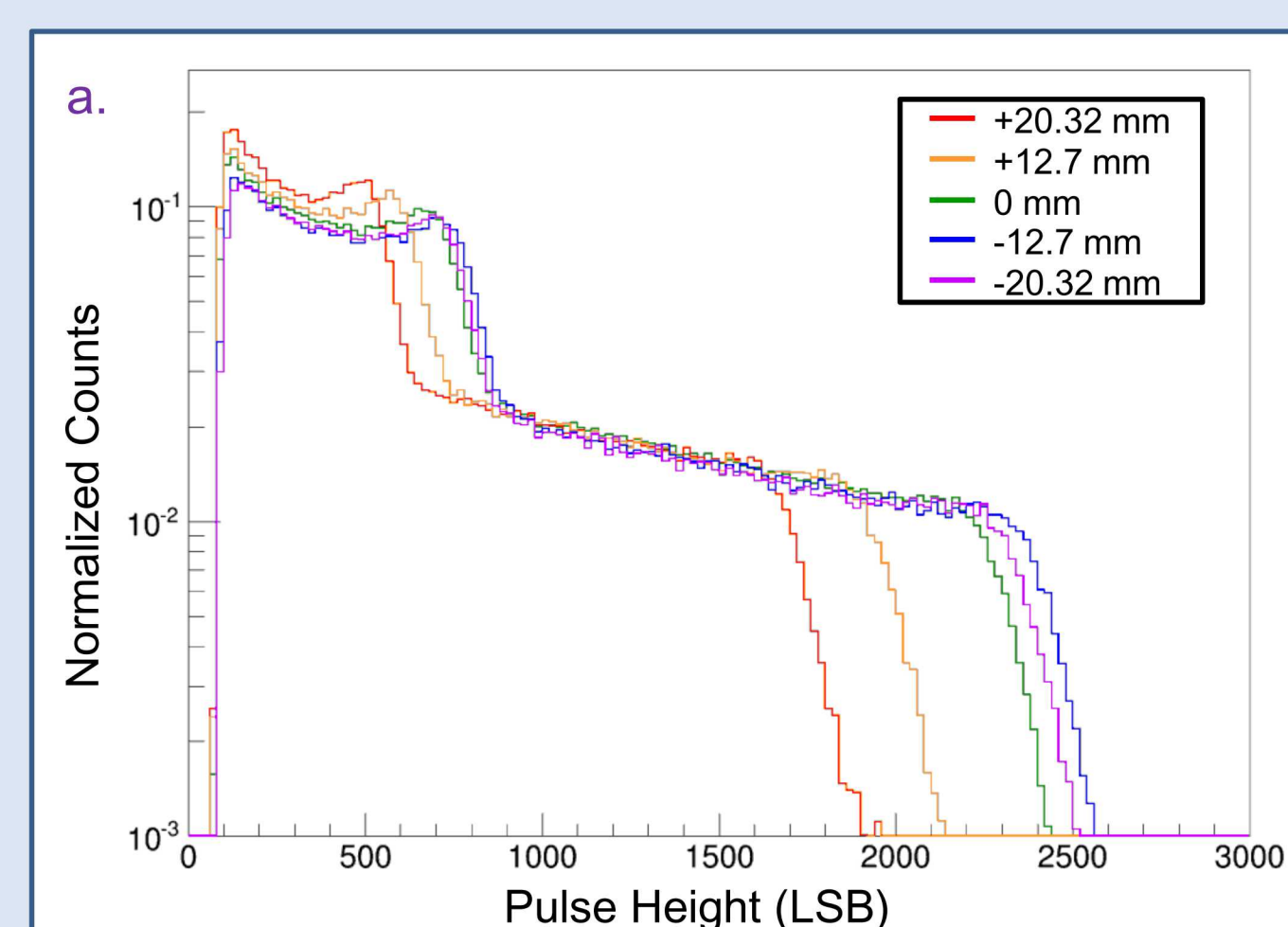


Figure 6: Pulse height distributions from the SiPM coupled to the top of a (a) PTFE-wrapped and (b) unwrapped stilbene crystal.

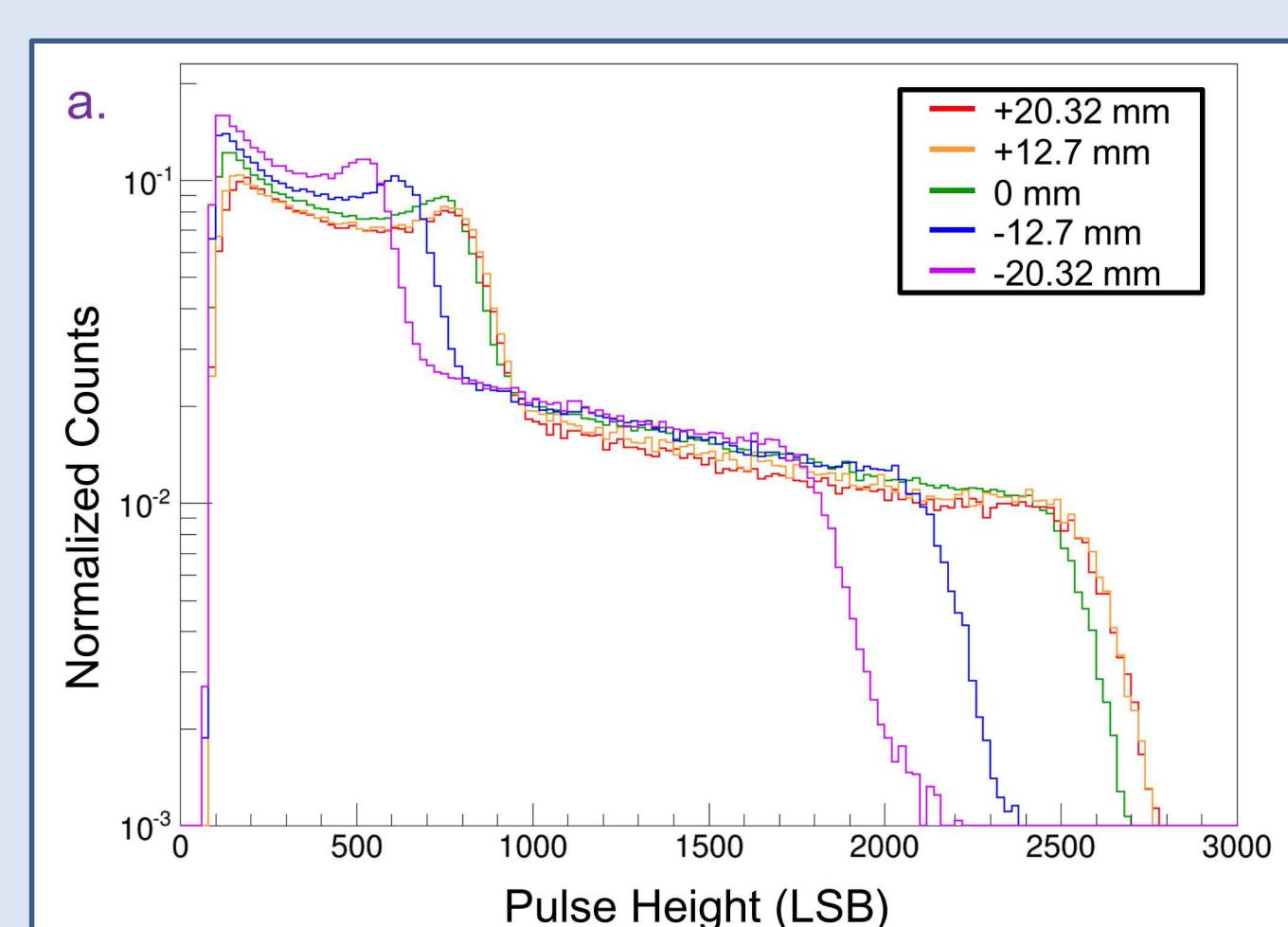


Figure 7: Pulse height distributions from the SiPM coupled to the bottom of a (a) PTFE-wrapped and (b) unwrapped stilbene crystal.

Results (continued)

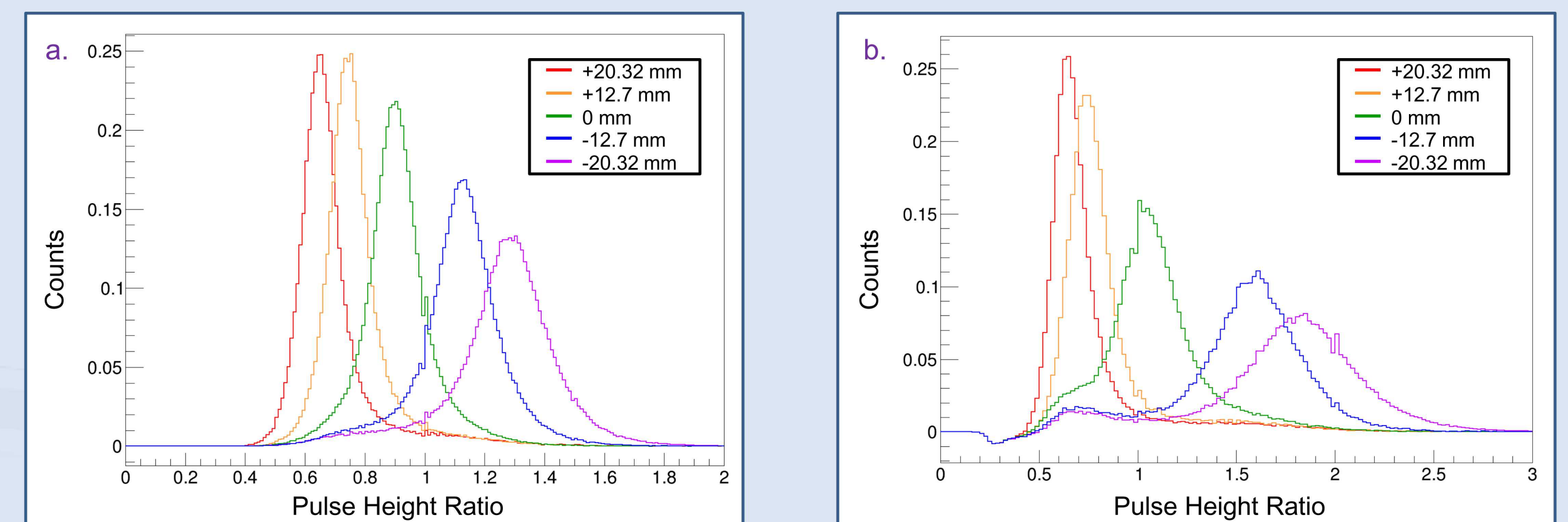


Figure 8: Top over bottom pulse height ratio distribution of a (a) PTFE-wrapped and (b) unwrapped stilbene crystal.

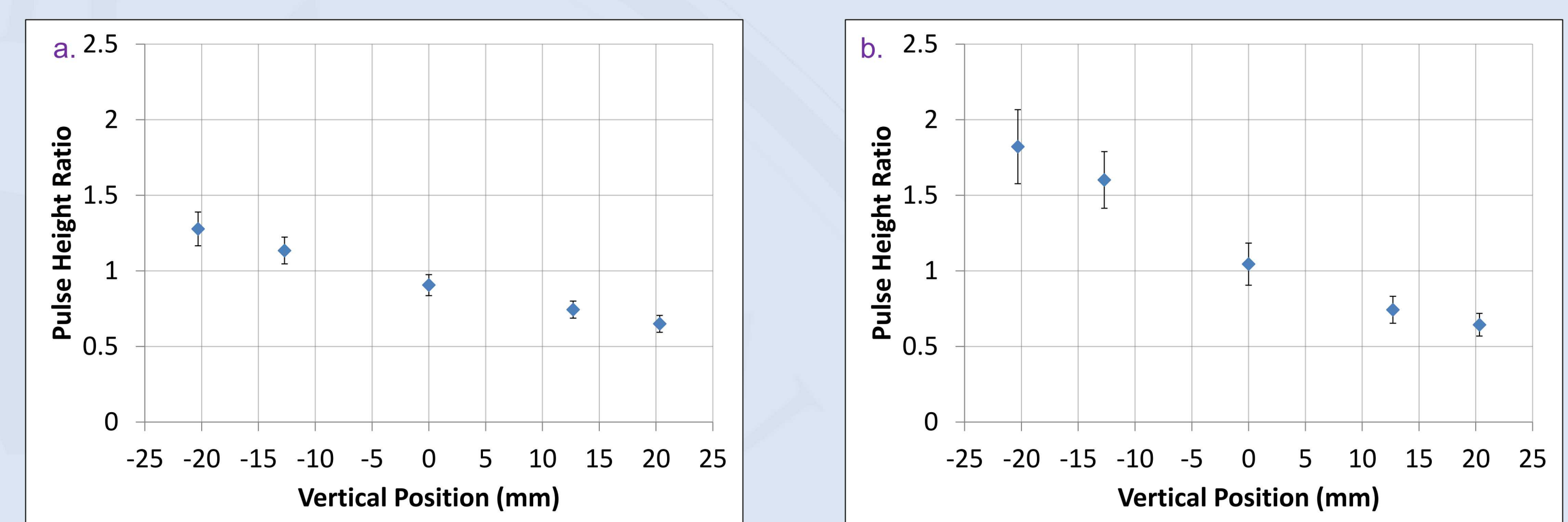


Figure 9: Mean pulse height ratio as a function of position within a (a) PTFE-wrapped and (b) unwrapped stilbene crystal.

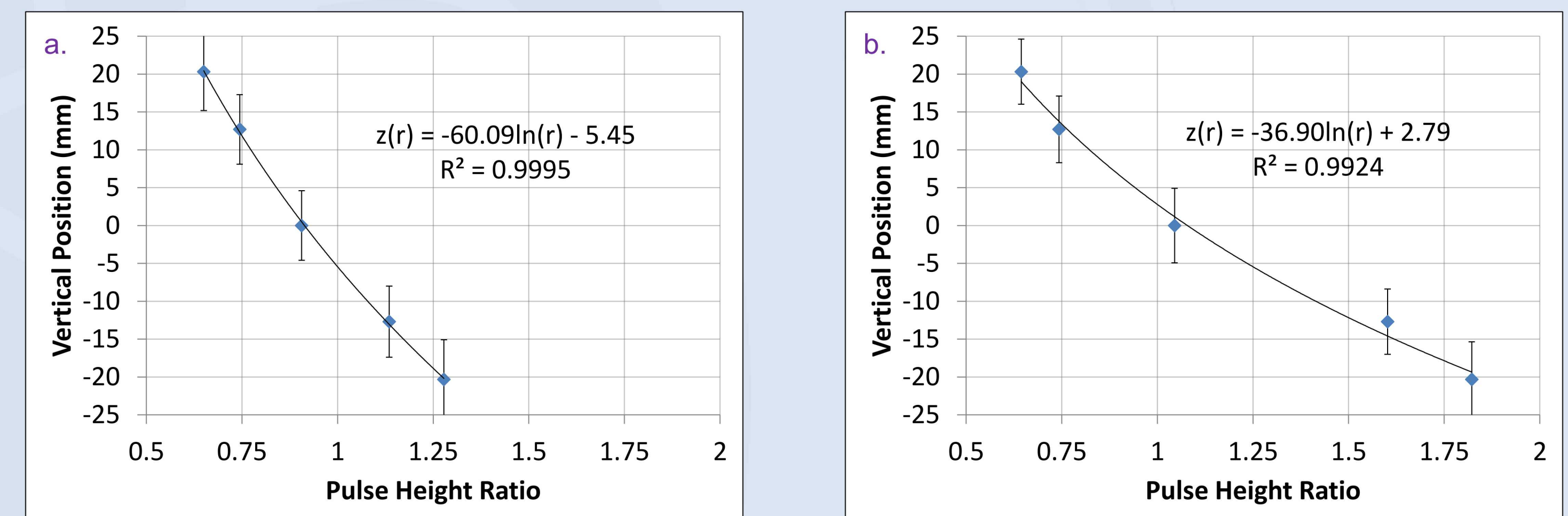


Figure 10: Vertical position as a function of pulse height ratio within a (a) PTFE-wrapped and (b) unwrapped stilbene crystal.

Position Sensitivity Results in Simulation of H²DPI

- Particle transport in MCNPX-PoliMi
- Simulated Cf-252 spontaneous fission source at 1-m
- Used experimental results in simulating detector response
- Back projected cones of possible source locations from multi-scatter events using neutron scatter camera and Compton camera principles
- Propagated uncertainties into back projected cone widths
- Performed list mode MLEM using cone projections as probability distribution functions

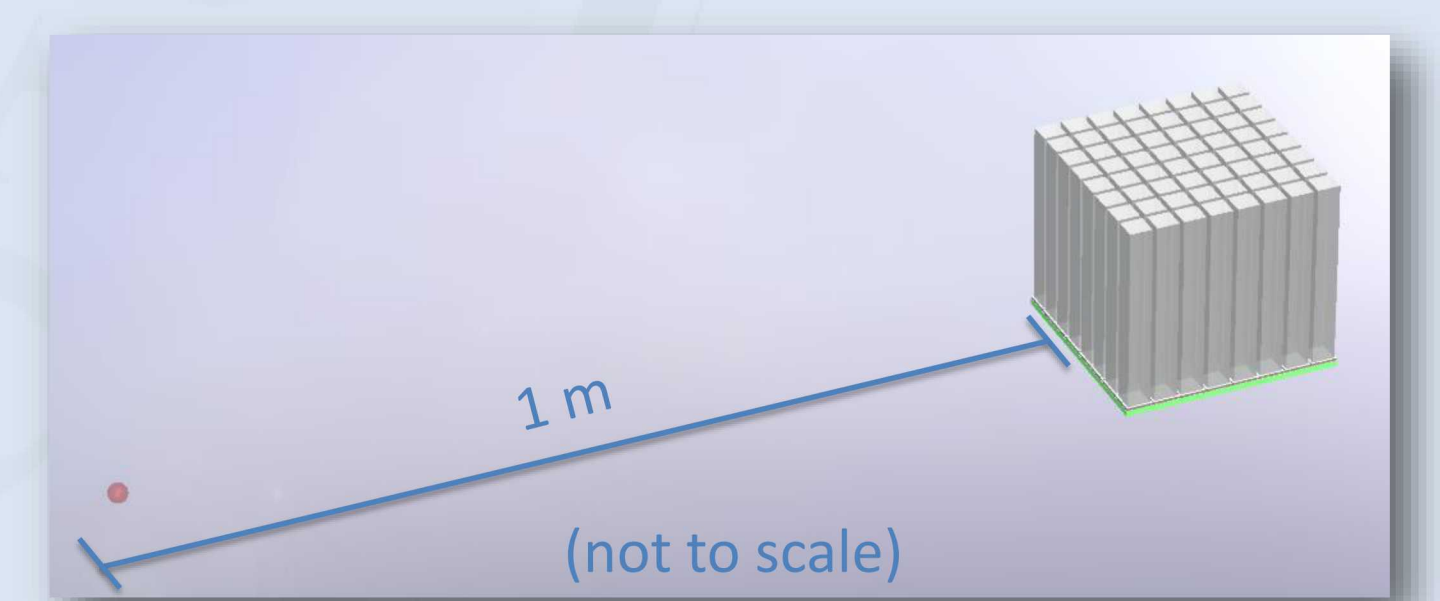


Figure 11: Diagram of source location simulations.

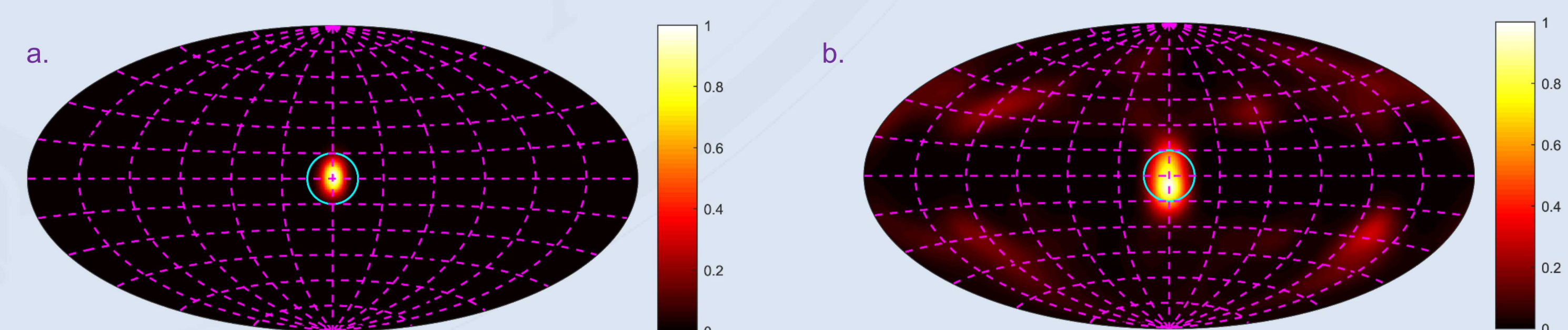


Figure 12: MLEM image of (a) neutrons and (b) photons from Cf-252 source at 1 m.

Conclusions

- Bare and PTFE-wrapped crystal show similar vertical position resolution
 - PTFE-wrapped crystal average resolution (1σ): 4.9 mm
 - Bare average resolution (1σ): 4.6 mm
- PTFE-wrapped crystal results in better overall photon collection ($\sim 2x$ at center)
 - Better expected energy resolution
 - Better expected PSD performance
- Intra-bar positional resolution sufficient to make H²DPI

Acknowledgement

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- Submitting for R&A (this line will be changed to include SAND number)