Scintillation-Based Compton Camera via Single Photon Imaging
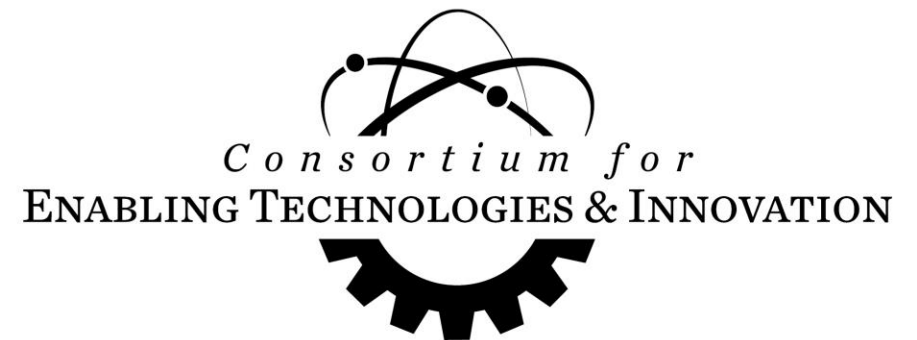
Alex Bocchieri

University of Wisconsin - Madison
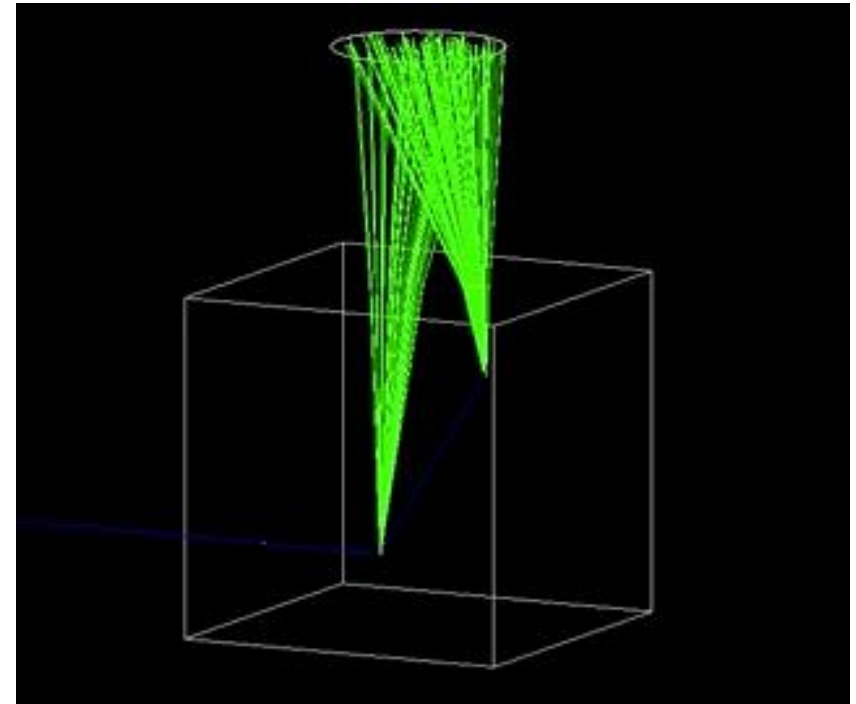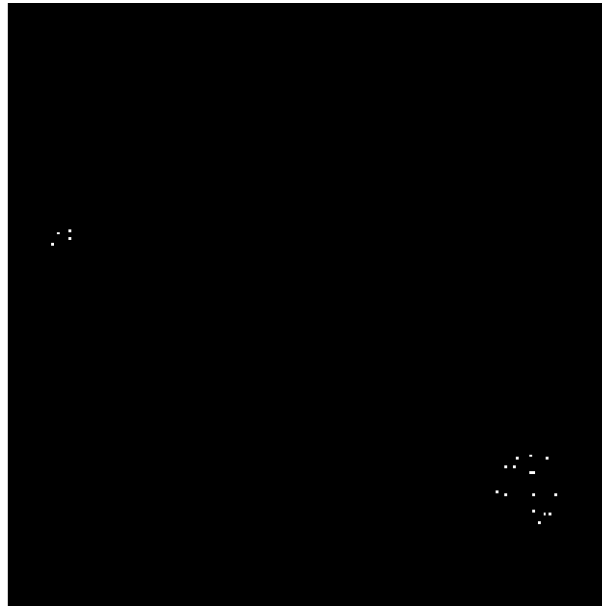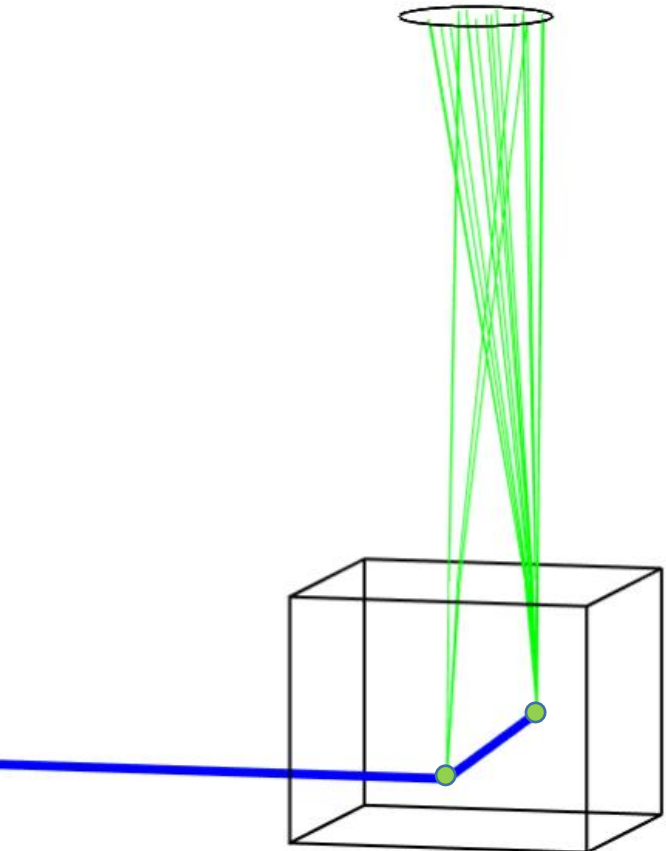
2/9/2023
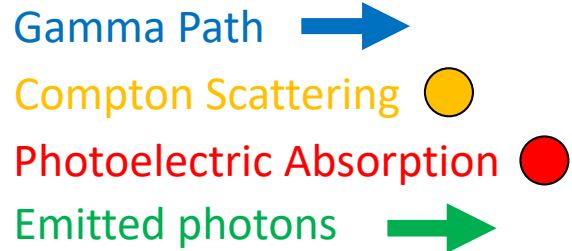
Overview

SPAD Sensor

- Single photon avalanche diode (SPAD)
- Pixels can count and timestamp individual photons
- Very high frame rate (~100,000 fps)
  - Fast to capture scintillation events from individual gamma rays
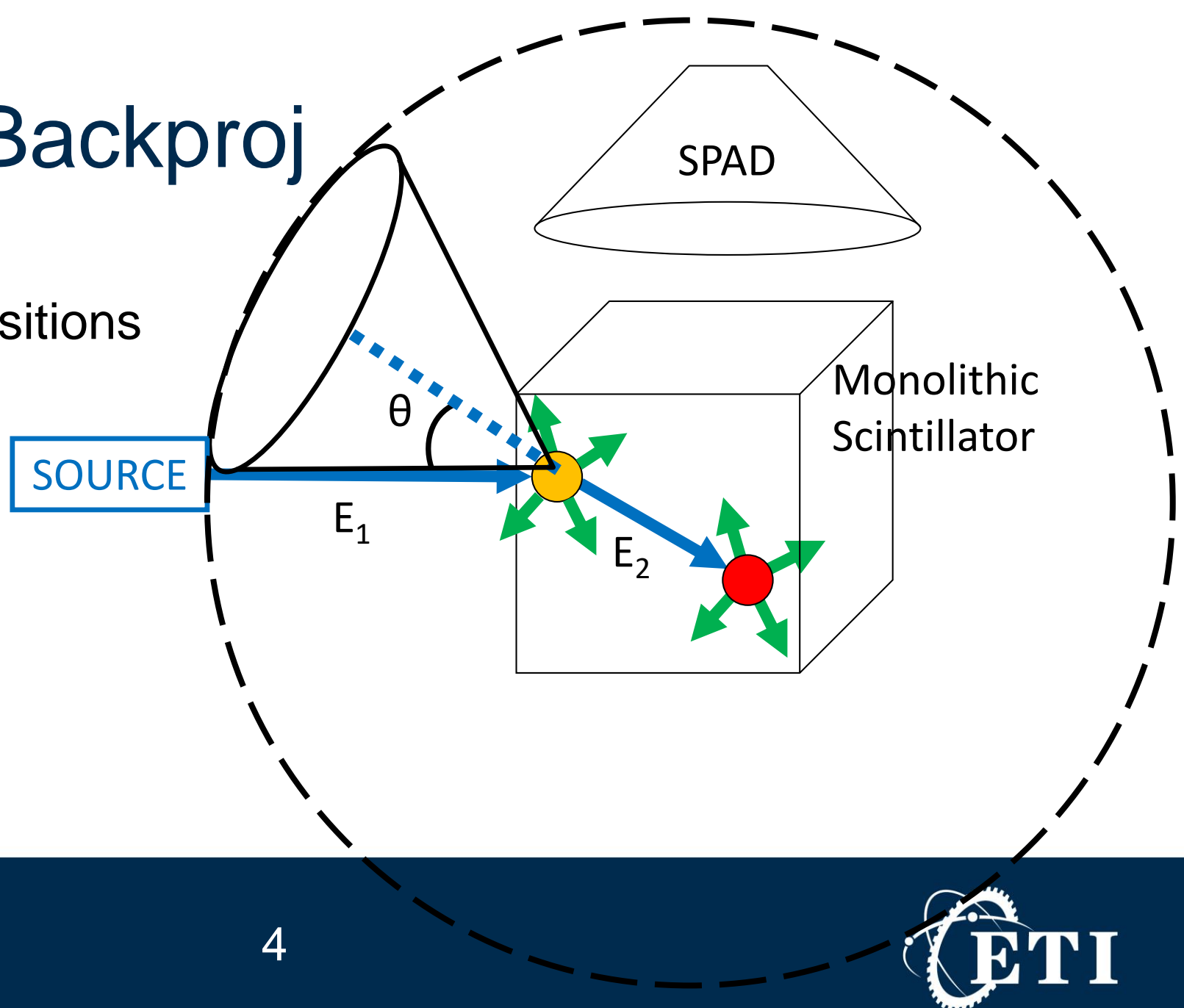- Large SPAD arrays will soon be available at low cost

Compton Backproj

Backproject cone using:
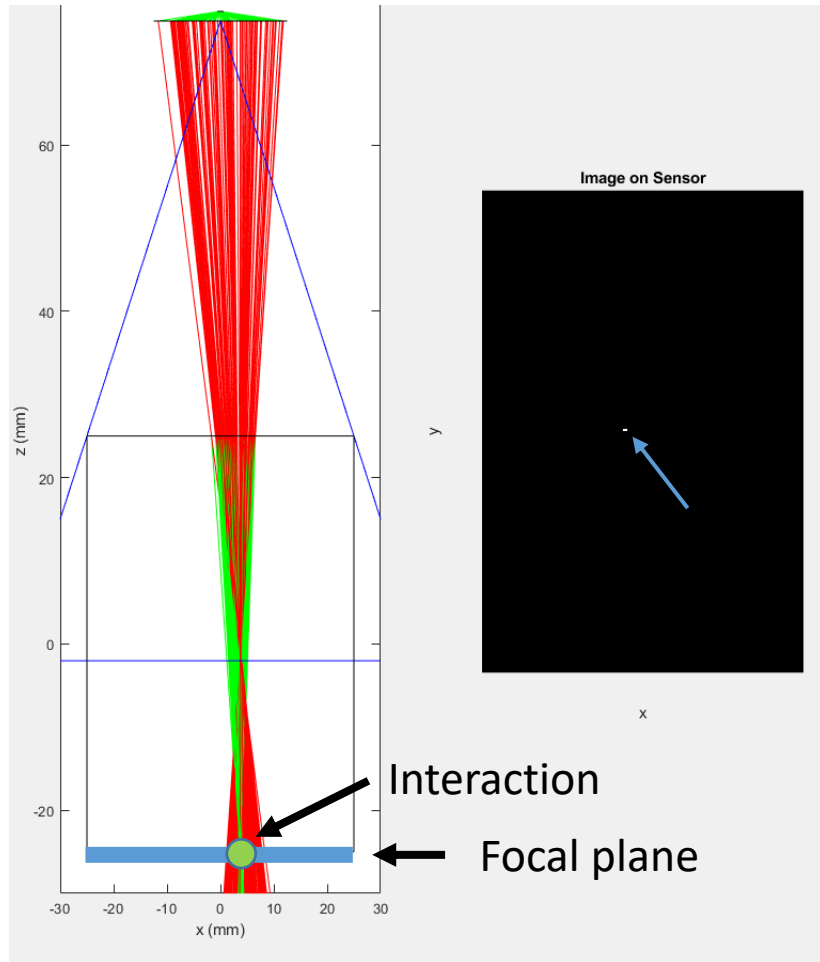1. Interaction energy depositions
2. Interaction locations

Gamma Path →

Compton Scattering ●

Photoelectric Absorption ●

Emitted photons →

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

SPAD

Monolithic Scintillator

SOURCE

θ

E_1

E_2

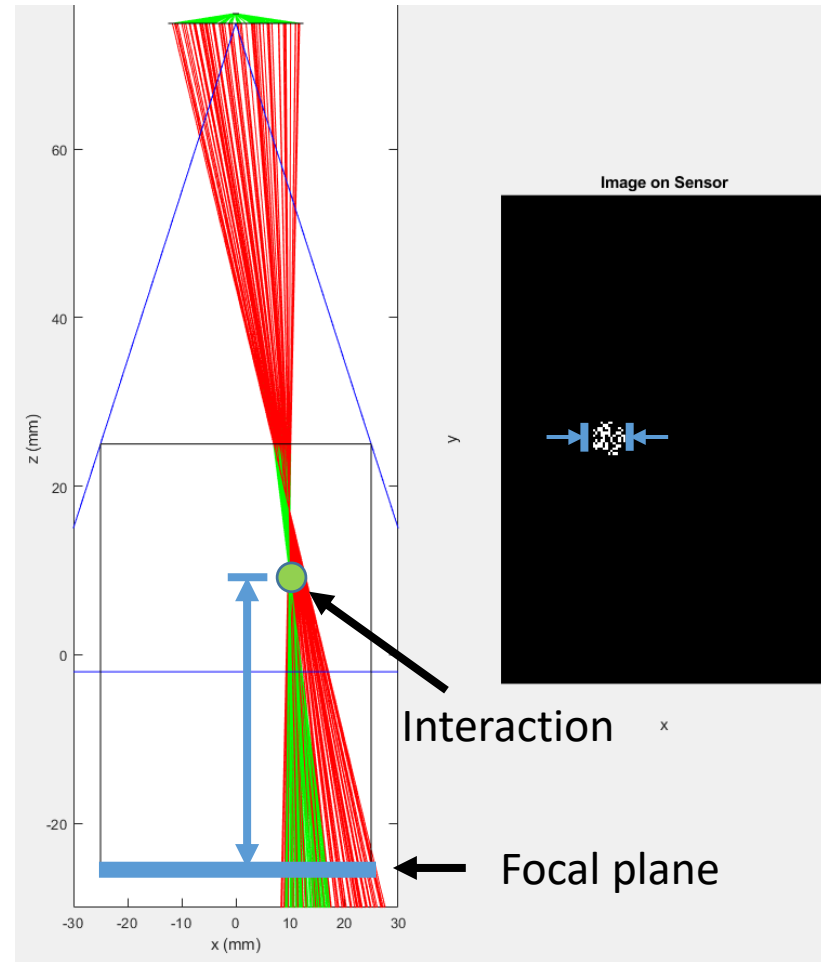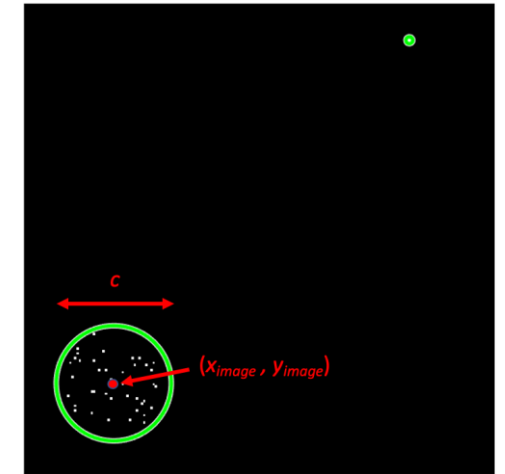National Nuclear Security Administration

ETI

Measuring Interactions

Interaction at bottom of scintillator (in focus)

Interaction at top of scintillator (out of focus)
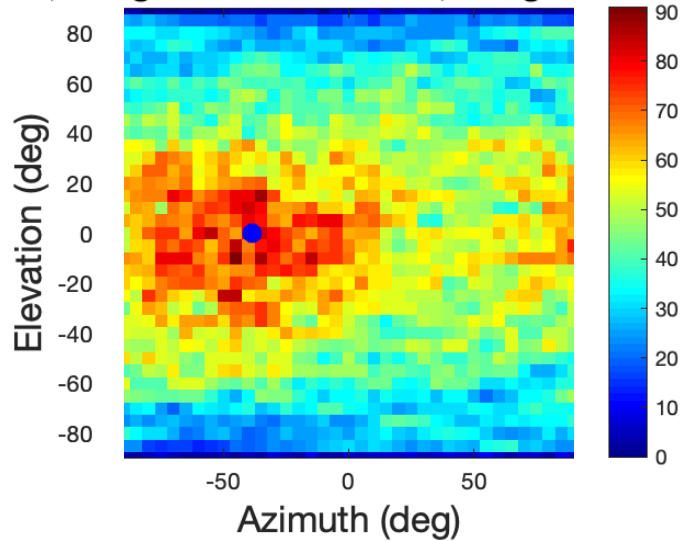
Cluster interaction photons

Interaction

Focal plane

Interaction

Focal plane

$$x_{image} = -f\frac{x_{scene}}{z_{scene}}$$

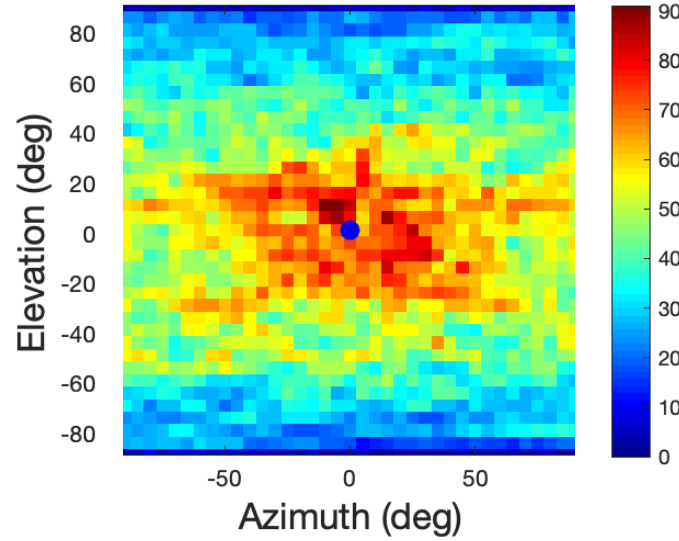$$y_{image} = -f\frac{y_{scene}}{z_{scene}}$$

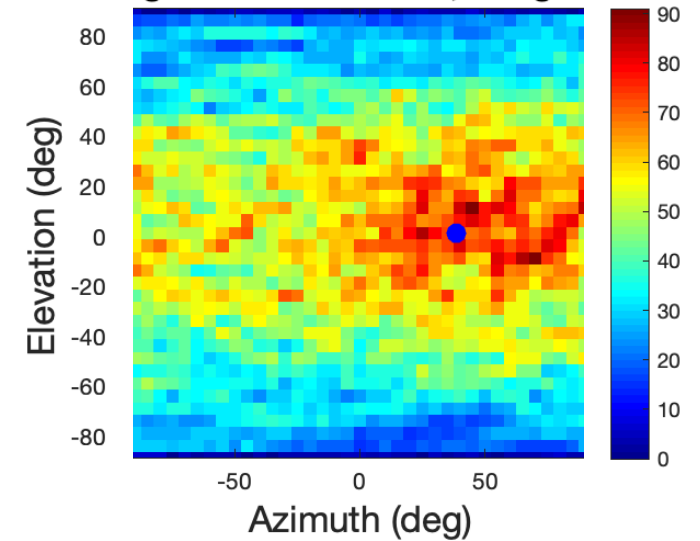Photons emitted $\propto$ energy deposition

Simulation Results

1,267 good events / 100,000 gammas
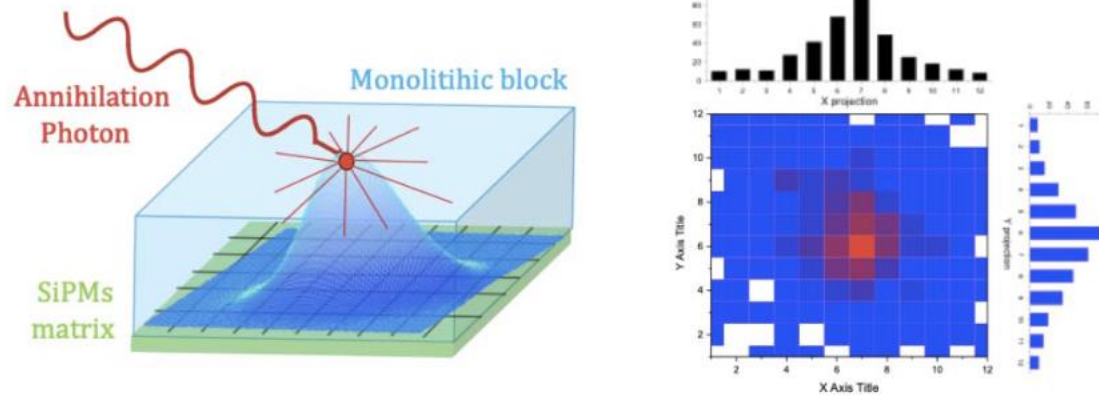
1,206 good events / 100,000 gammas

1,257 good events / 100,000 gammas

Previous Methods

- Monolithic scintillator coupled with SiPM

"Evolution of PET Detectors and Event Positioning Algorithms Using Monolithic Scintillation Crystals."
Gonzalez-Montoro et al. IEEE trans. radiat. plasma med, 2021.
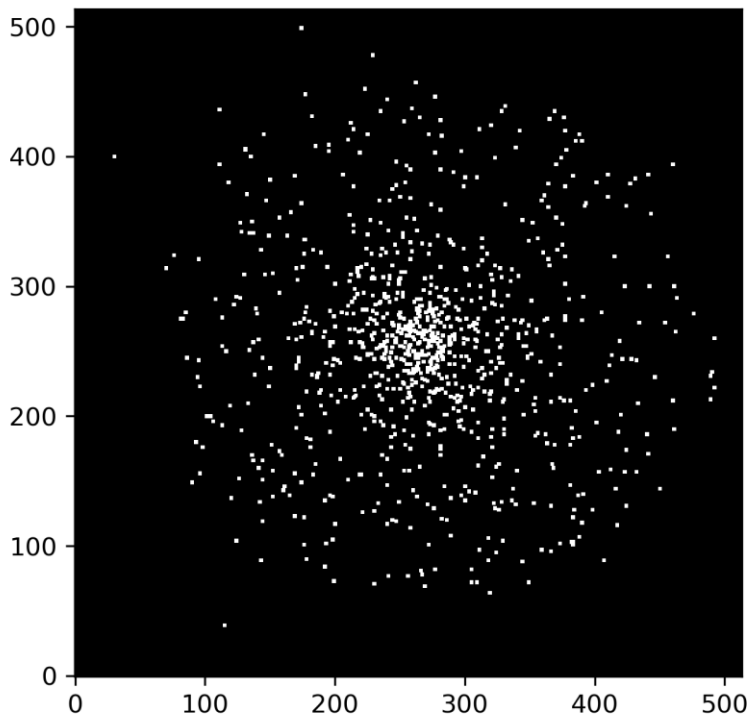
Problem: Multi-interaction information lost due to light overlapping on SiPM array

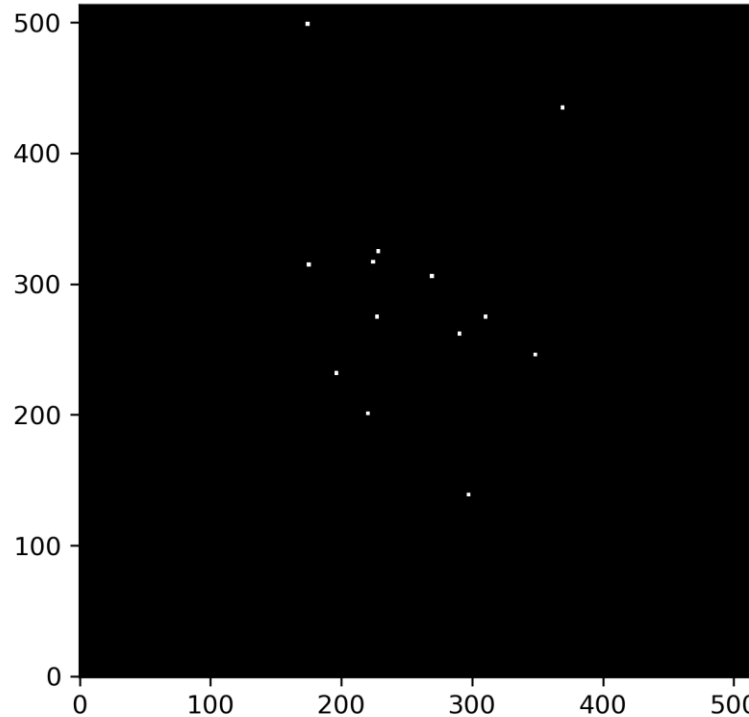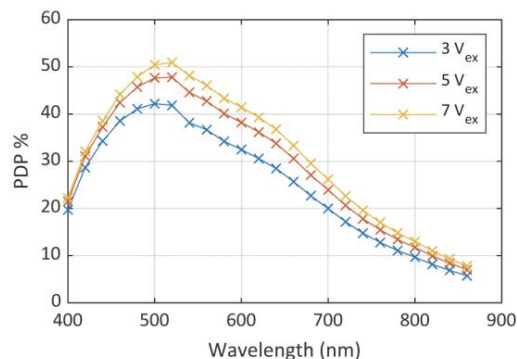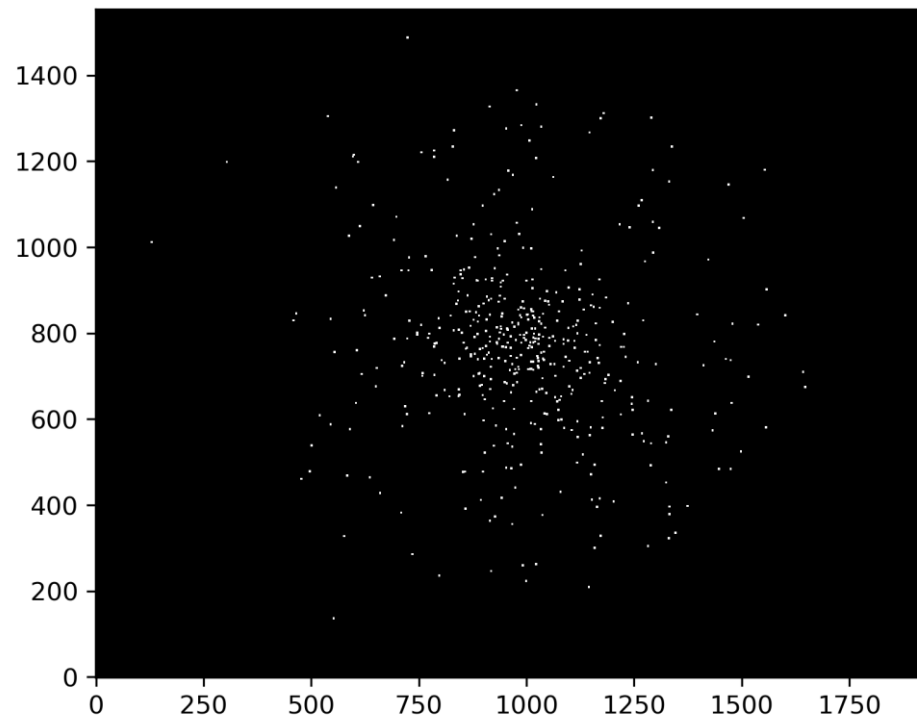Solution: Image the interactions with a lens

Hardware Setup

Lens

NaI scintillator

10 uCi Cs-137
(662 KeV)
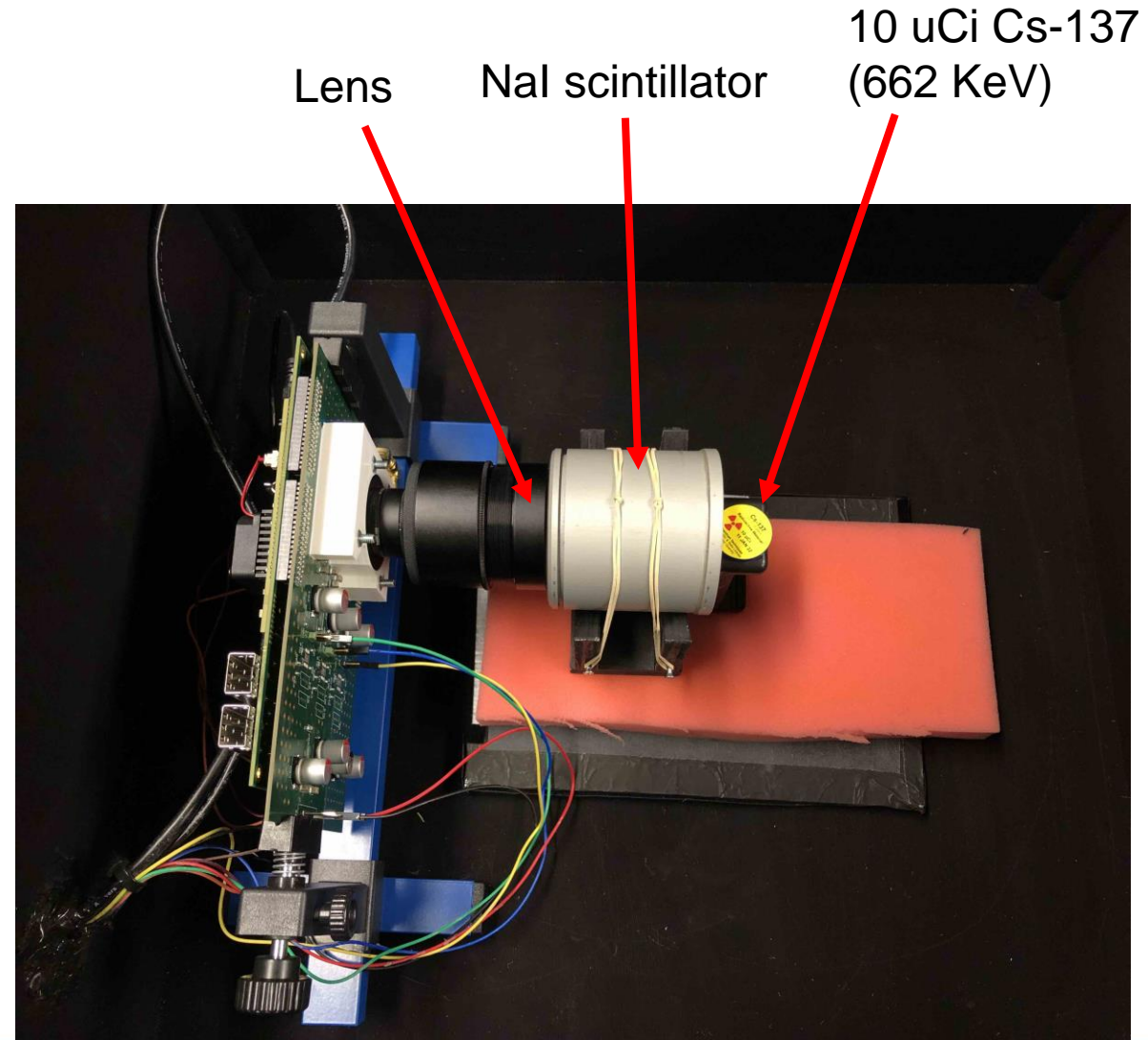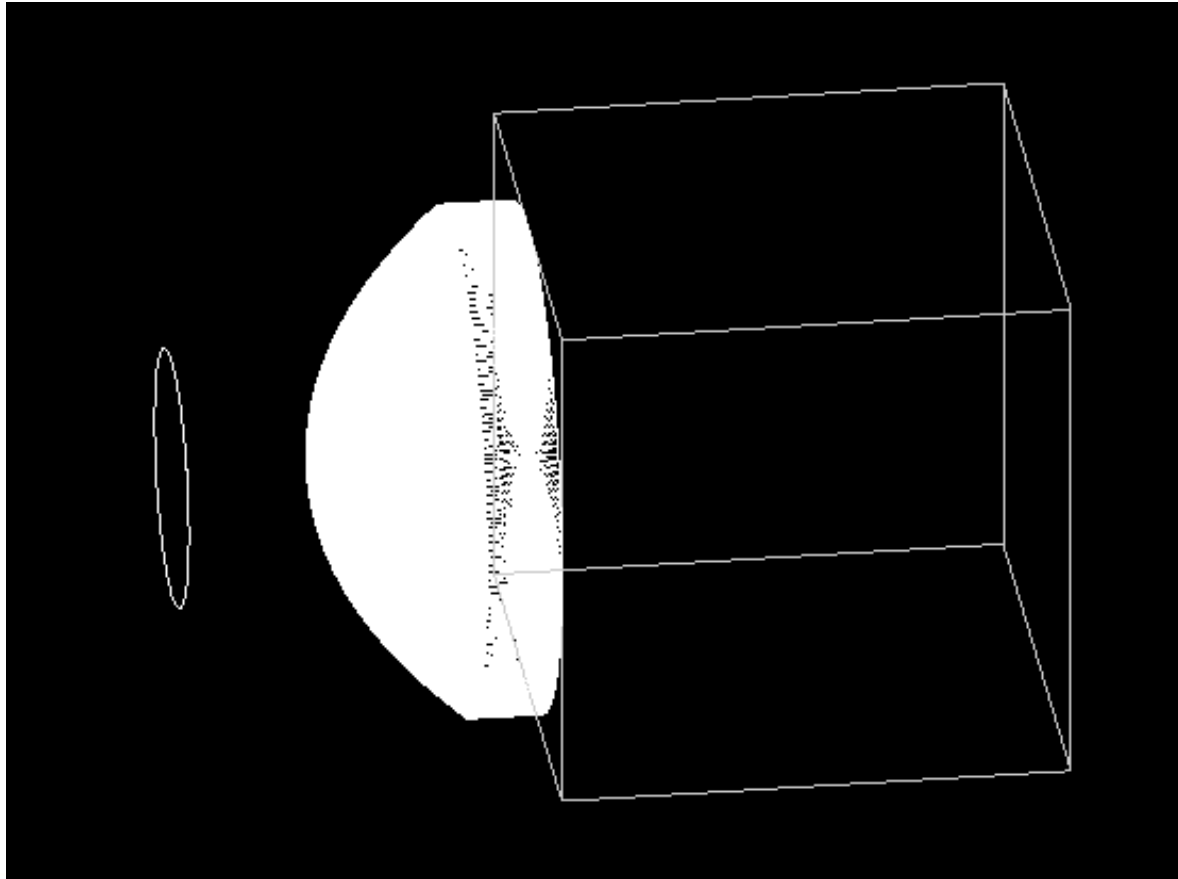
662 keV deposited, 941 : 0 real:dark photons
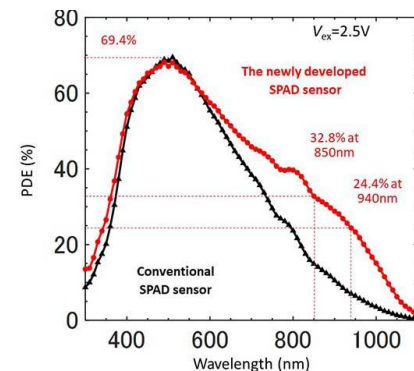[[0.   0.   -17.925 0.662 941.]]

662 keV deposited, 13 : 0 real:dark photons
[[0.   0.   -17.925 0.662 13.]]

662 keV deposited, 483 : 0 real:dark photons
[[0.   0.   -17.925 0.662 483.]]

10% fill factor
9.6x9.5mm, 0.26 megapixel
SwissSPAD2[1]

100% fill factor
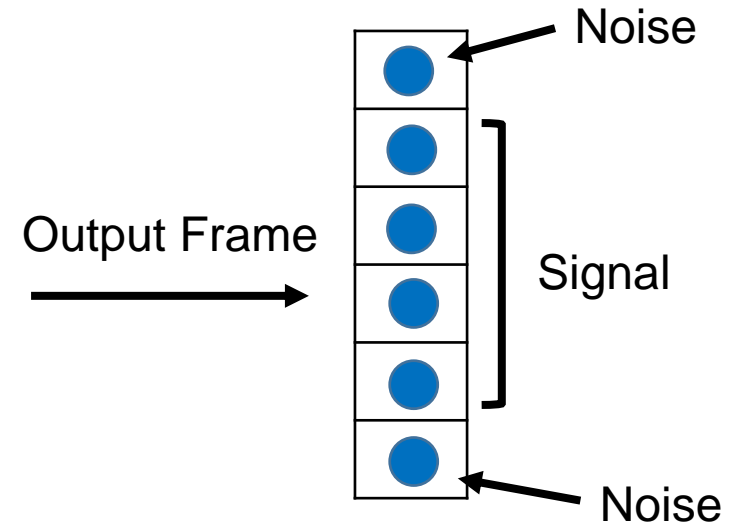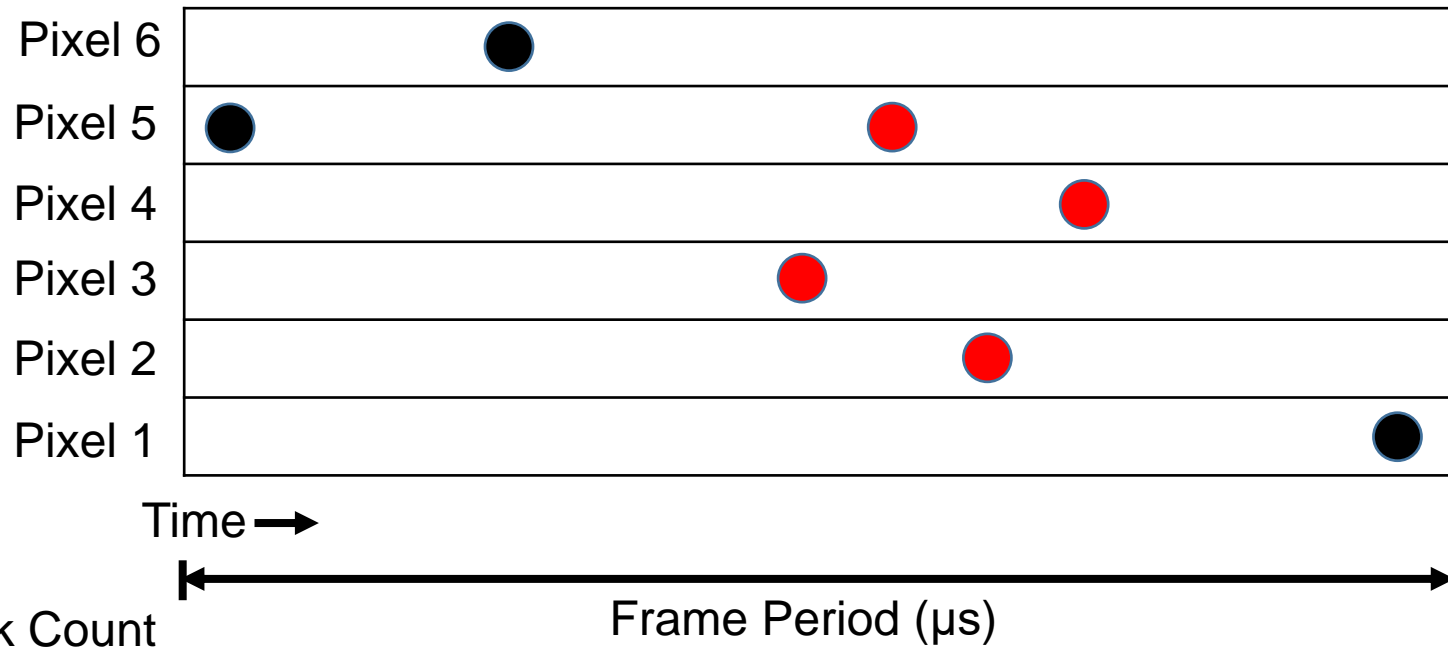13.2x9.9mm, 3.2 megapixel
Canon

[1] "A 512 × 512 SPAD image sensor with integrated gating for widefield FLIM." Ulku et al. IEEE J Sel Top Quantum, 2019.

SPAD sensor without time binning

NaI decay time: 250 ns
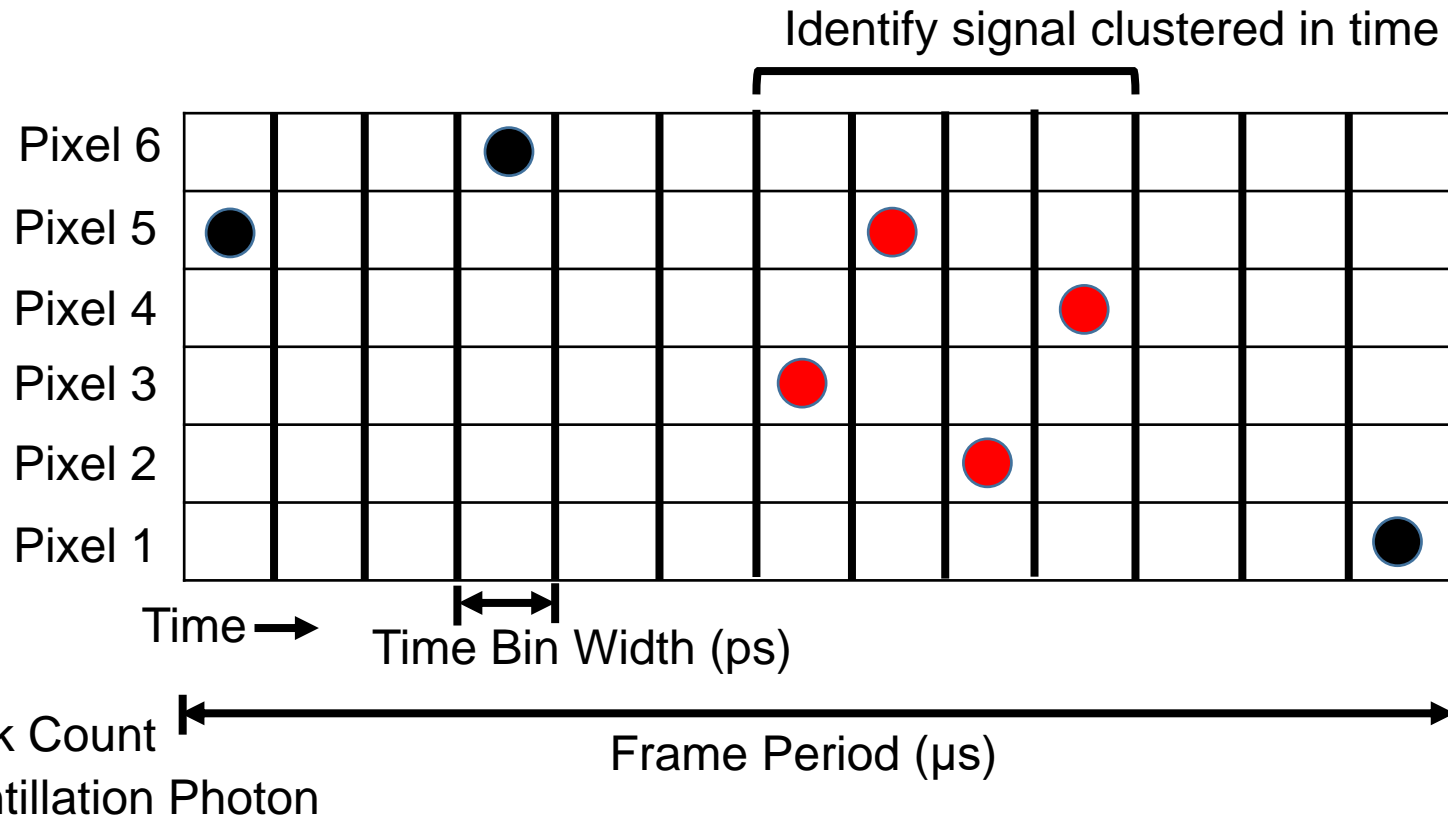SwissSpad2 frame period: 10 µs

Pixel 6
Pixel 5
Pixel 4
Pixel 3
Pixel 2
Pixel 1

Time →

Frame Period (µs)

Output Frame

Noise
Signal
Noise

Noise accumulated throughout frame period

● Dark Count
● Scintillation Photon

SPAD sensor with time binning

Identify signal clustered in time

Pixel 6
Pixel 5
Pixel 4
Pixel 3
Pixel 2
Pixel 1

Time →
Time Bin Width (ps)

Frame Period (μs)

Access individual time bins within frame

Significant increase in SNR!

● Dark Count
● Scintillation Photon

SPAD sensor with time binning

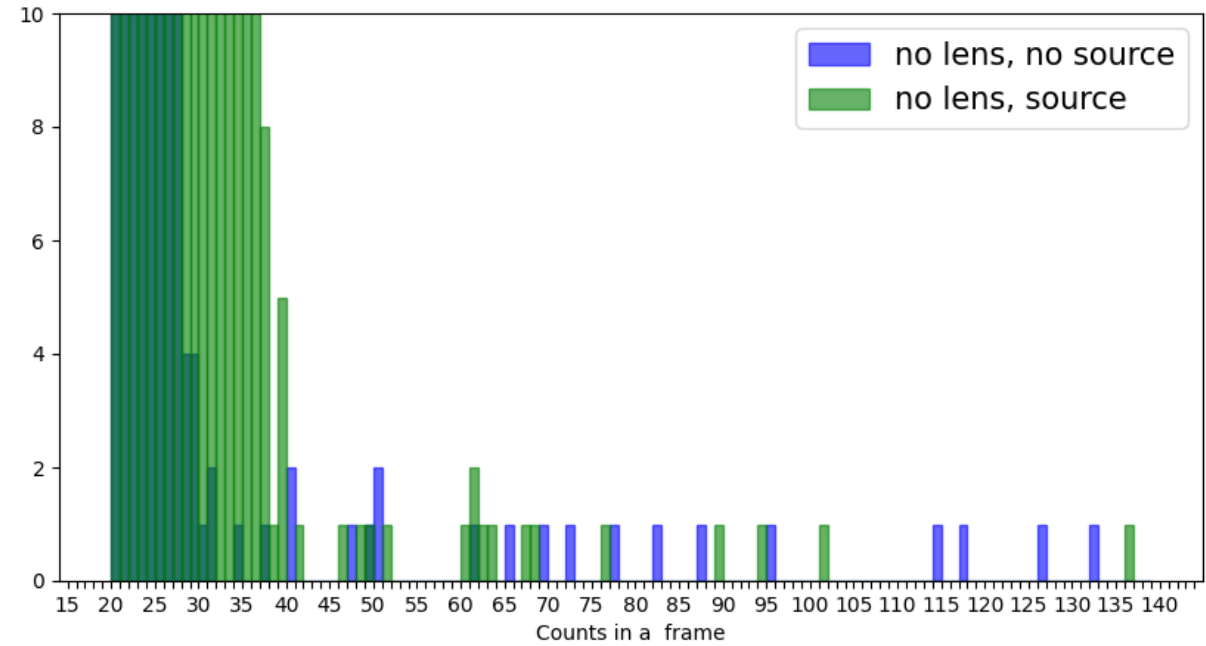Cerenkov photons emitted instantaneously
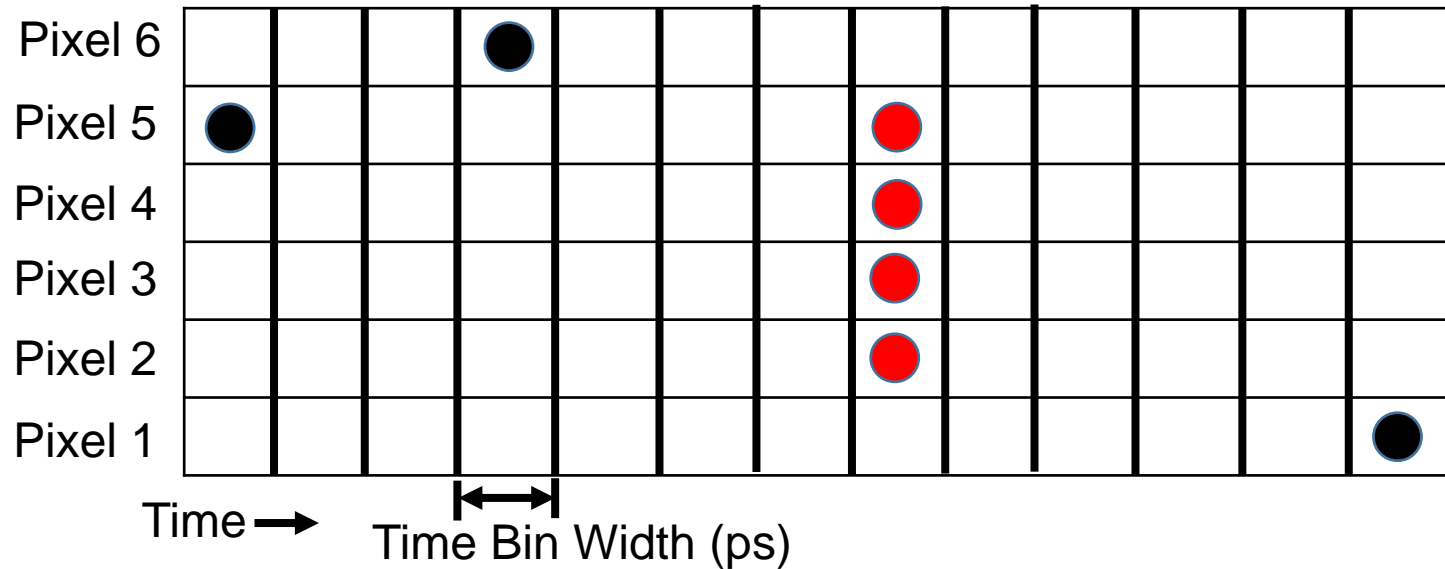
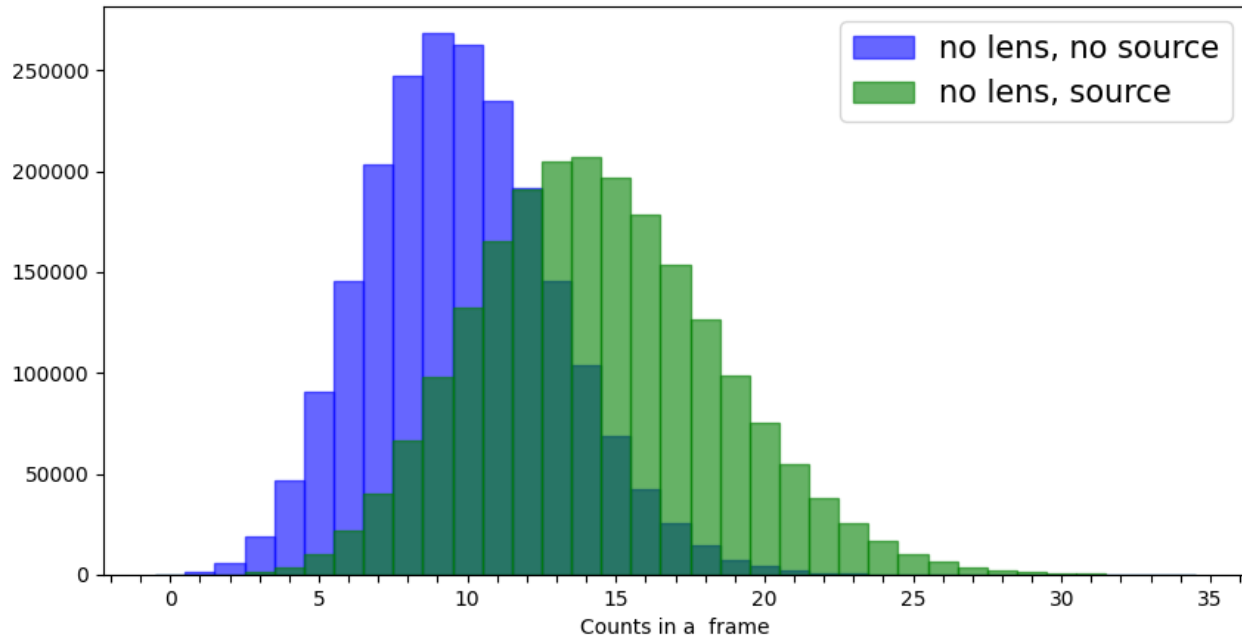
Identify Cerenkov photons for timing applications

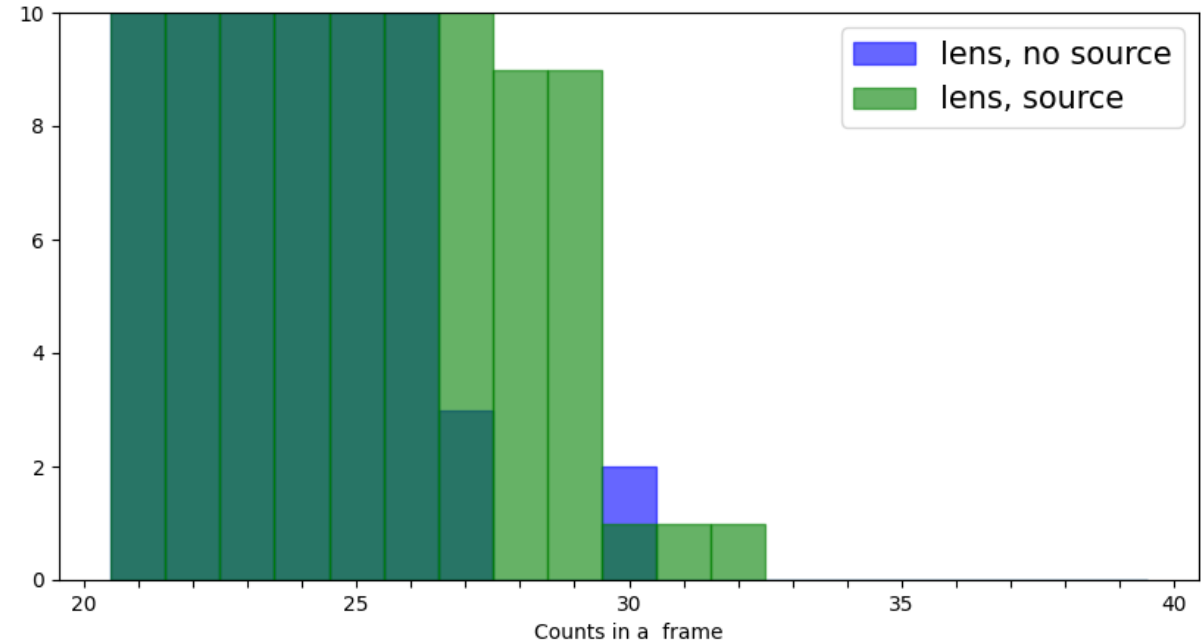Image Cerenkov cone to determine electron trajectory

Time Bin Width (ps)

Frame Period (μs)

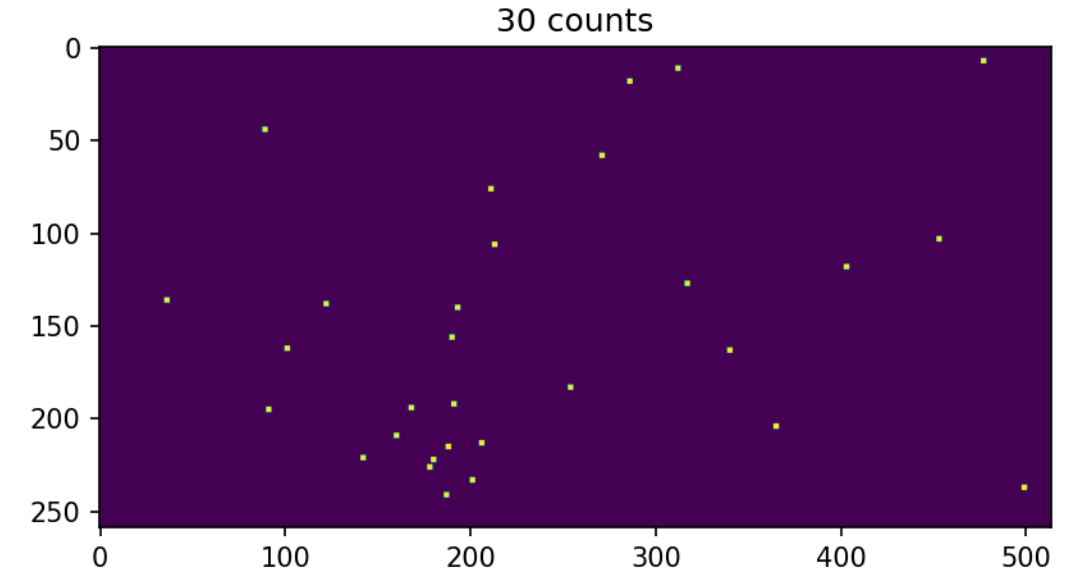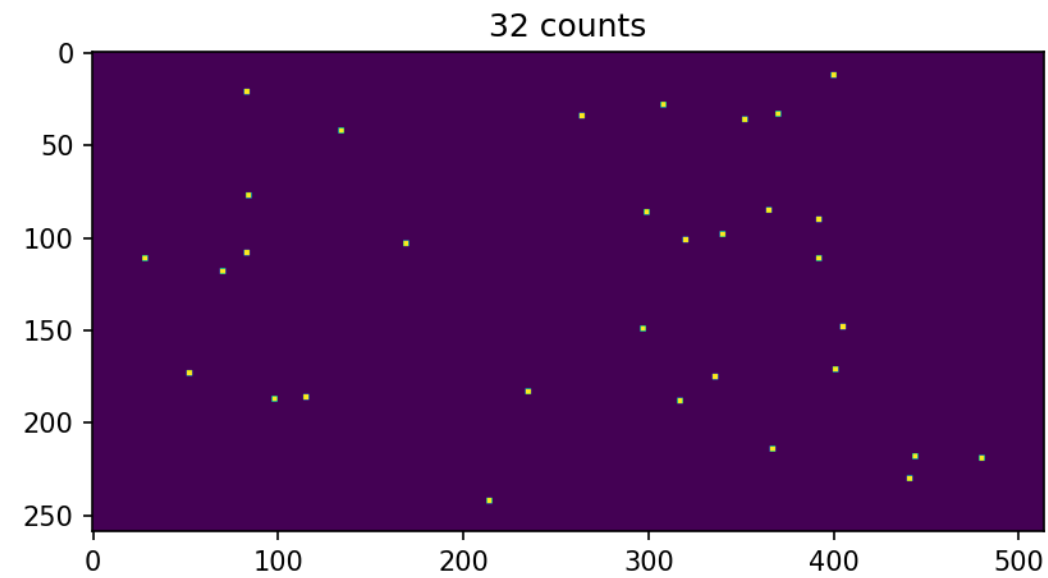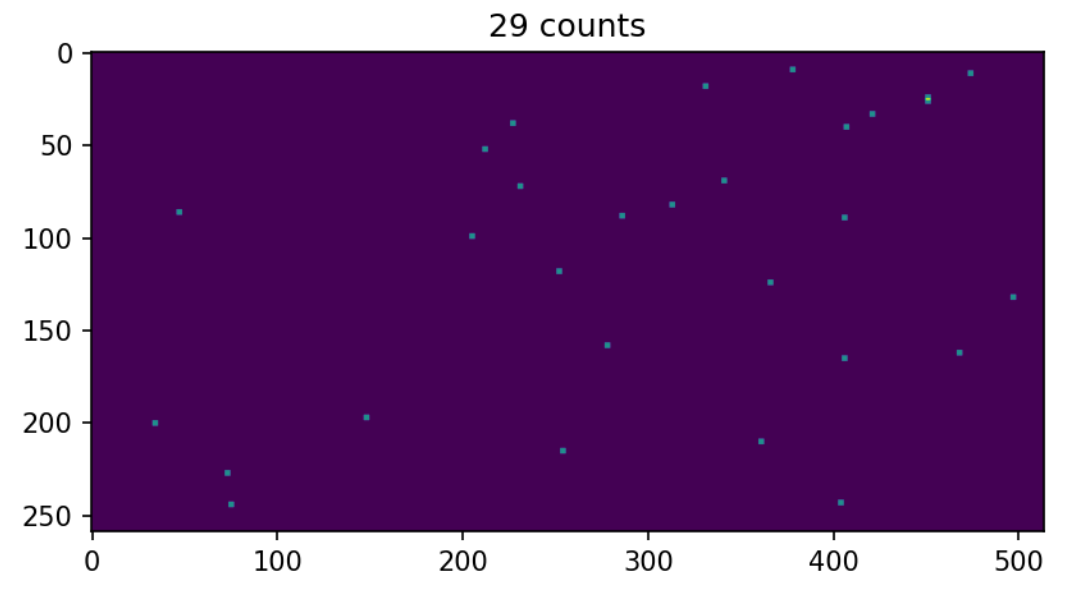● Dark Count
● Cerenkov Photon

Data Captures

Data Captures
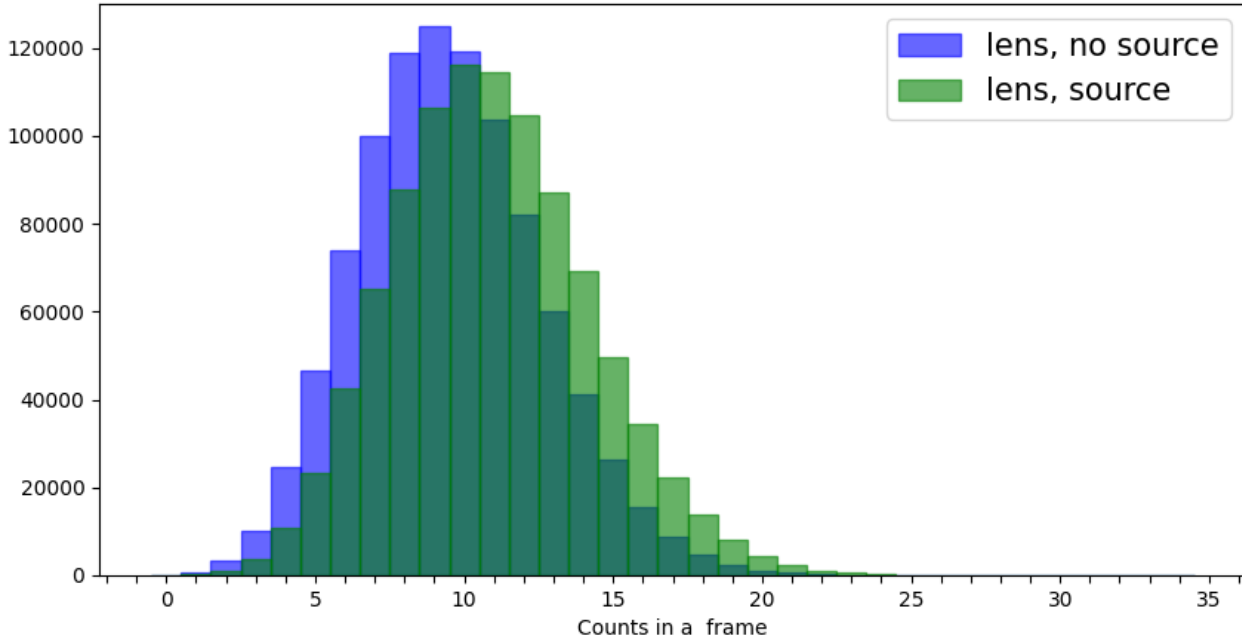
Examples of higher-count frames with lens

29 counts

29 counts
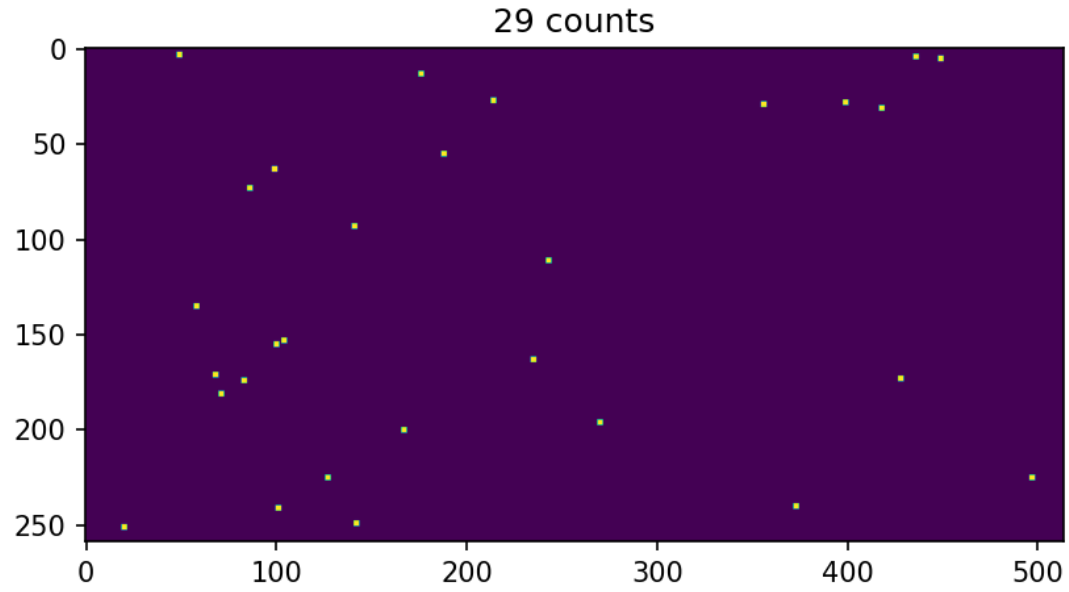
32 counts
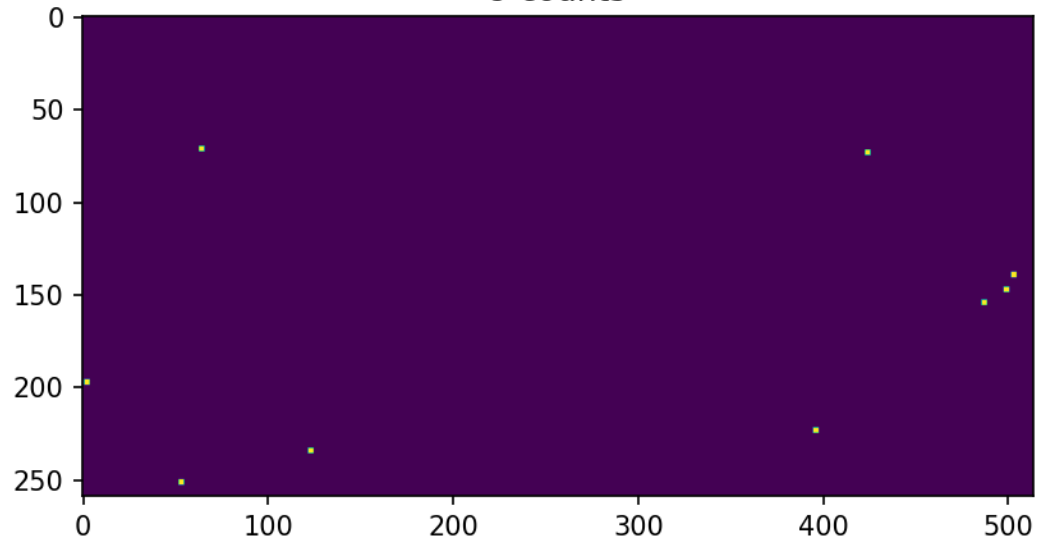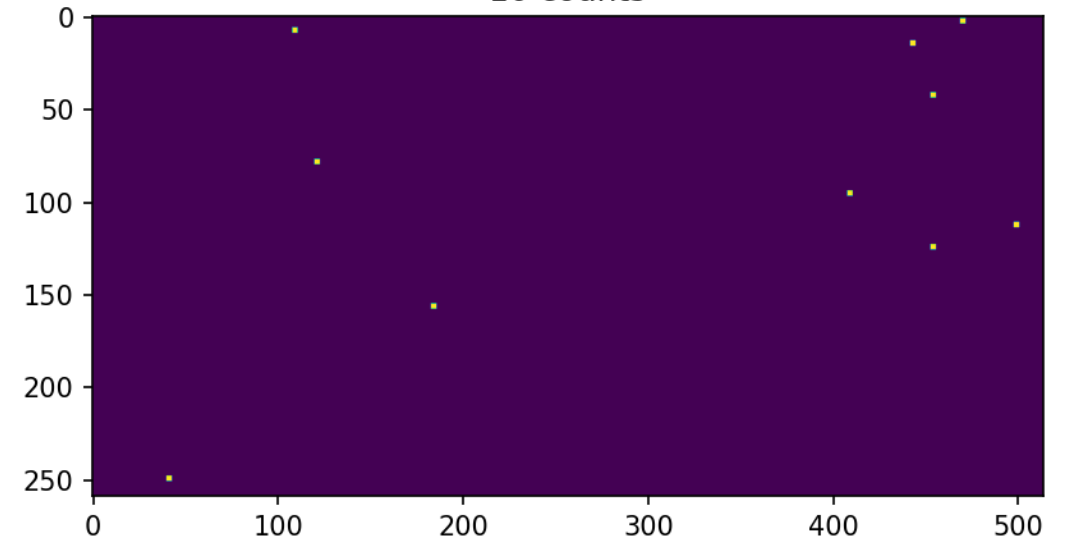
30 counts

Examples of lower-count frames with lens

9 counts

10 counts

Milestones

1. Detect individual interactions ✓

2. See interaction spatial structure

3. Perform backprojection

- Need to perform further data collection and analysis; improve SNR

ACKNOWLEDGEMENTS