Optically Segmented Neutron Scatter Camera Simulation Results

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Introduction

- Neutron scatter cameras use the kinematics of elastic neutron-proton scattering to estimate the incoming direction of neutrons to locate SNM or other neutron emitting sources
- Neutrons must scatter twice in the detector to reconstruct incident neutron direction
- Single volume design enables for an order-of-magnitude efficiency increase compared to a dual plane neutron scatter camera developed at Sandia National Laboratories

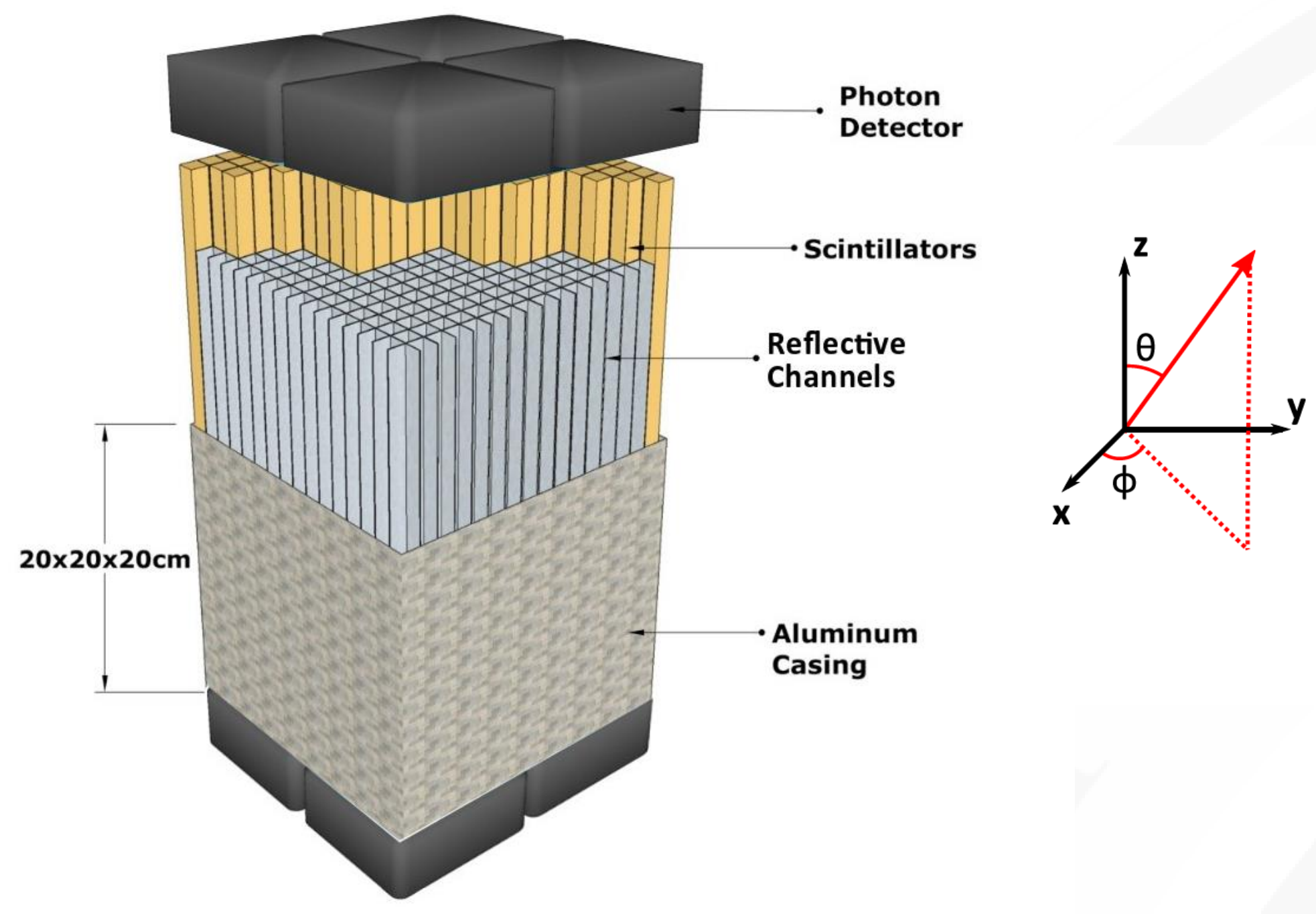

Figure 1: Instrument conceptual design using pillars of scintillator and angular definition

- Instrument design uses a single, contiguous volume of organic scintillator that is internally subdivided into optically isolated pillars (Figure 1)
- An air gap surrounds each scintillator pillar enabling total internal reflection
- Escaping light is reflected back into the pillar using a specular reflector lining the channel walls
- Photodetectors (PD) are affixed to opposing ends each pillar to collect scintillation light
- Multiple observables needed to back-project incident angle neutron cones:
  - Scintillation position along the pillar for first and second scatter
  - Proton recoil energy in first scatter
  - Time between neutron scatter events
- Evaluate best combination of scintillator, photodetector, and pillar size to estimate scintillation position, time, and brightness
- This work is in support of the nonproliferation mission of the NNSA

Methods

- Position along pillar axis estimated using intensity vs. time history of charge carriers emitted by the photodetectors at each end of the pillar
- Tabulate nominal responses of scintillation photons to establish expected scintillation responses along pillar

$$R_{nom} = R_{scint}(t) * R_{chan}(t) * R_{TTS}(t) * R_{imp}(t)$$

- $*$ is the convolution operator
- R_{nom} is the nominal response
- R_{scint} is the scintillator time response
- R_{chan} is the channel response
- R_{TTS} is the transit time spread of the PD
- R_{imp} is the impulse response of the PD

Methods (cont.)

- Scintillation response, transit time spread, and photodetector impulse responses obtained from manufacturer data
- Nominal response functions tabulated by simulating 10^7 scintillation photons in 0.5 cm increments in Geant4
- Channel response functions estimate temporal spread of photons as they propagate throughout the pillar
- We fit the observed responses to nominal responses (Figure 2) using Broyden-Fletcher-Goldfarb-Shanno minimization (MLEM) method and a negative log Poisson likelihood objective function

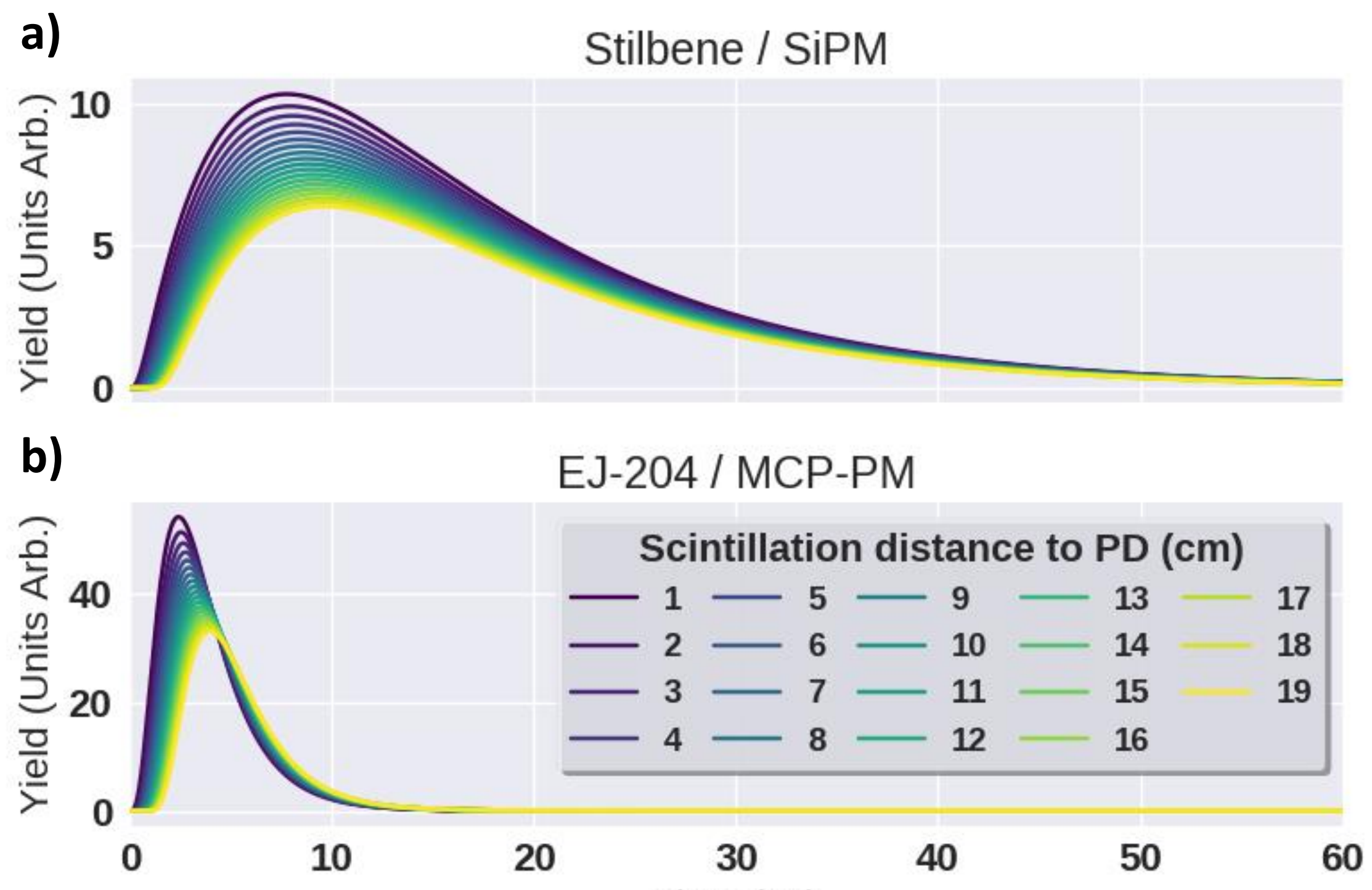

Figure 2: Nominal responses created using Equation 1. **a)** Responses using stilbene/SiPM combination. **b)** Responses using EJ-204/MCP-PM combination

Results

- Simulated results shown for 10,000 2 MeV neutron elastic scatter events
- Comparison using MLEM, leading edge (LE) and the amplitude of the observed waveforms to estimate scintillation position (Figure 3)

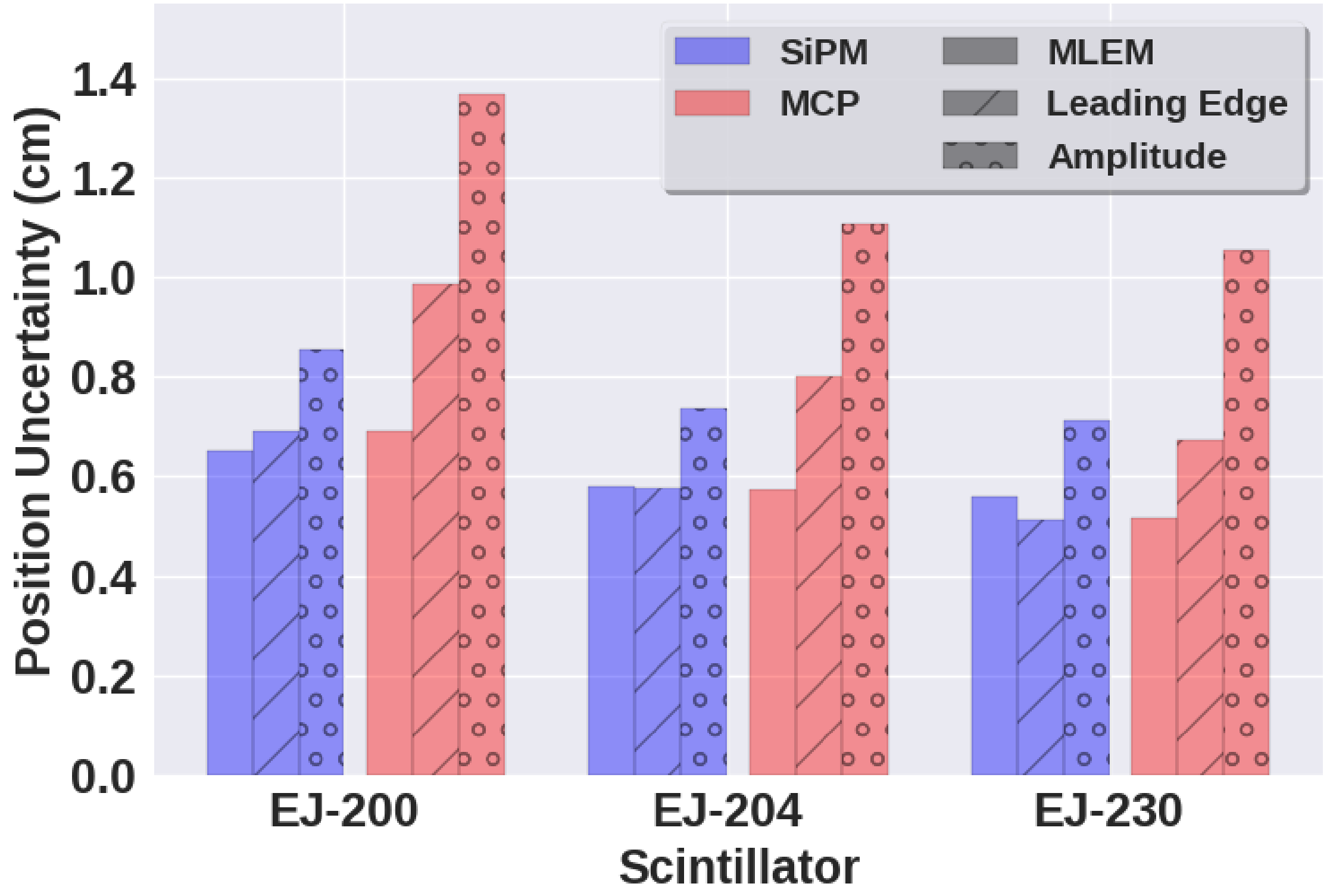

Figure 3: Comparison of scintillation position uncertainty at 2 MeV using MLEM, the timing of the two opposing waveforms (LE), and the overall light intensity for three scintillators

- Overall, the SiPM outperforms MCP uncertainty due to larger quantum efficiency and rise time of the photodetector
- MLEM produces smaller position uncertainties when fitting nominal responses to observed waveforms with similar uncertainty for both photodetector regardless of scintillator
- The fast and bright scintillation of EJ-230 yields the best position reconstruction

Results (cont.)

- Scintillation timing uncertainty estimated using constant fraction discrimination (CFD) and MLEM (Figure 4)
- MELM and EJ-230 outperformed the other scintillators and methods where MLEM and EJ-230 resulted in a ~ 25% better timing uncertainty compared to CFD

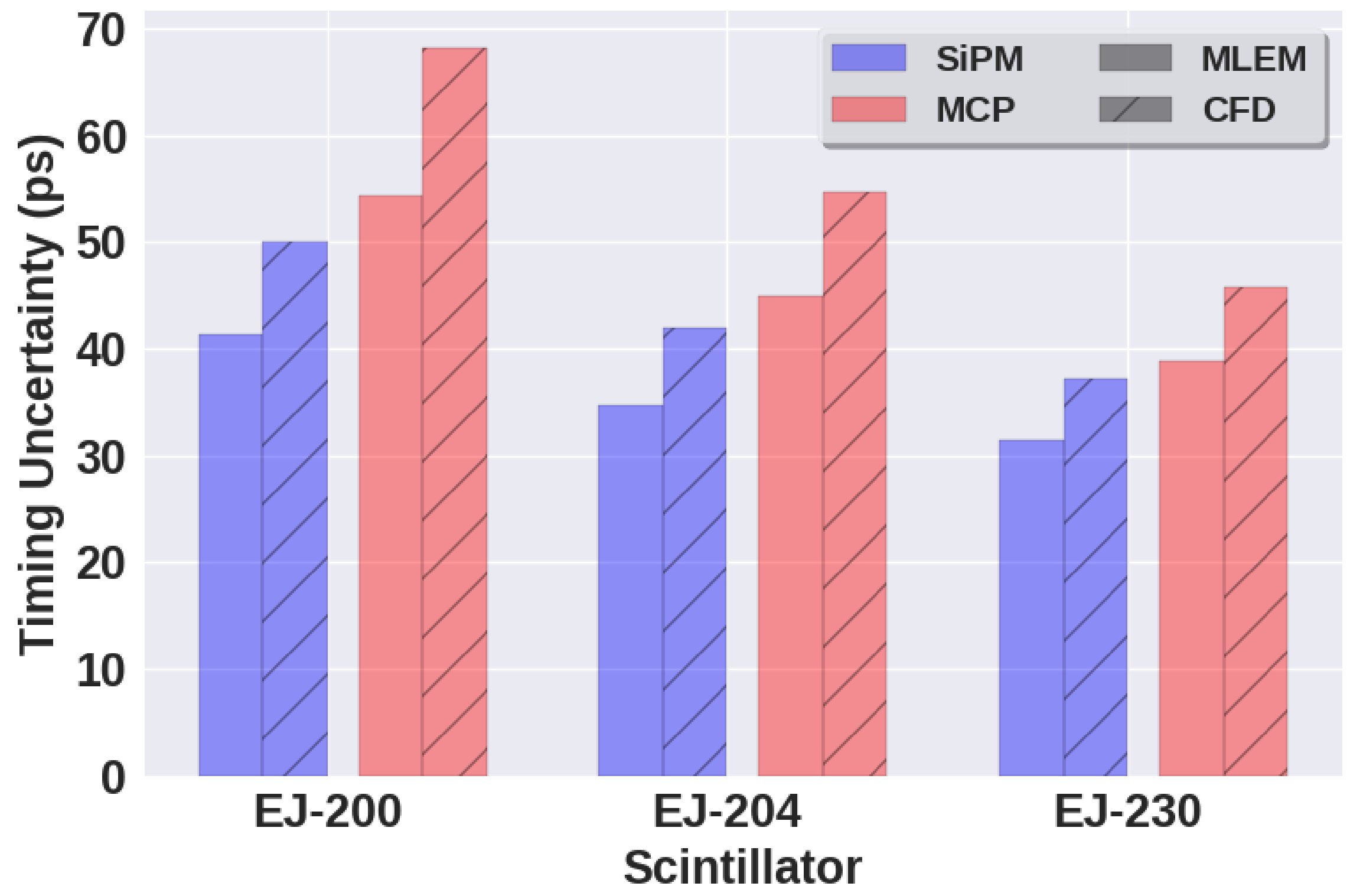

Figure 4: Timing uncertainty comparison of constant fraction discrimination and MELM for three scintillators

- ~25% of double scatter interactions occurred in neighboring pillars when using a pillar size of 1 cm x 1 cm x 20 cm
- More precise source localization can be achieved when eliminating events where neutrons scattered in neighboring pillars, consequently eliminating high uncertainty back-projected cones from the image (Figure 5)

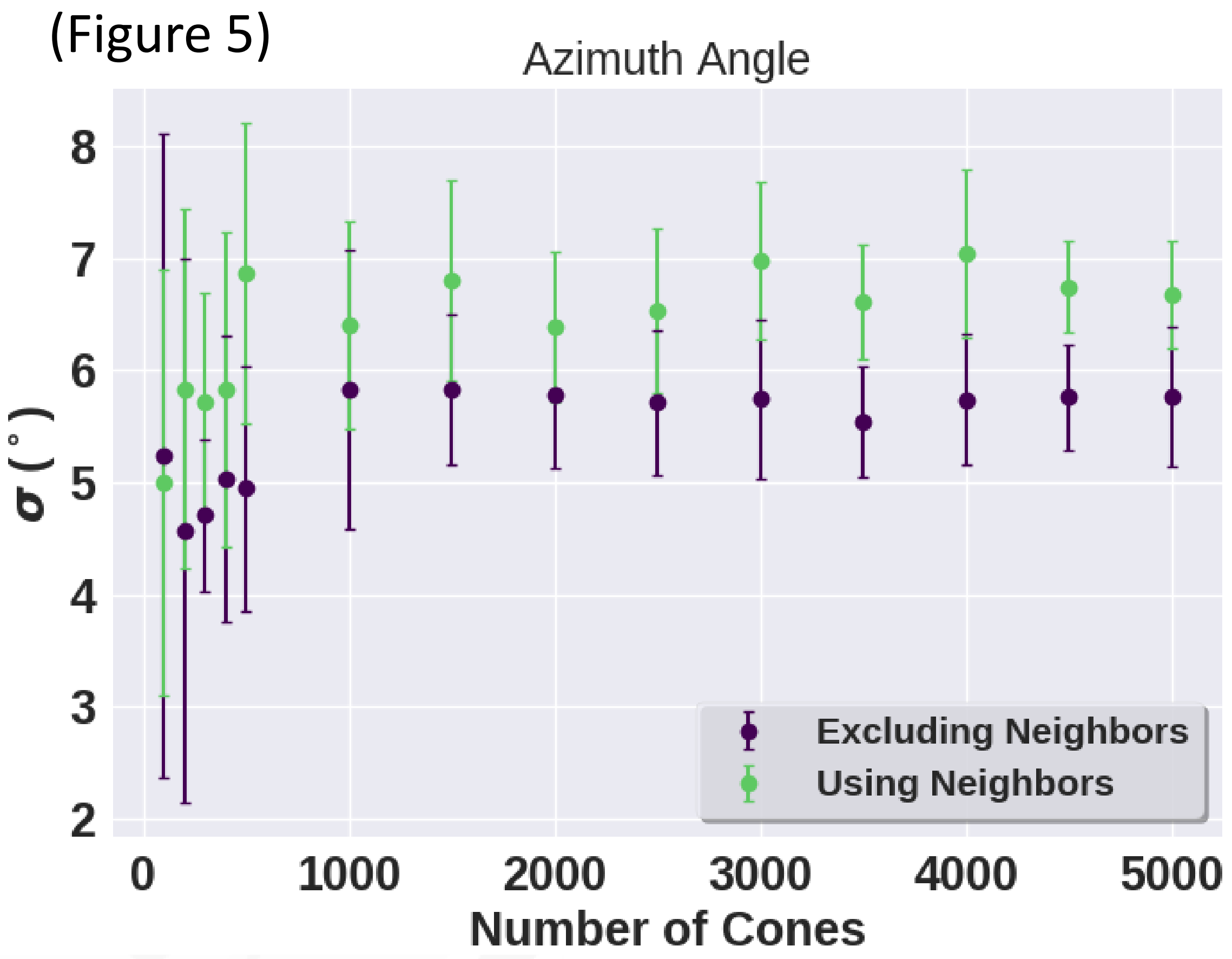

Figure 5: Azimuth angle uncertainty after 15 MLEM iterations to a Cf-252 point source . Excluded events due to interaction in neighboring pillars counted towards the number of back-projected cones

- Removing neighboring events improved azimuth resolution while the polar resolution remain approximately the same

Conclusions

- Scintillator of choice for an optically segmented neutron scatter camera is EJ-230 due to having fast and bright scintillation of ~0.55 cm
- Overall, MLEM yields the lowest scintillation position uncertainty
- The fast rise time of an SiPM results in the best scintillation time estimates
- Excluding events in neighboring pillars increases source localization precision

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