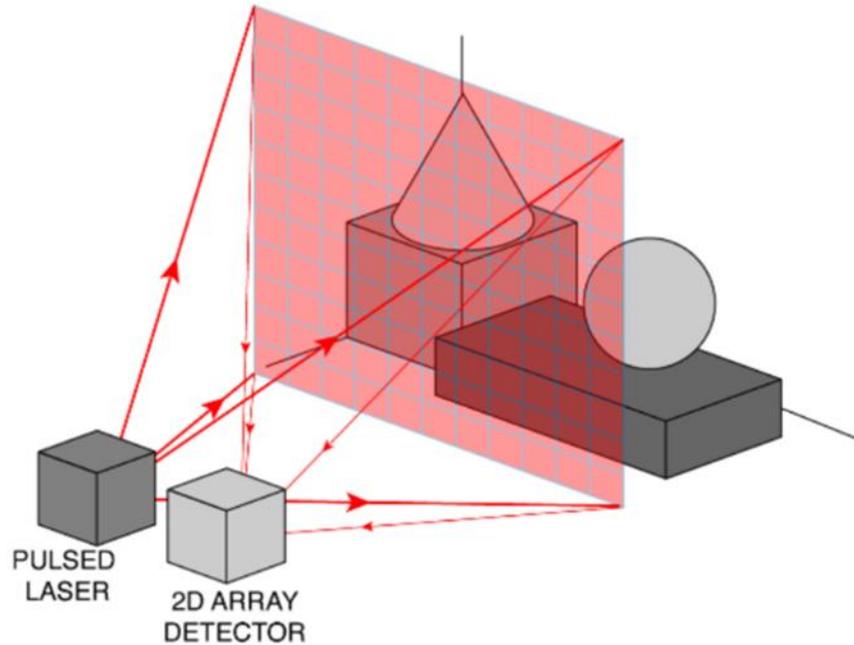# Asynchronous Depth Sensing through Direct Time-of-Flight Flash LiDAR

Yiyang Liu, Rongxuan Zhang, Filip Taneski, Istvan Gyongy and Robert K. Henderson
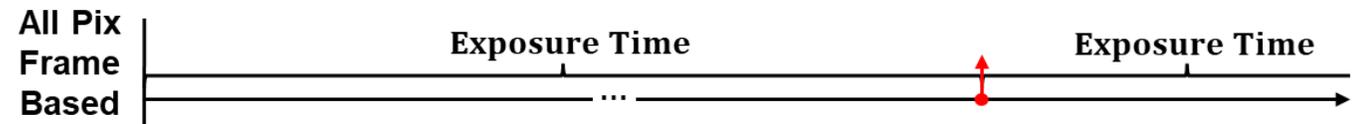
The University of Edinburgh, Edinburgh, UK

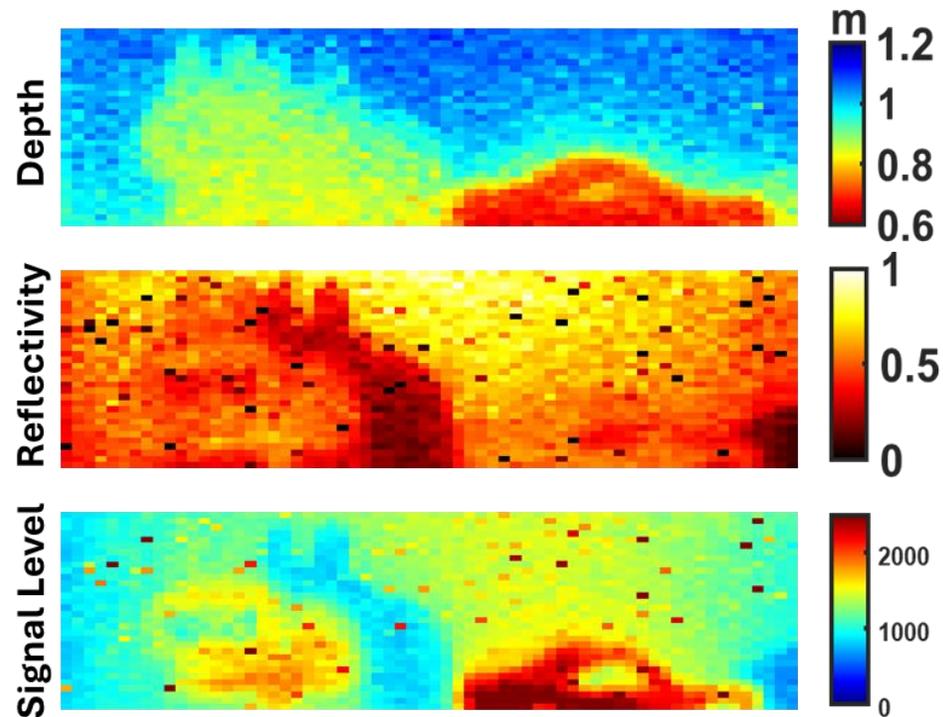THE UNIVERSITY of EDINBURGH

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Flash LiDAR

Flash/Solid State LiDAR [1]

- Laser flash illuminate whole scene at once
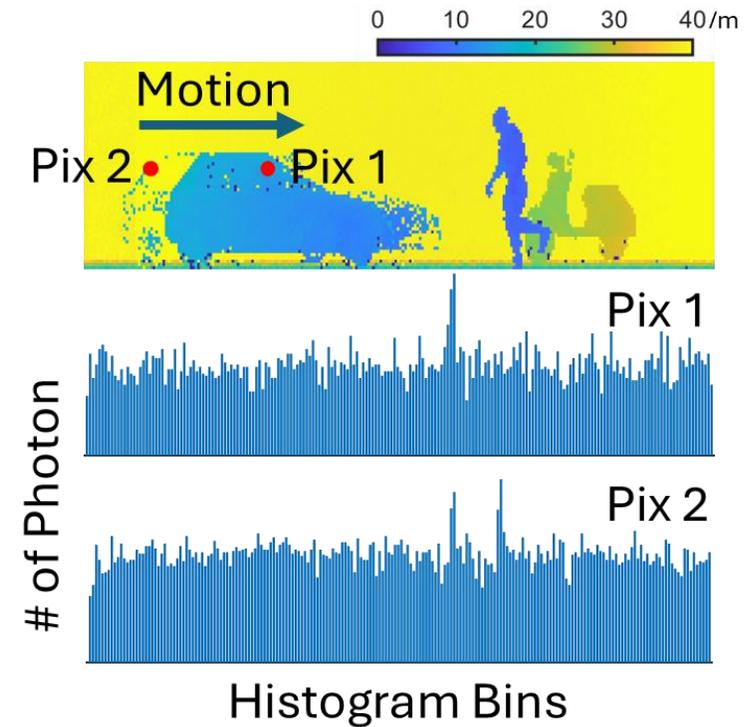- All pixels in the sensor expose at same time
- Frame Based

[1] F. Villa et al., MDPI Sensors 2021

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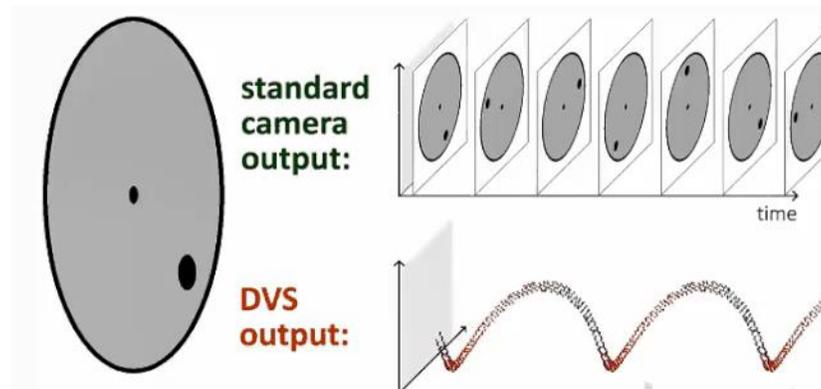CMOS Sensors & Systems Group

2

Problems in Frame based LiDAR
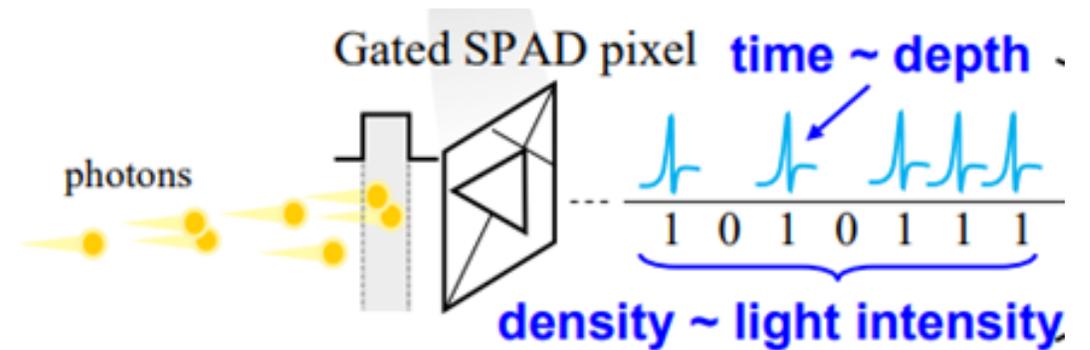
Inefficient Photon Utilization

Motion Blur

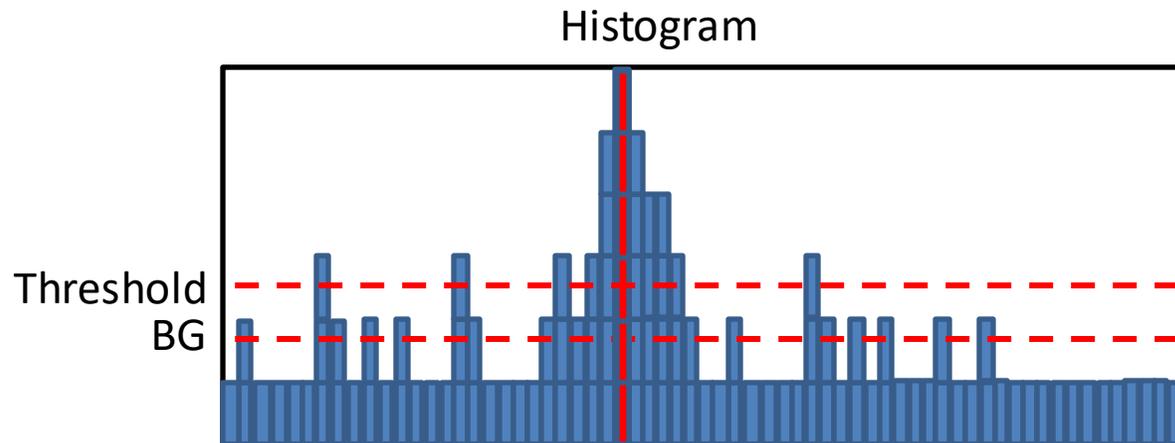# Asynchronous Vision Sensing

Dynamic Vision Sensor[2]

➢Event = ΔPixel Intensity > Threshold
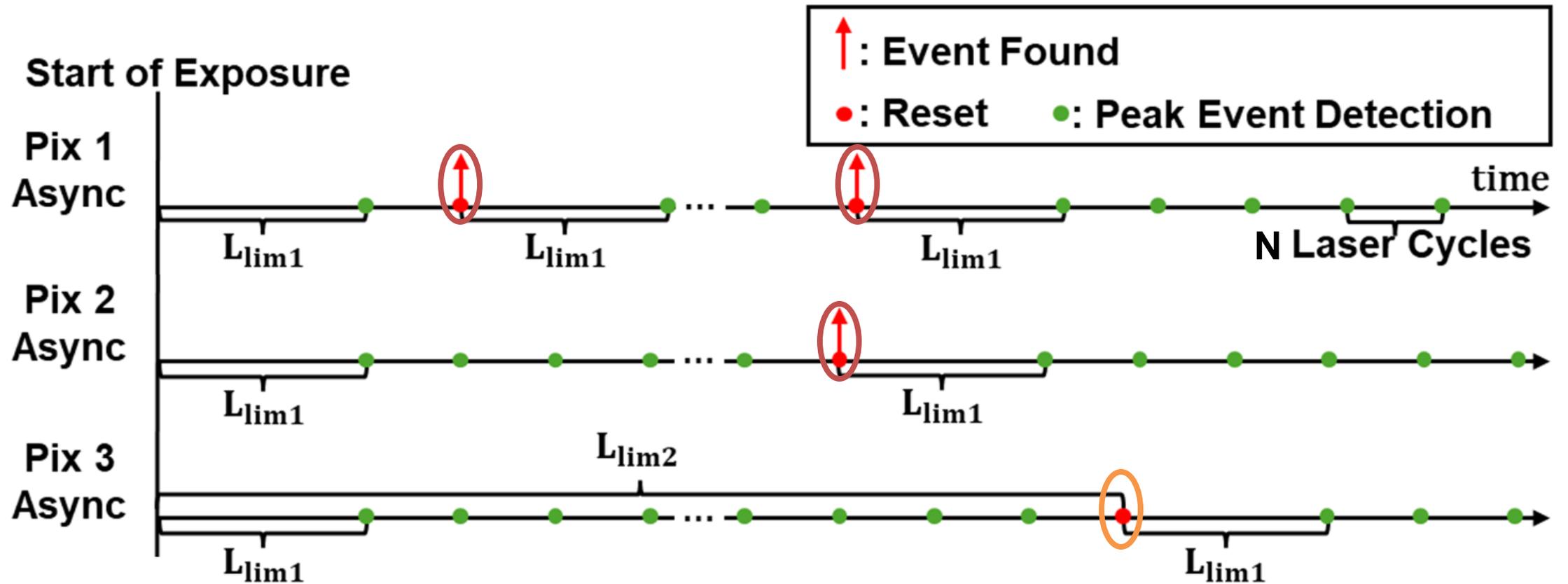

Spiking SPAD Imager[3]

➢Event = Photon Detection

[2] E.Mueggler et al., IROS 2014
[3] X.Yang et al., IEEE JSSC 2024

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Events in Asynchronous Depth Sensing

Histogram

- Peak = Max of all bins
- BG = Mean of all bins
- $\text{Threshold} = \text{BG} + \alpha\sqrt{\text{BG}}$

➢ **Event = Peak > Threshold**

Threshold

BG

Operation of Proposed dToF Pixels

Experiment Set Up

256x128 SPAD Array,
4x4 Binned[4]

Opal Kelly XEM6310
Xilinx XC7A75T-1C

OSELA 860 nm TOFI
Period=$0.84\mu s$
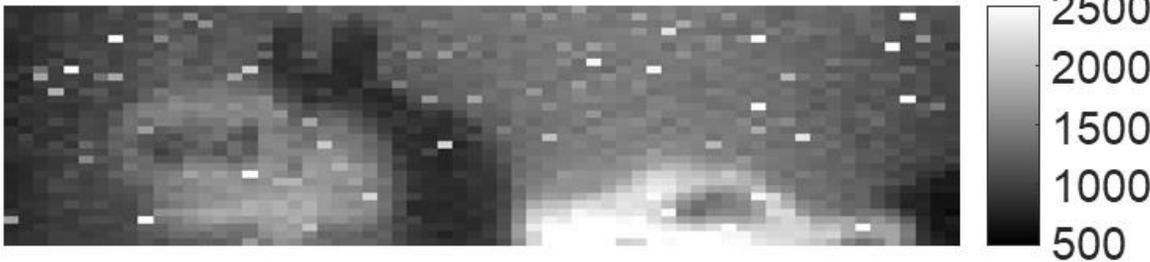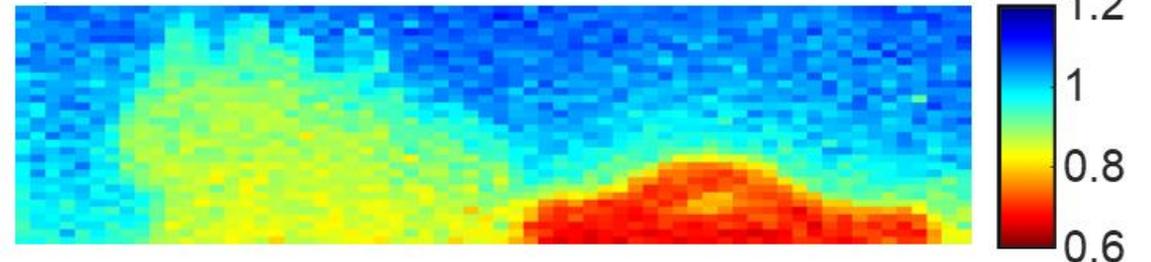
FPGA

Sensor

Laser

Experiment Scene

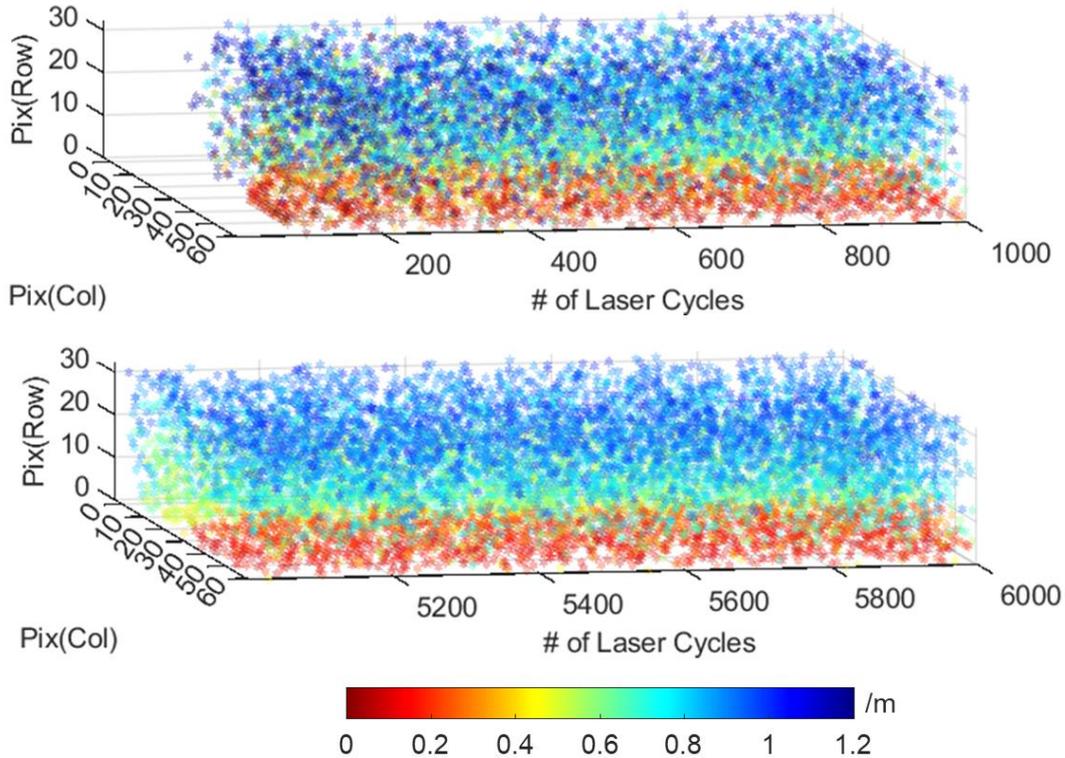RGB Image

Single Photon Counting (Laser off, no filter)
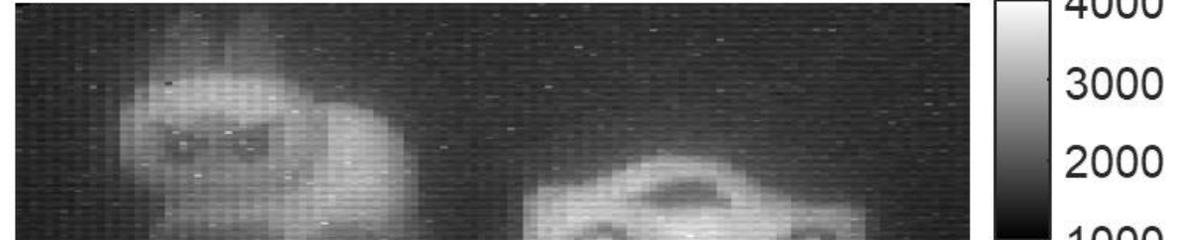
Single Photon Counting (Laser on, with filter)

Depth Map (Taken in frame-based mode)
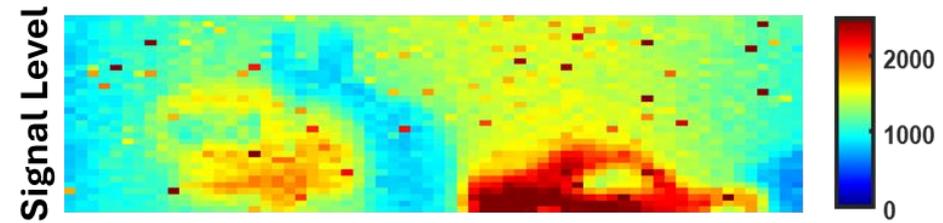
Output of Asynchronous LiDAR

- Each point is a peak event
- Colour of point is depth of the peak event

- Car = Red
- Cat = Yellow/Green
- Background = Blue

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Peak Event Rate Analysis
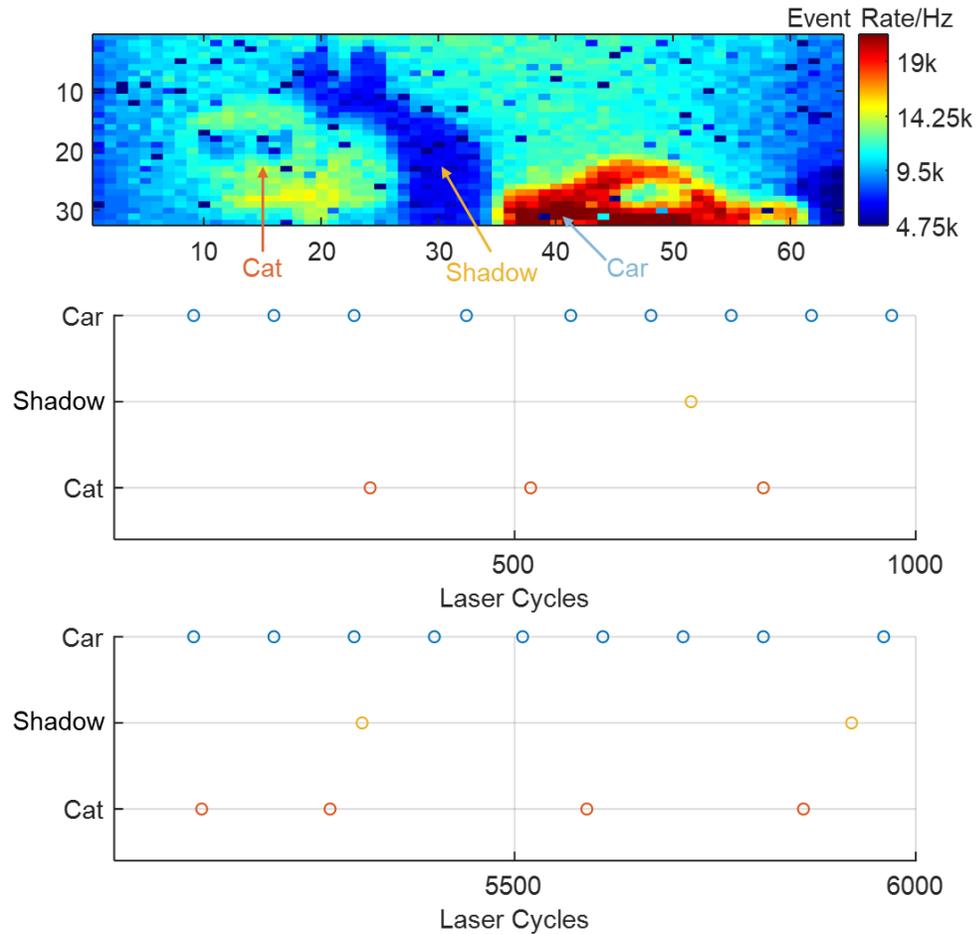
- Event Rate $\propto$ Signal Level $\propto \dfrac{\rho}{z^2}$

- relative $\rho \approx$ Event Rate $\times z^2$
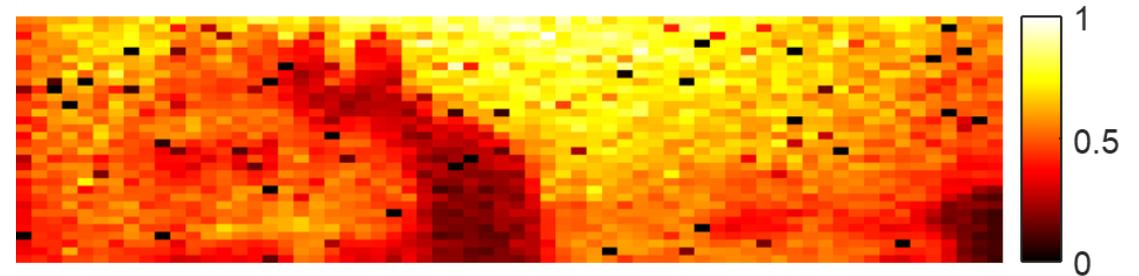
Hyperparameter Analysis

Dynamic Object Study – Radial Motion

Dynamic Depth Events – Radial Motion
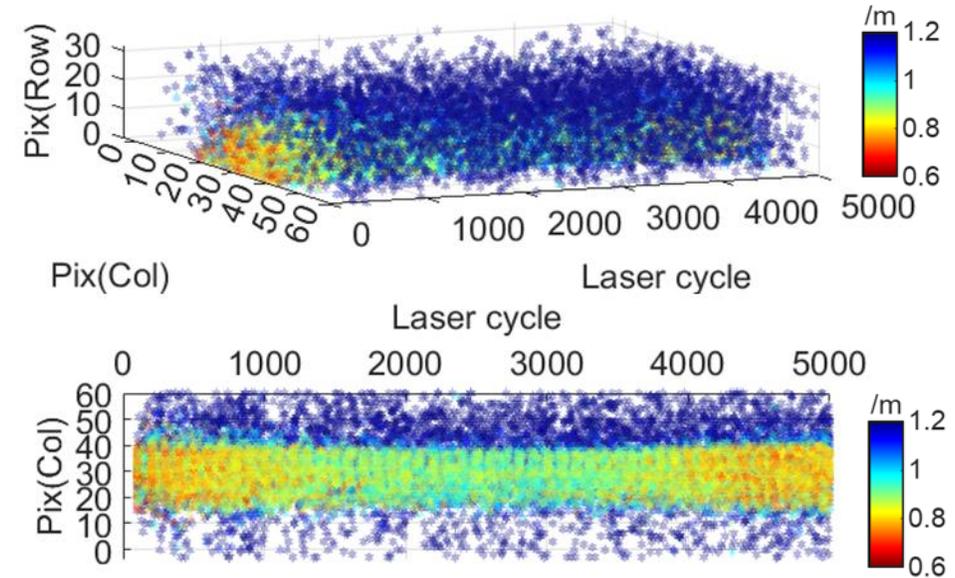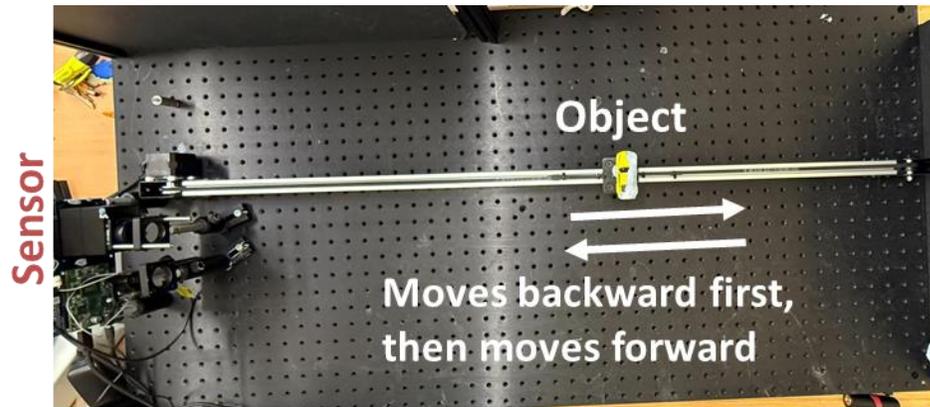
➤ Event = **Δ**Depth> Threshold

Dynamic Object Study – Transverse Motion
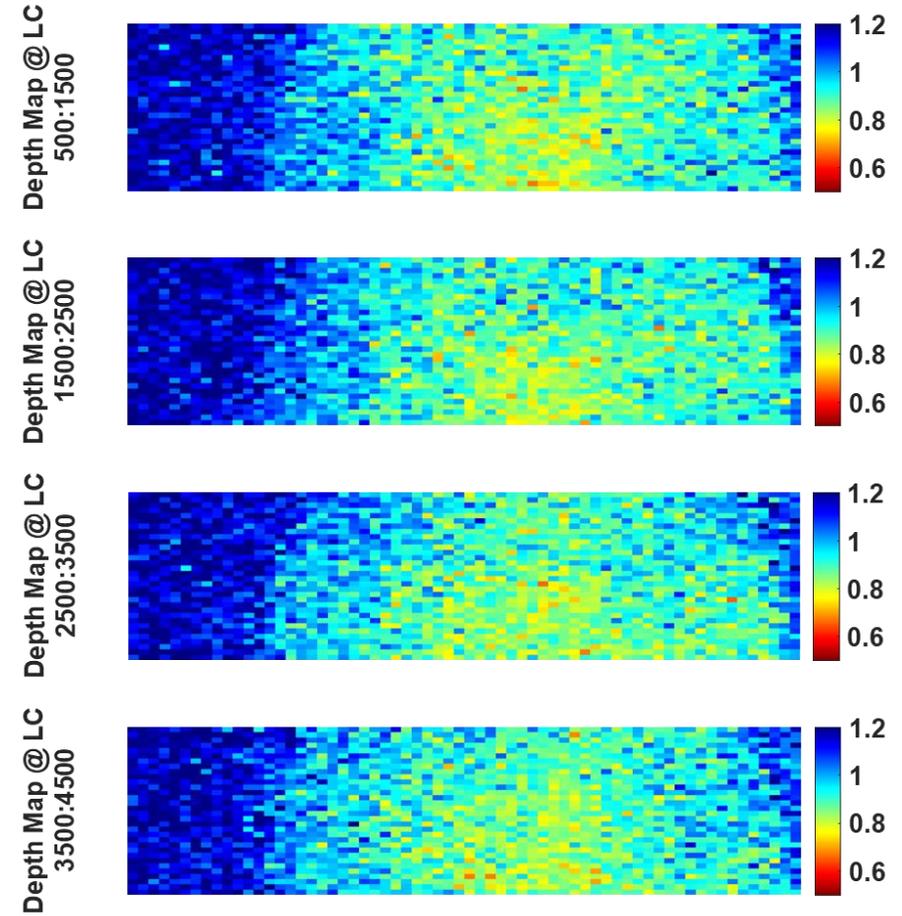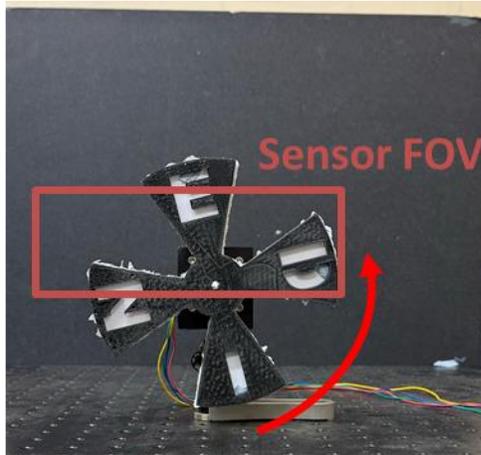
Dynamic Depth Events – Transverse Motion

Red Events: +ve ΔDepth

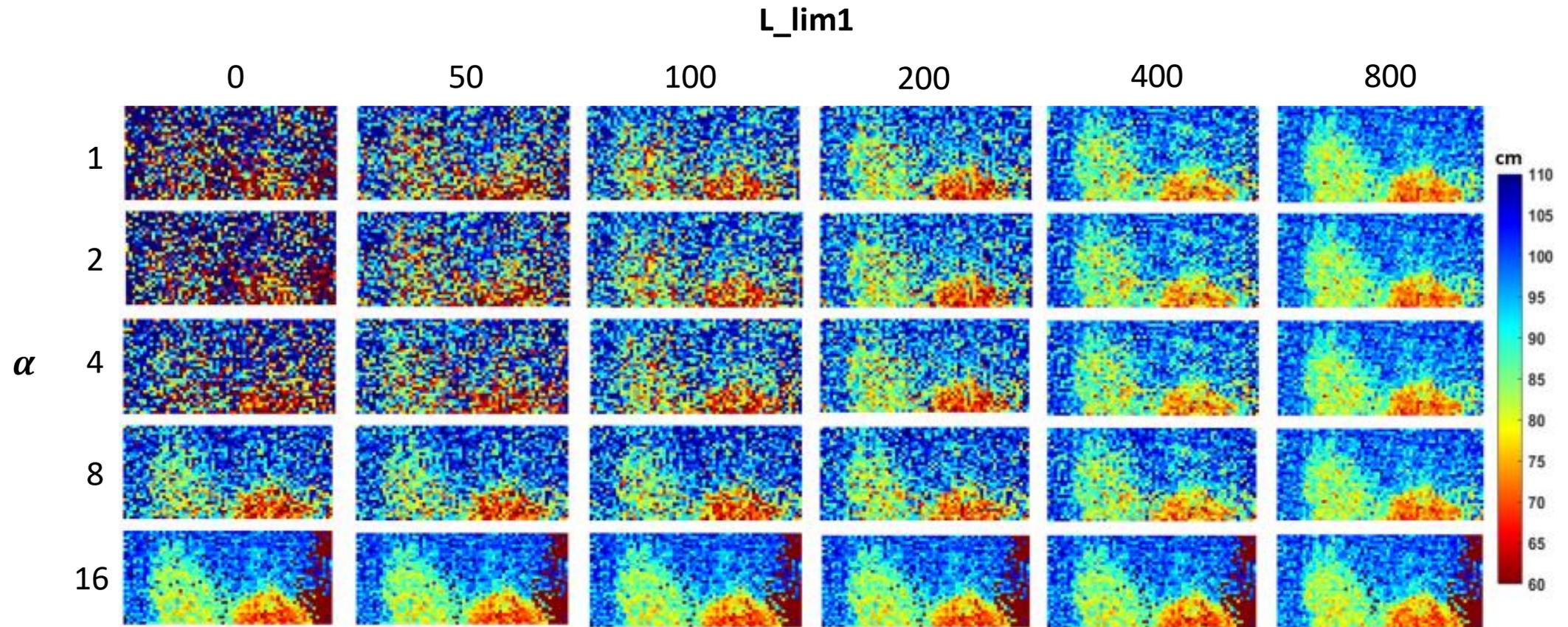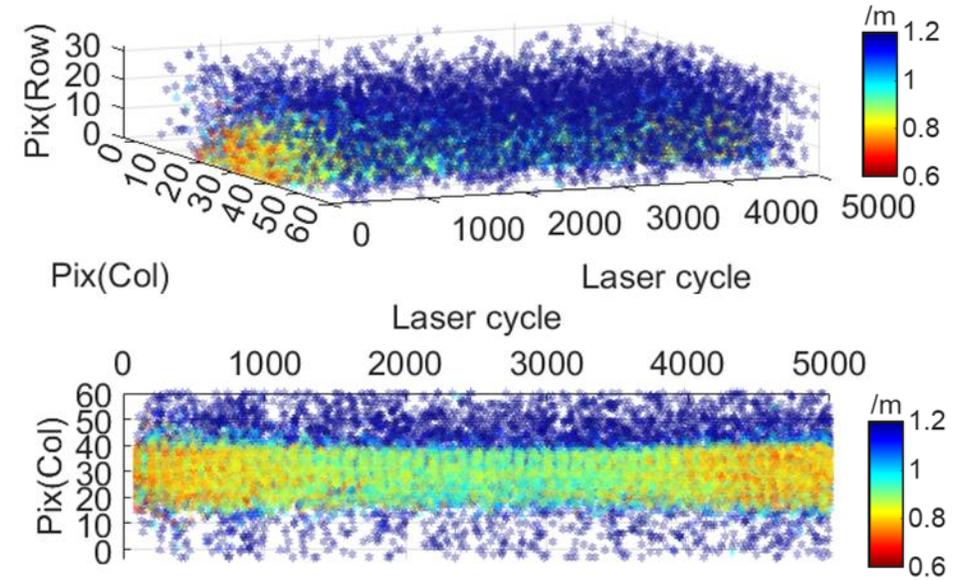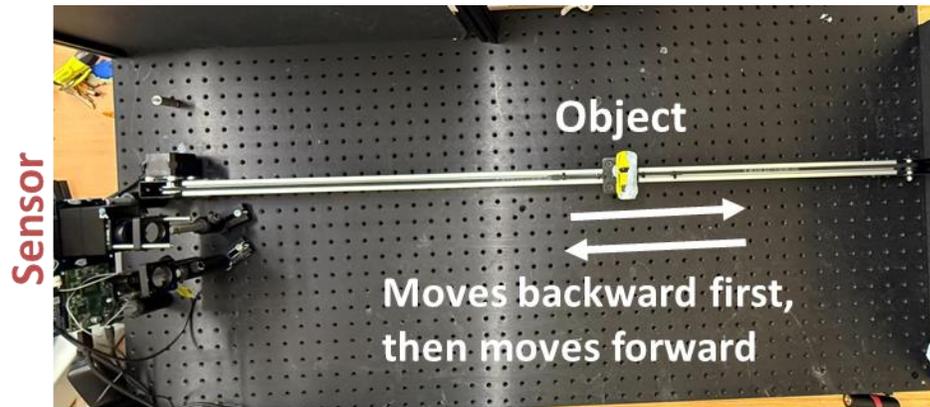**Blue Events: -ve ΔDepth**
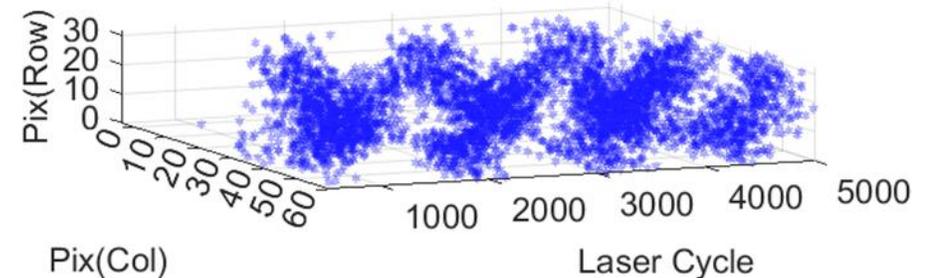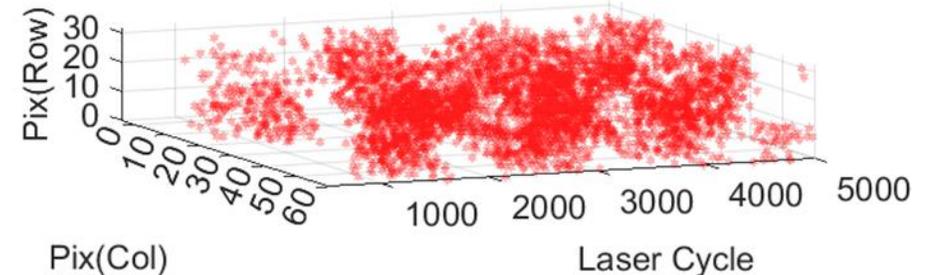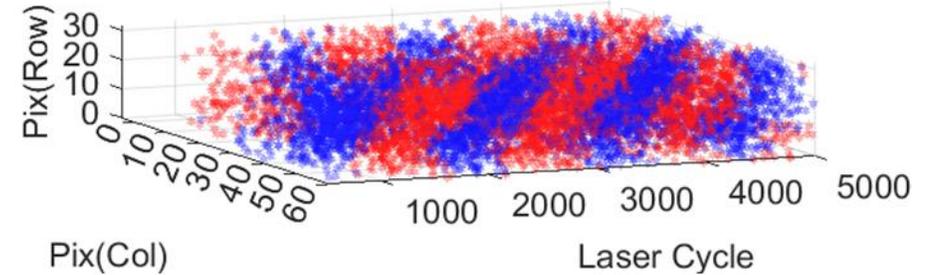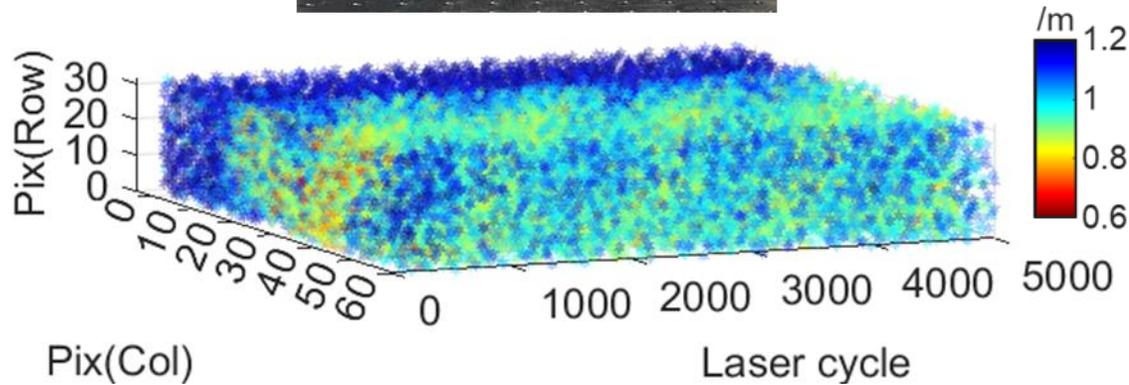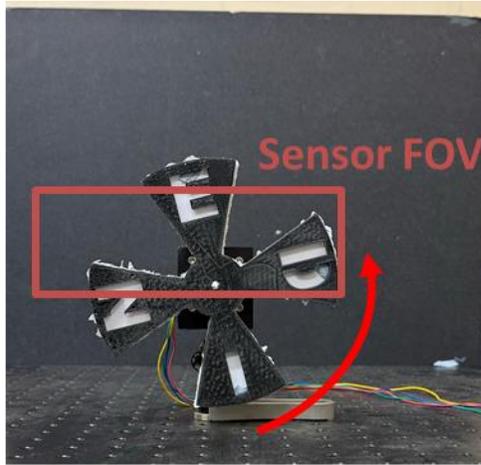
Conclusion

- Proposed an **Asynchronous** operation approach for dToF flash LiDAR
  - Different pixels adaptively reports at different rate
  - More **Robust to Motion Blur**
- Studied the **Hyperparameter Selection** and **Reflectivity Reconstruction**
- Proposed method to produce **Dynamic Depth Events**

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Thank You, Questions?

Data Flow

- 1000 frames of 5 laser cycle each (4.2μs exposure in total)
- 8 bin histogram with bin width of ~8.75ns
- Process offline on MATLAB

Proposed Hardware Implementation

Exposure	On Chip	Peak Detect Algorithm	Readout	Remove Less Confident Pixels Off Chip
• 1000s of Laser Cycles to Enhance SNR • For Global Worst-Case Conditions	• TDC • Per Pixel Histogram	• Zooming[1]/Sliding[2] Histogramming • Maximum Searching[3] • Matched Filtering[4]	• Depth Map • Confidence Level	

Exposure	On Chip	**In Pixel** Peak Detect	**Event Driven** Readout
• **Pixelwise Exposure Control** • **Async Start and Reset**	• TDC • Histogram	• Zooming[1]/Sliding[2] Histogramming • Maximum Searching[3] • Matched Filtering[4]	• **Use Confidence Level as Threshold** • **Remove Less Confident Pixels On Chip**

Proposed Hardware Implementation

Proof-of-concept Hardware Implementation

FPGA Implementation
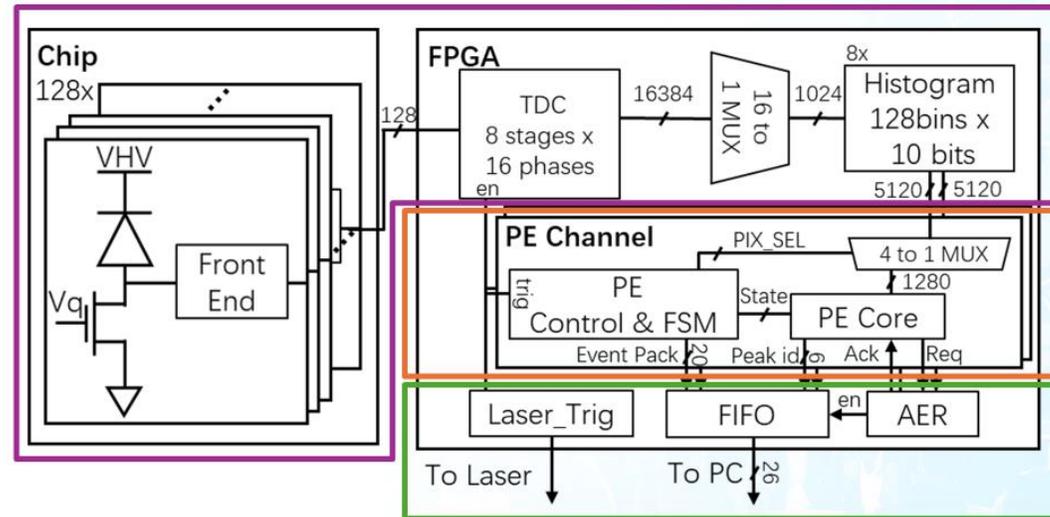
TCSPC System (LiDAR)

Peak Detection and Event Generation

Readout and Peripheral Control

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Hyperparameter Analysis
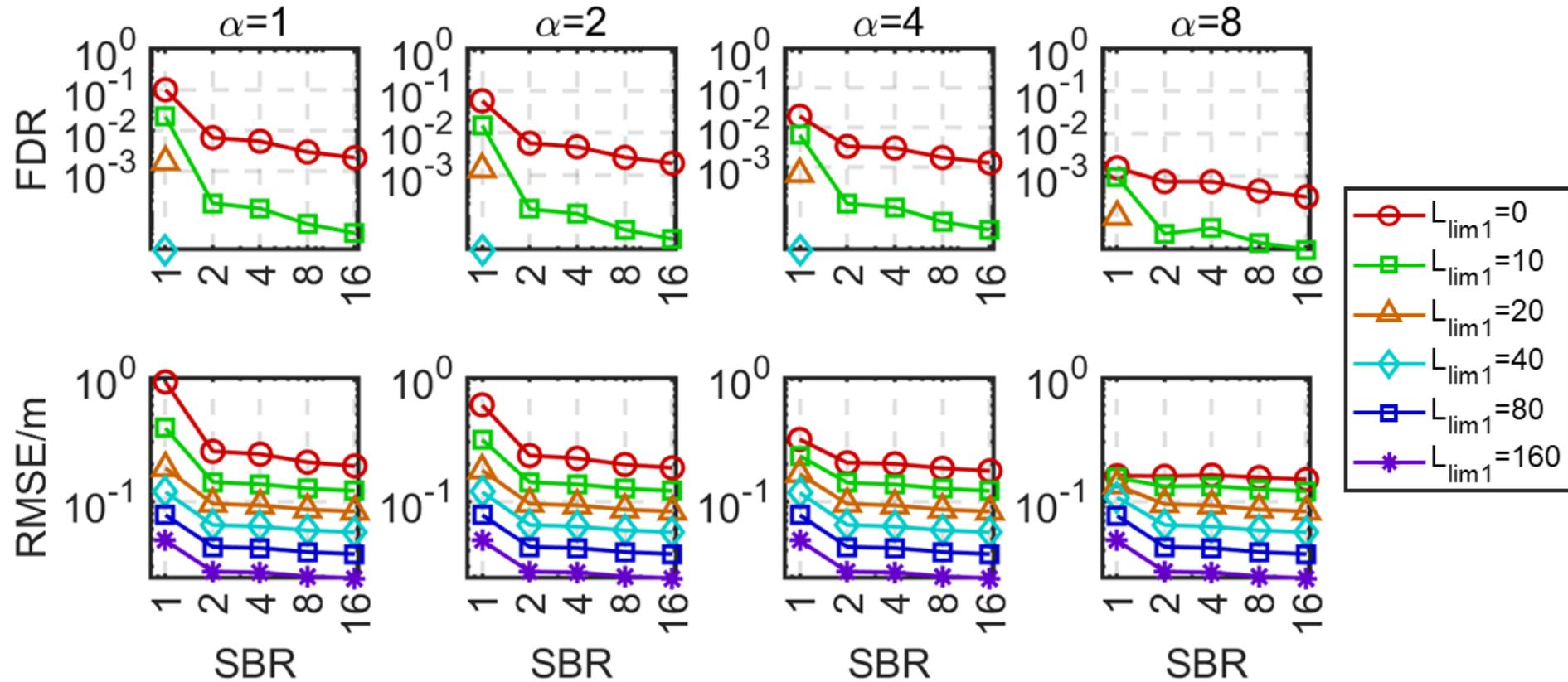
- Note that bin width = ~1.3m, CMM method was applied for sub-bin interpolation

Hyperparameter Analysis Conclusion

$\alpha\uparrow$

FPR$\downarrow$ $\longrightarrow$ $\uparrow$Depth Quality

FNR$\uparrow$ $\longrightarrow$ $\downarrow$Event Rate

$L_{lim1}\uparrow$

FPR$\downarrow$ $\longrightarrow$ $\uparrow$Depth Quality

Texp$\uparrow$ $\longrightarrow$ $\uparrow$Latency
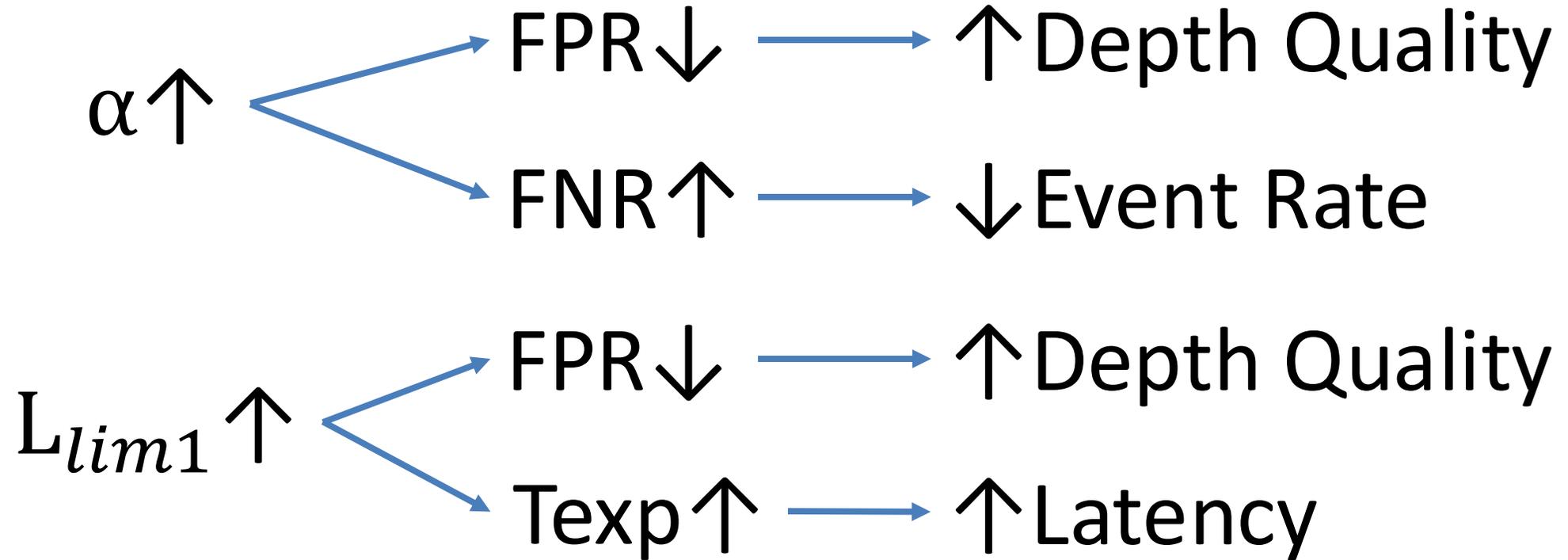
Async vs. Sync

Async vs. Sync
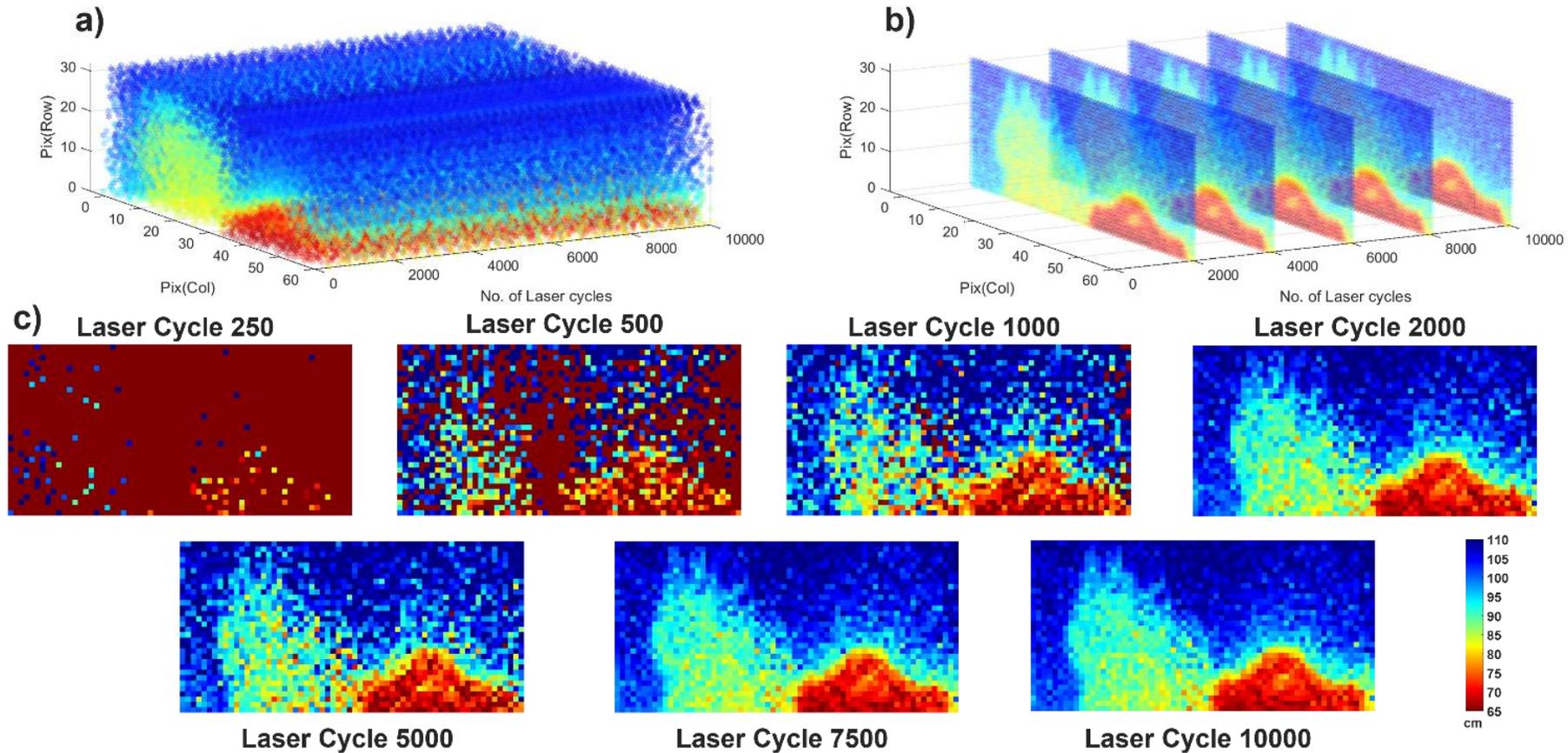
Neuromorphic Depth Sensing

Depth Sensing

Single Image Depth Perception
Stereo
Structure Light

CIS + Algo
→ DVS + AI

Neuromorphic Depth Sensing

J. Hidalgo-Carrió et al., 3DV 2020
S. Ghosh, G. Gallego, Adv. Intell. Syst. 2022
M. Muglikdar et al., 3DV 2021

ToF

Requires Higher Temporal Reso. Than DVS*

?

PASSIVE STEREO | ACTIVE STEREO | STRUCTURED LIGHT | TIME OF FLIGHT [1]

Left image | Right image
Base line

Left image | Right image
P | Projector
Base line

Image
C | P
Projector

Infrared Light (laser)
C | L
Laser Source

[1] https://community.arm.com/arm-community-blogs
/b/mobile-graphics-and-gaming-blog/posts
/the-rise-of-depth-on-mobile

* For dToF

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