



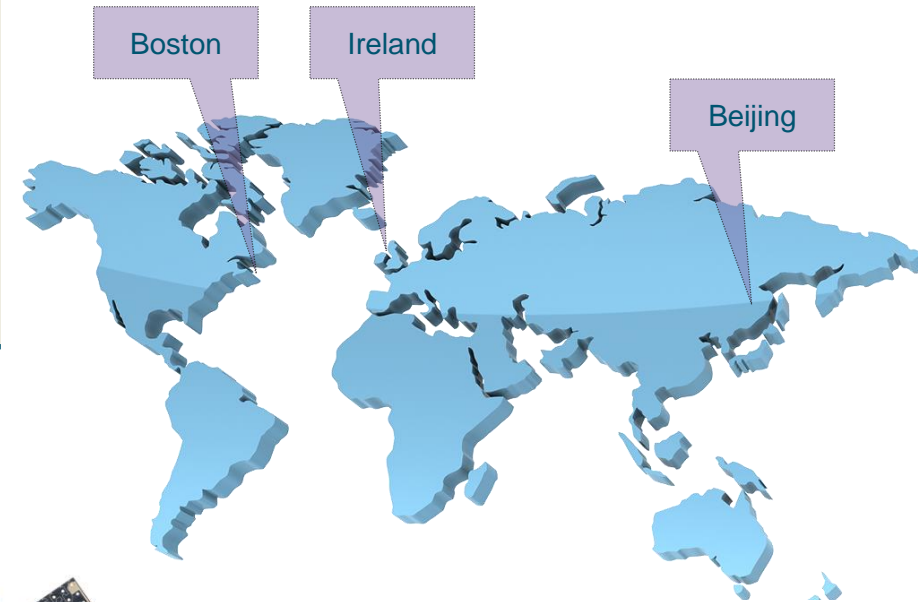
# SiPM and SPAD Arrays for Next Generation LiDAR

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Senior LiDAR Engineer

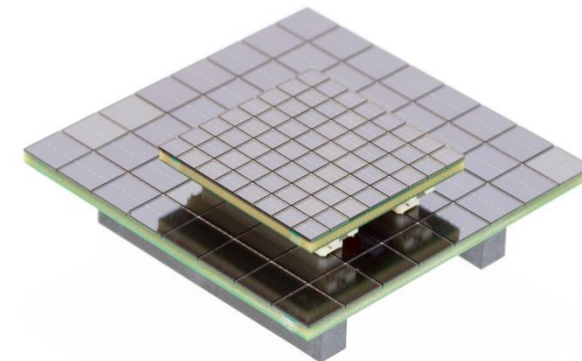
International SPAD-Sensor Workshop

# SensL Quick Facts

Business	Low Light Sensors
Markets	Medical Imaging Radiation Detection Automotive LiDAR
Model	Fabless Semiconductor

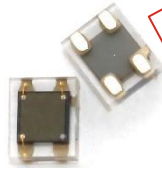


- Established 2004
- ISO9001:2008 Certified



# LiDAR Product & Demonstrator Roadmap

## Products



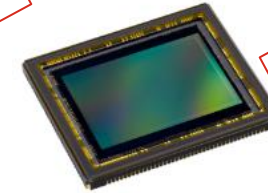
Released

RA-Series SiPM



Sampling

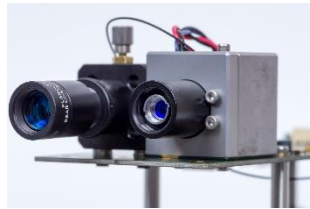
1x16 SiPM Array



Sampling  
Q2 2019

3D ToF SPAD Array

## Demonstration Platforms



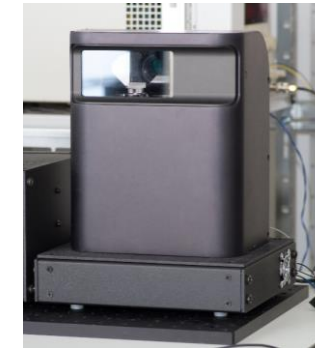
### Gen 1 – Single Point

- 30m indoors
- February 2016



### Gen 2 – Single Point

- 100m outdoors
- Low reflective targets
- September 2016



### Gen 3 – 3D ToF Imaging

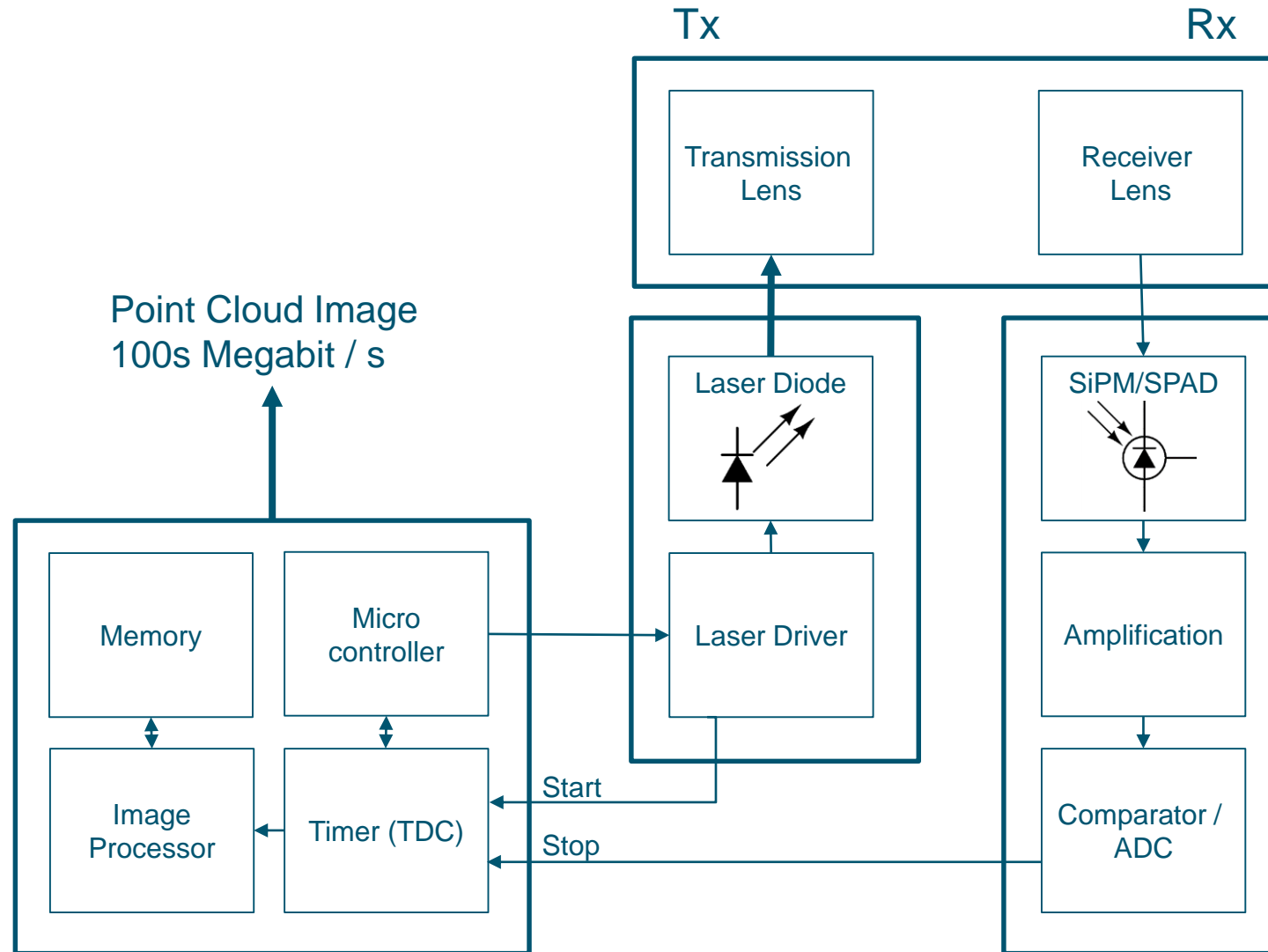
- 100m+ outdoors
- Low reflective targets
- June 2017

# Agenda

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- Anatomy of a LiDAR system
  - Tx: eye safe laser beam
  - Rx: high sensitivity SiPM/SPAD sensors
- Challenges for long distance outdoor LiDAR systems
- Current LiDAR systems solutions based on SiPM sensors
- Future LiDAR sensors based on SiPM/SPAD array sensors
- SensL Gen3 demonstrator

# Anatomy of a LiDAR System

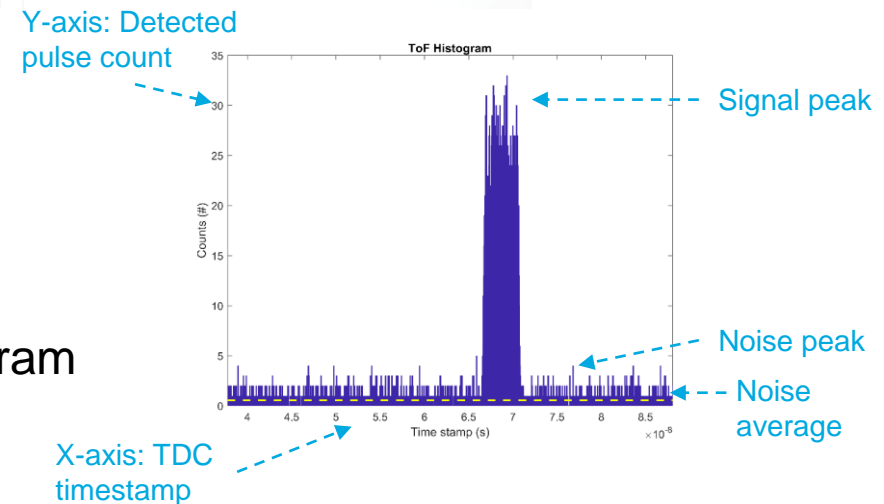


# Direct ToF LiDAR Measurement Techniques

- **Single shot:** one laser pulse per measurement (**SiPM**)
  - A single returned pulse is time stamped and the range determined
  - High optical SNR required



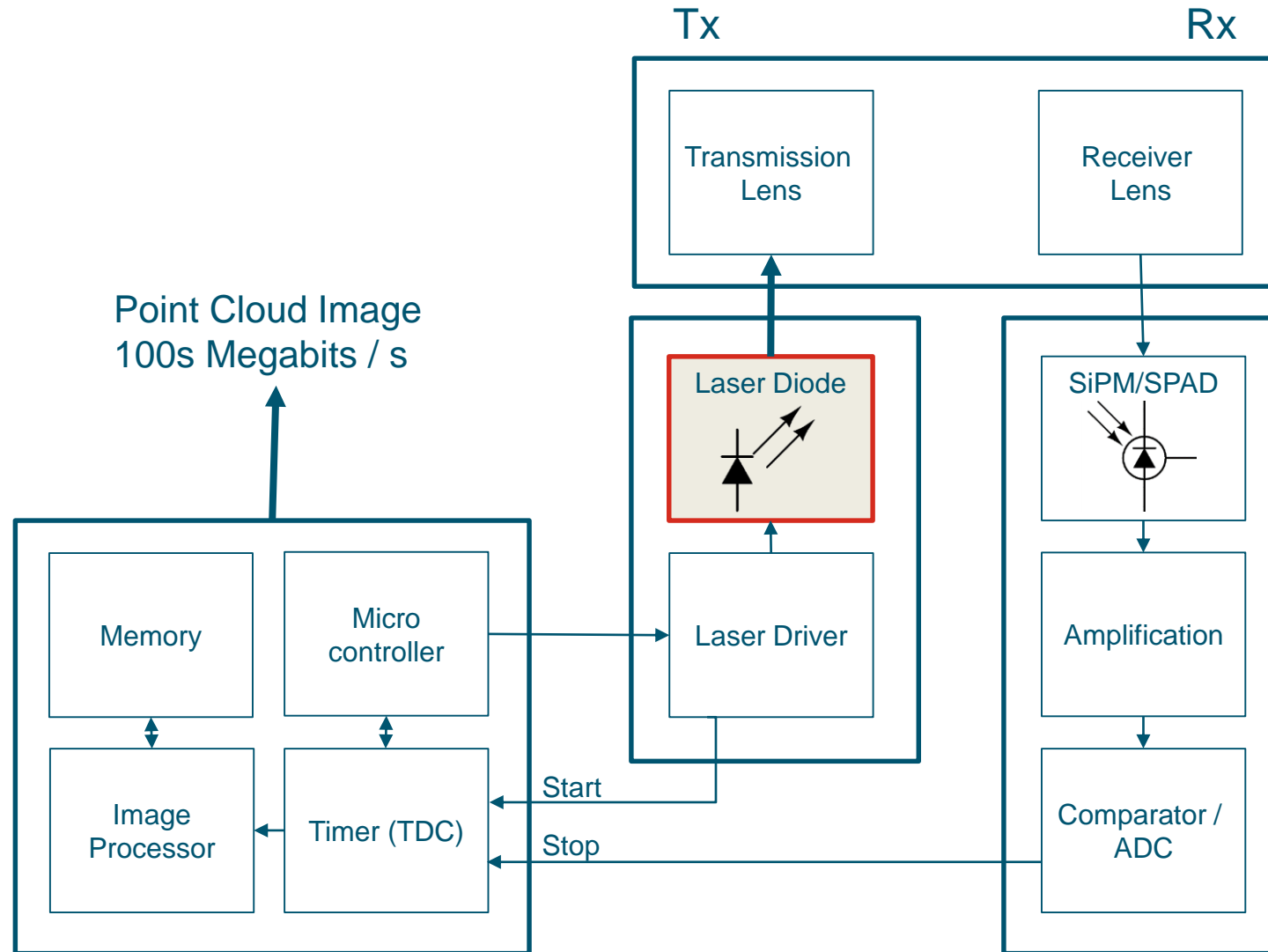
- **Multishot:** multiple laser pulses per measurement (**SiPM or SPAD**)
  - Laser pulses are time stamped & histogrammed
  - Range is determined from the histogram data
  - Increases SNR extending range



# Challenges for Long-distance LiDAR Systems

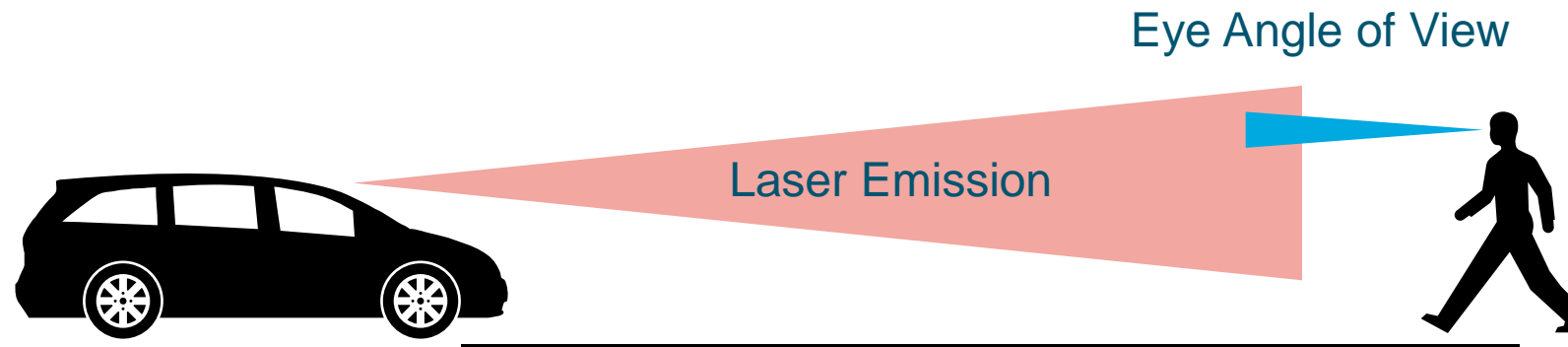
- Tx: Laser diodes / Scanning method
  - High and eye safe laser peak power required for long distance
  - High repetition rate for high frame rate systems
  - Short laser pulses for power optimization
  - Wavelength drift over temperature
    - Allows for narrower bandpass filters to be used and improve ambient rejection
  - Solid-state scanning methods
    - MEMS
    - OPA
- Rx: **SiPM/SPAD**
  - High responsivity at 905 nm and 940 nm for long range
  - High dynamic range for ambient light rejection
  - Compact size – cost effective
  - High pixelization
    - For high angular resolution
    - For best SNR performance
  - High data rate
  - Fast read out

# Anatomy of a LiDAR System



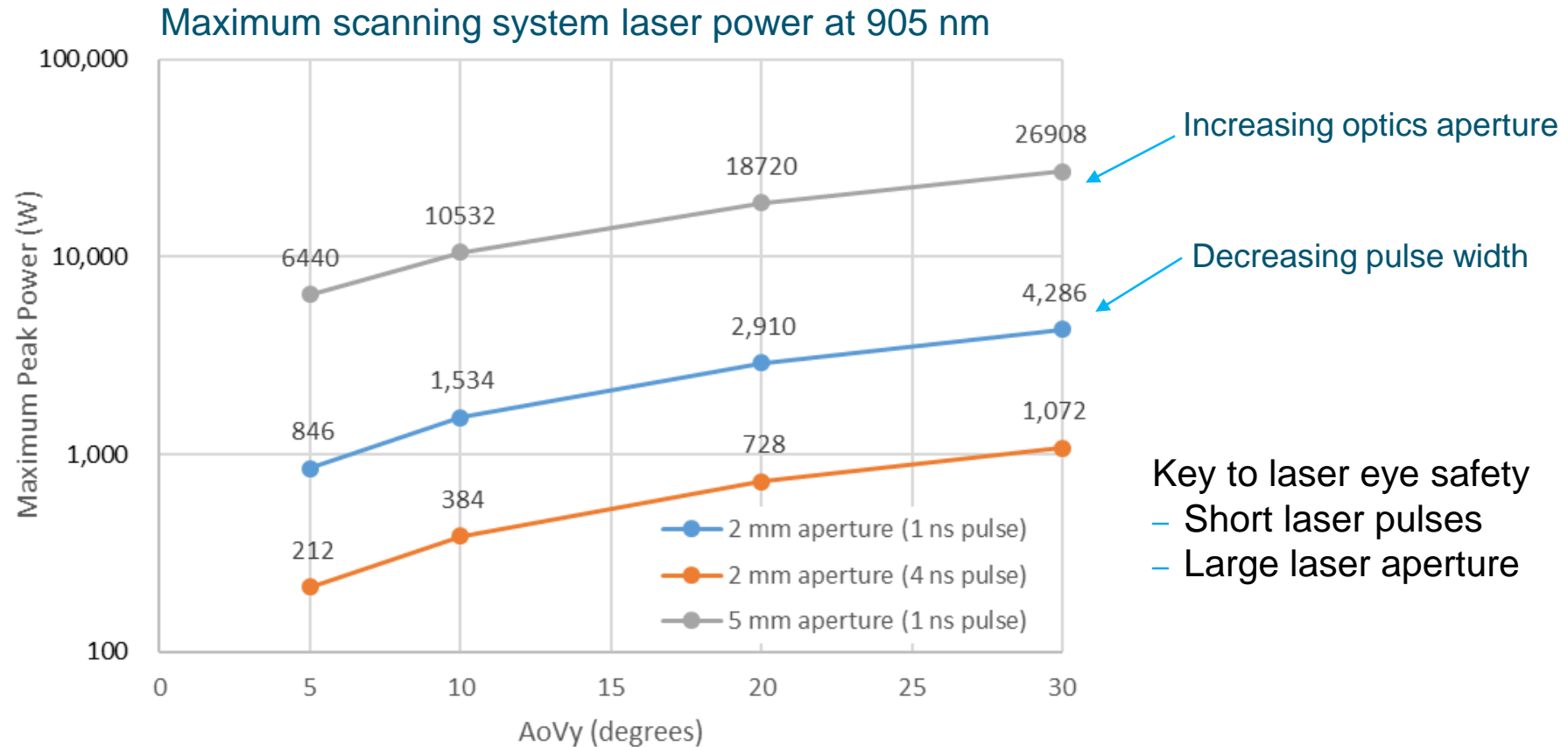


# Laser Eye Safety and LiDAR Systems



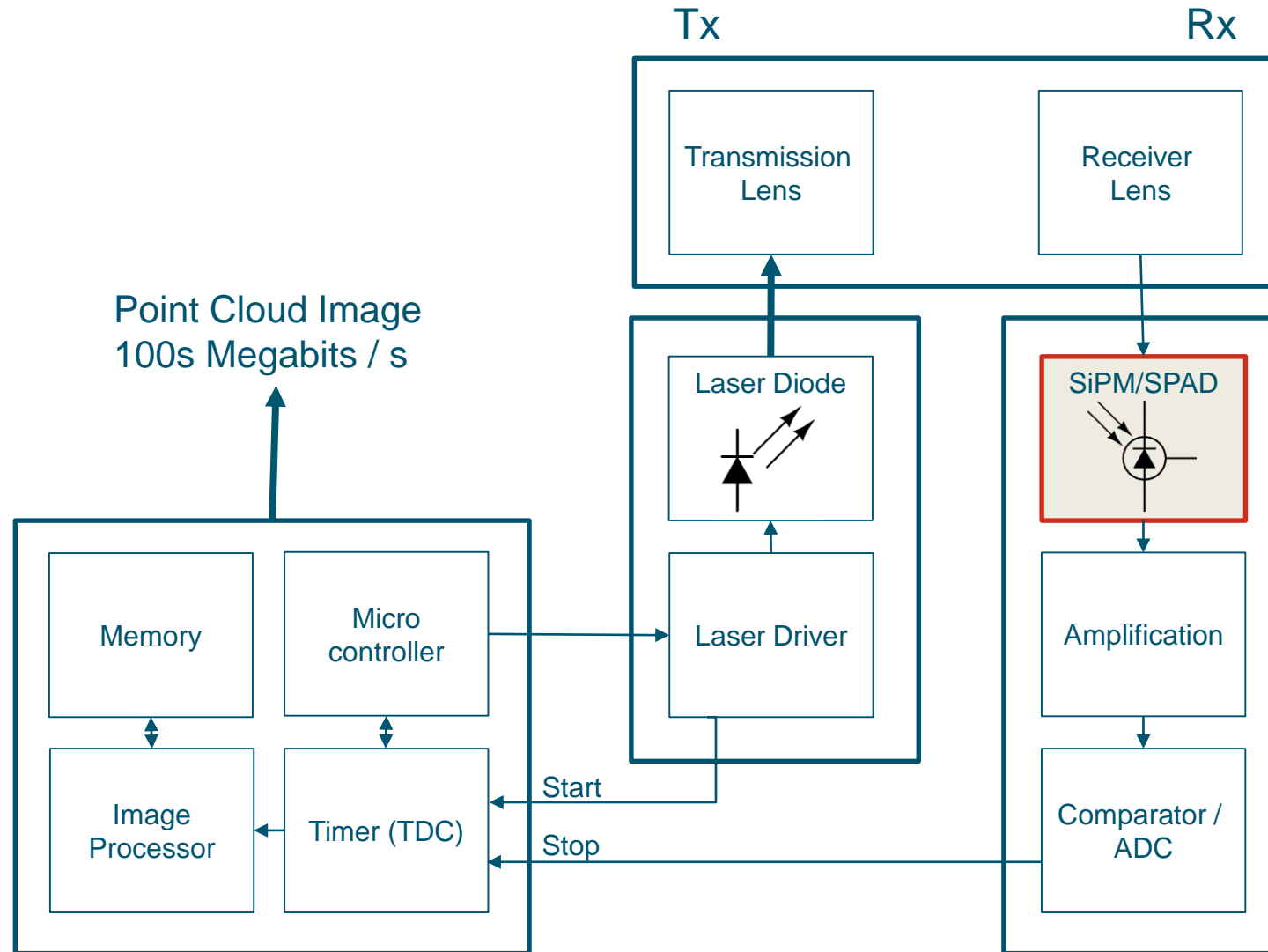
- Long range LiDAR requires high peak power lasers
- Laser power is spread over a wide angle of view (AoV)
- Aperture of the human eye has a limited AoV
- Important factors to meet eye safety limits from IEC 68025
  - Shorten the laser pulse to reduce energy per pulse
  - Increase the laser aperture for light leaving the LiDAR system

# Laser Eye Safety



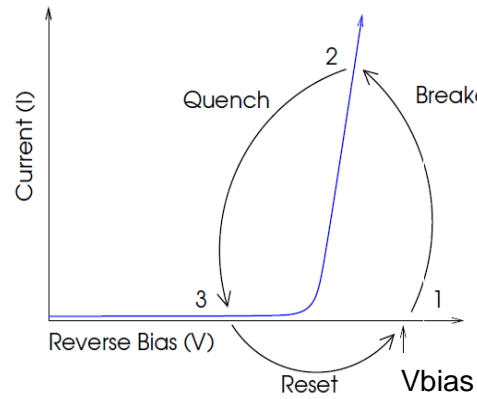
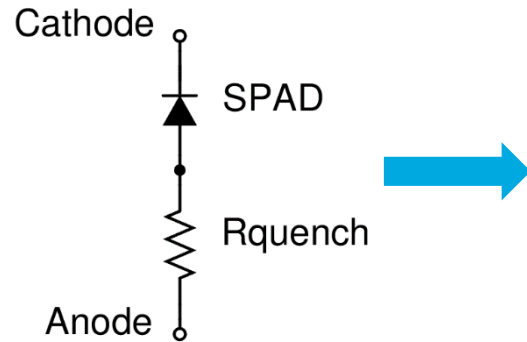
Maximum Permissible Exposure (MPE) IEC 68025-1 (2014)  
AoV<sub>x</sub> = 0.1°, assumes viewer is 10 cm (4") from laser aperture

# Anatomy of a LiDAR System

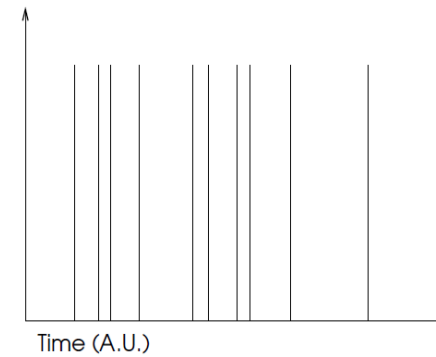


# Nomenclature: SPAD and SiPM

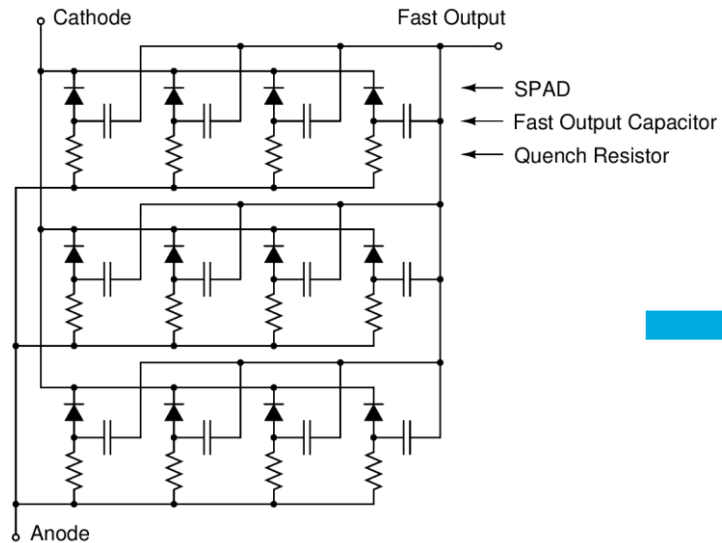
Single microcell/SPAD



Time or count single photons

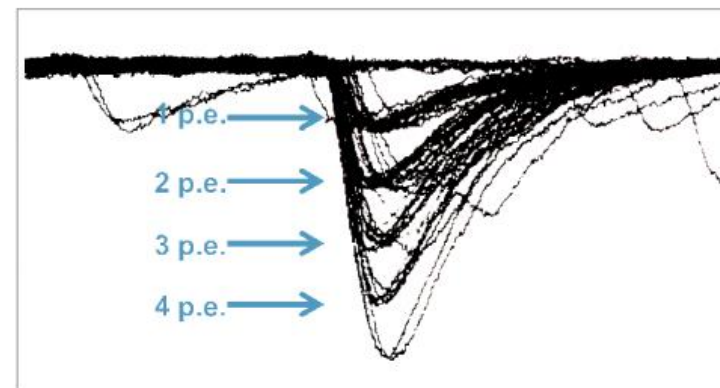


SPAD



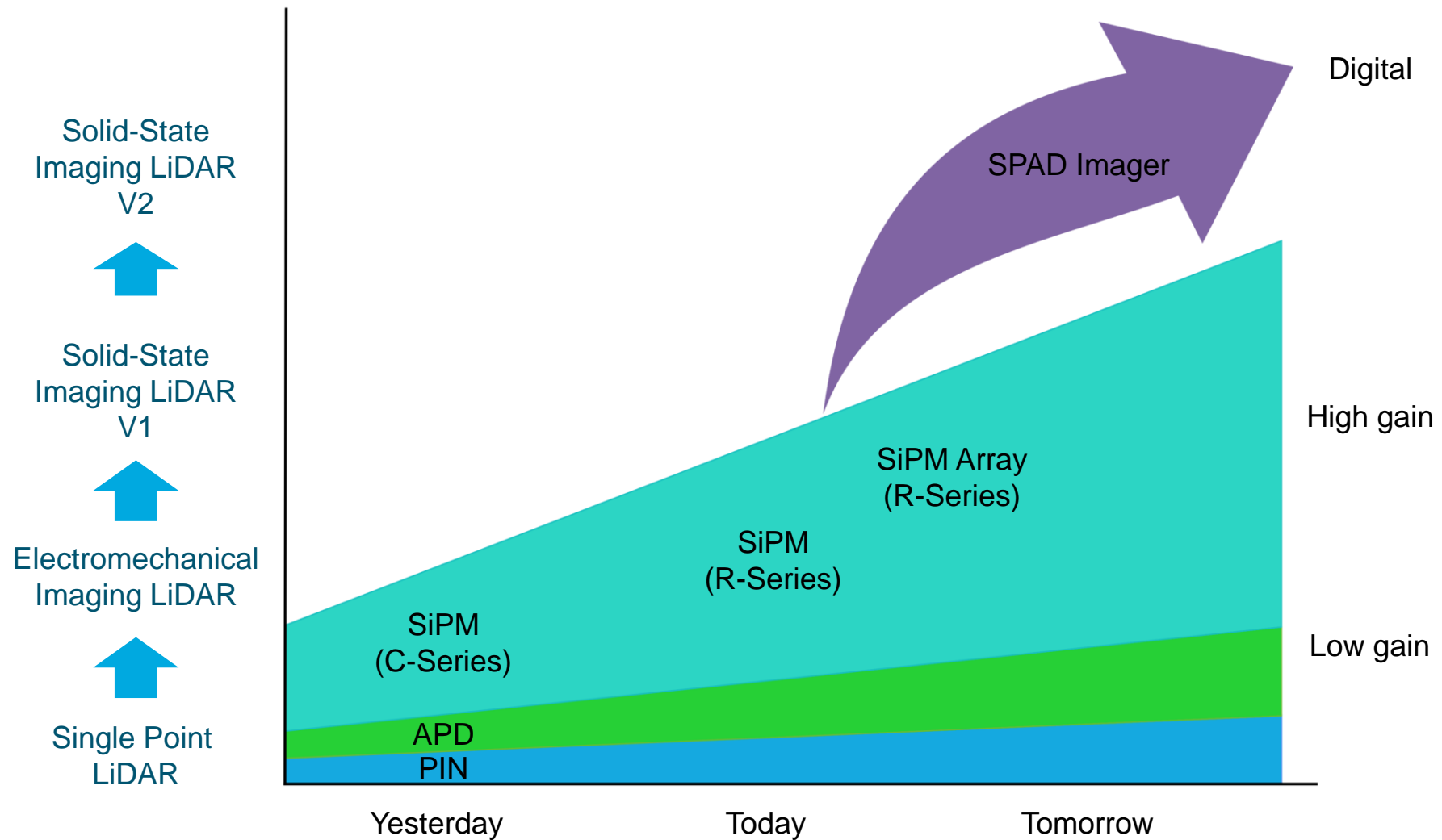
Example of 12 microcell/SPAD SiPM

Time or count multiple photons



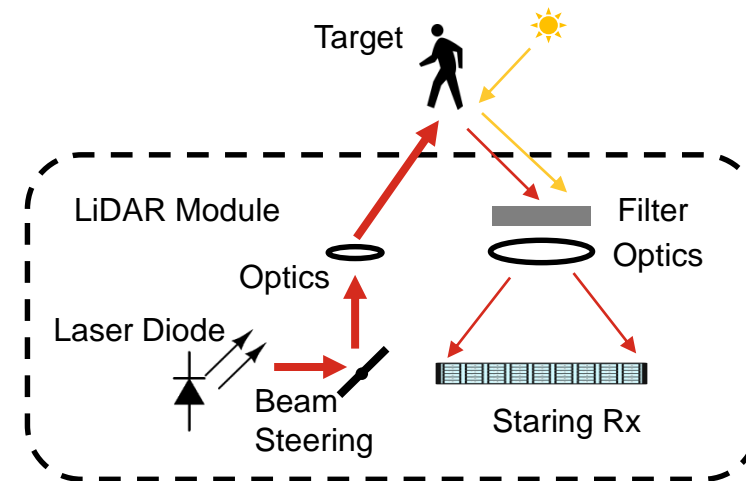
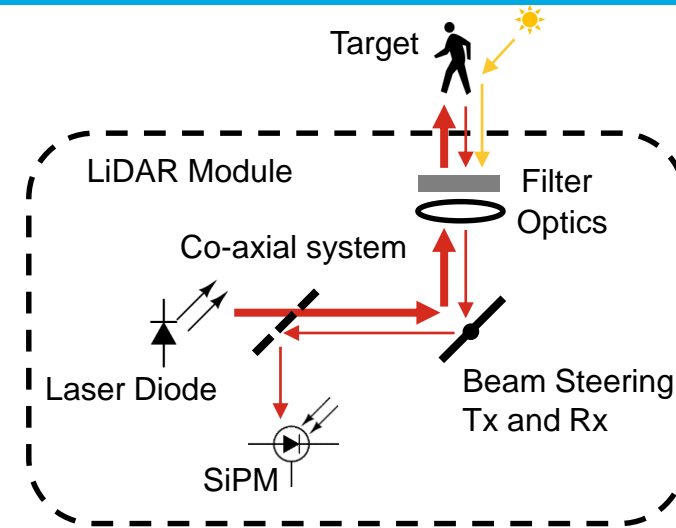
SiPM

# LiDAR Sensor Technology Evolution



# Long-distance LiDAR Systems Evolution

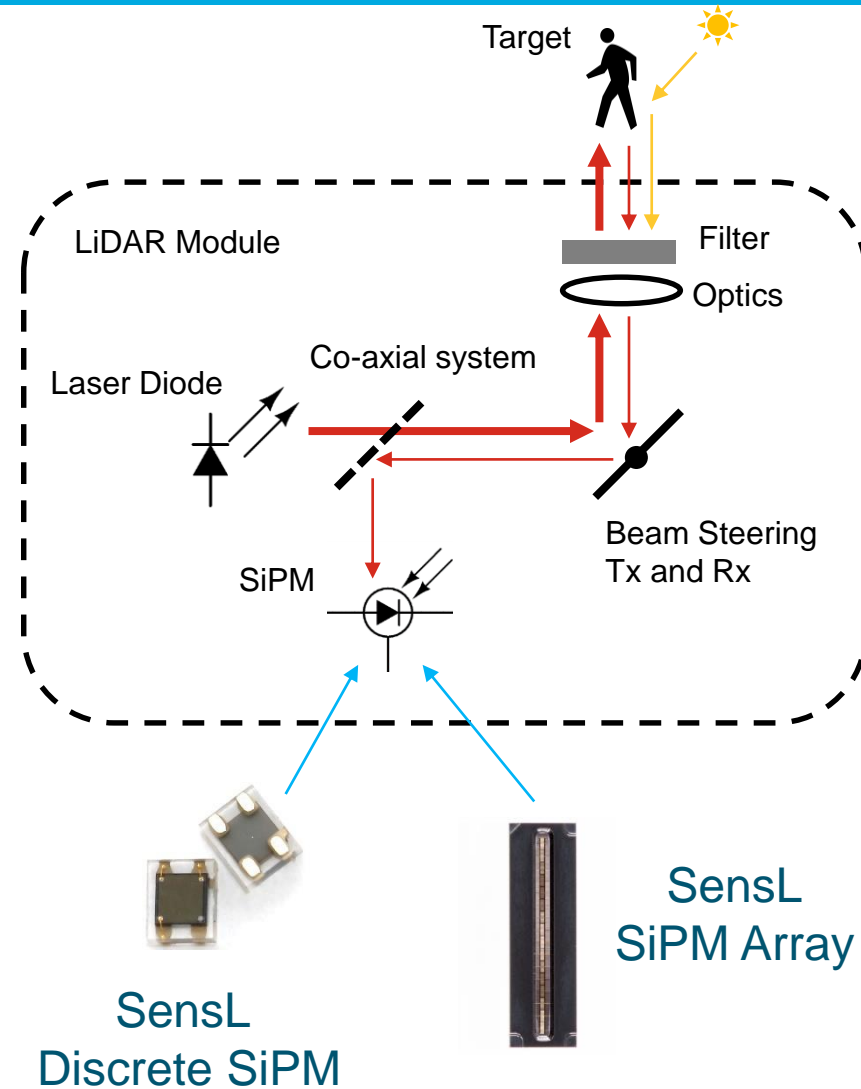
- **Today:** Electromechanical scanning TX \ RX (coaxial)
  - Single point (2D scan)
  - Single SiPM
  - Vertical/Horizontal line (1D Scan)
  - SiPM array
- **Future:** Solid-state scanning TX \ Staring RX
  - Single point (2D scan)
  - MEMS mirrors for TX
  - SiPM/SPAD array for RX
  - Vertical/Horizontal line (1D Scan)
  - MEMS mirrors/array for TX
  - SiPM/SPAD array for RX



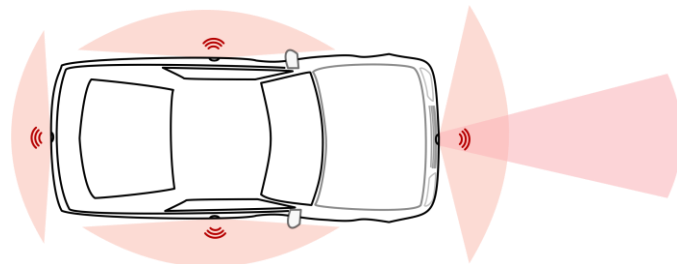
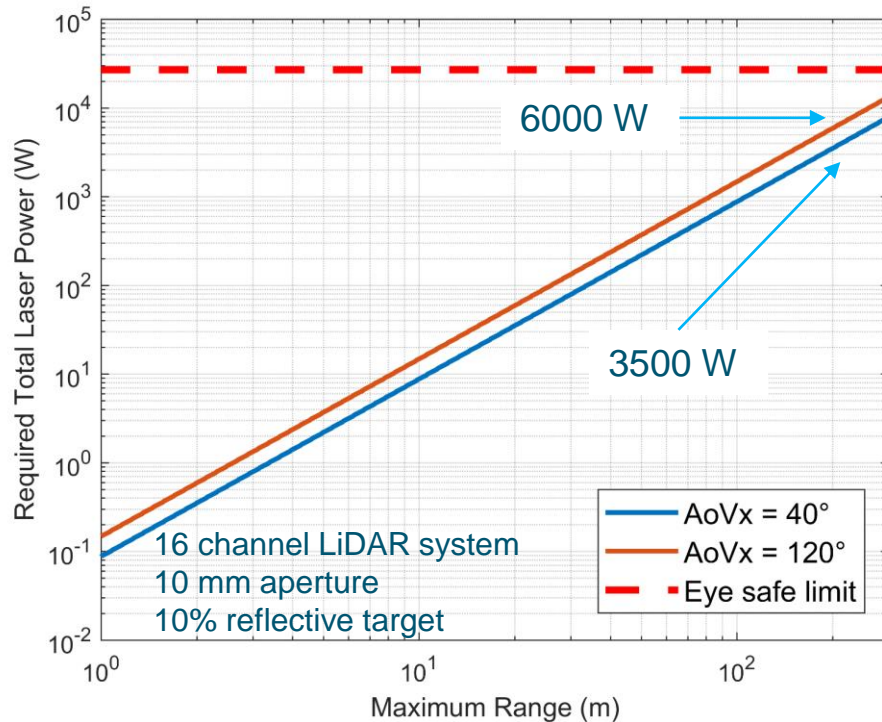
# LiDAR Design with SiPM

## Practical Solutions for Today's LiDAR Modules

- **Beam Steering**
  - 1D or 2D
    - Electromechanical or MEMS
- **Laser Diode**
  - High peak power (1000s W)
    - 905 nm commercially available
    - 940 nm solar minimum advantage
  - High pulse rep. rate (100s kHz)
  - Short pulse width (1ns or less)
- **Optics**
  - Small AoV per pixel
    - Optical bandpass filter (10 to 50 nm)
      - Driven by laser technology
    - Small aperture size
      - For optimal SNR and system size
- **SiPM Sensor or SiPM Array**
  - High responsivity @ 905 & 940 nm (100kA/W+)
  - High dynamic range
  - Highly uniform (+- 10% output)
  - Low voltage (<50V)



# How to Range >200m With SiPM Technology

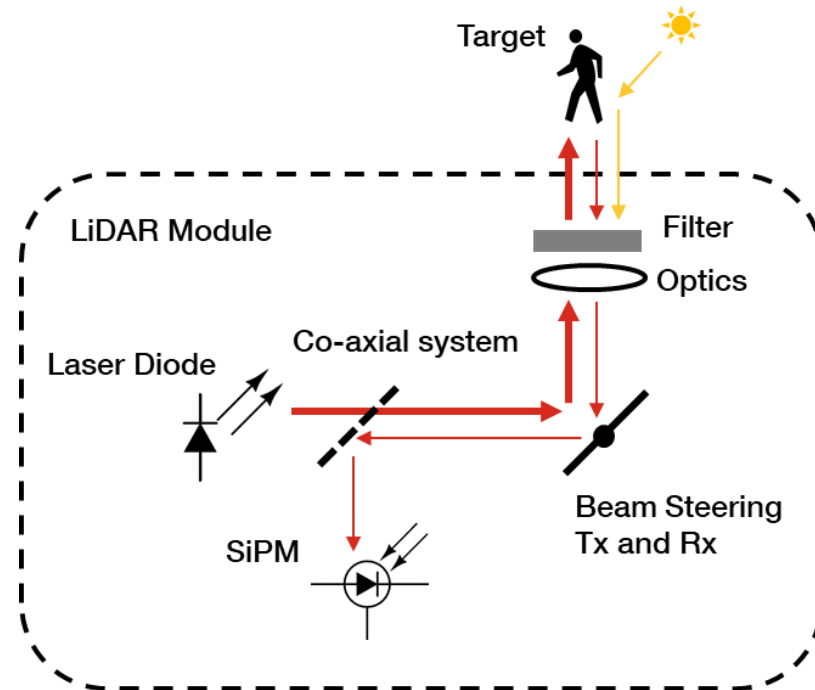


Multiple AoV LiDAR system

- Ranging Solution
  - 40° x 30° Long range
  - 120° x 30° Short range
- Sensor Specification
  - 1x16 SiPM
  - R-Series
- Resolution
  - AoVx = 0.1°
  - AoVy = 1.9°
- Laser Specification
  - 905 nm or 940 nm
  - 1ns laser pulse
  - 500 kHz repetition rate
  - Maintains eye-safety for both systems



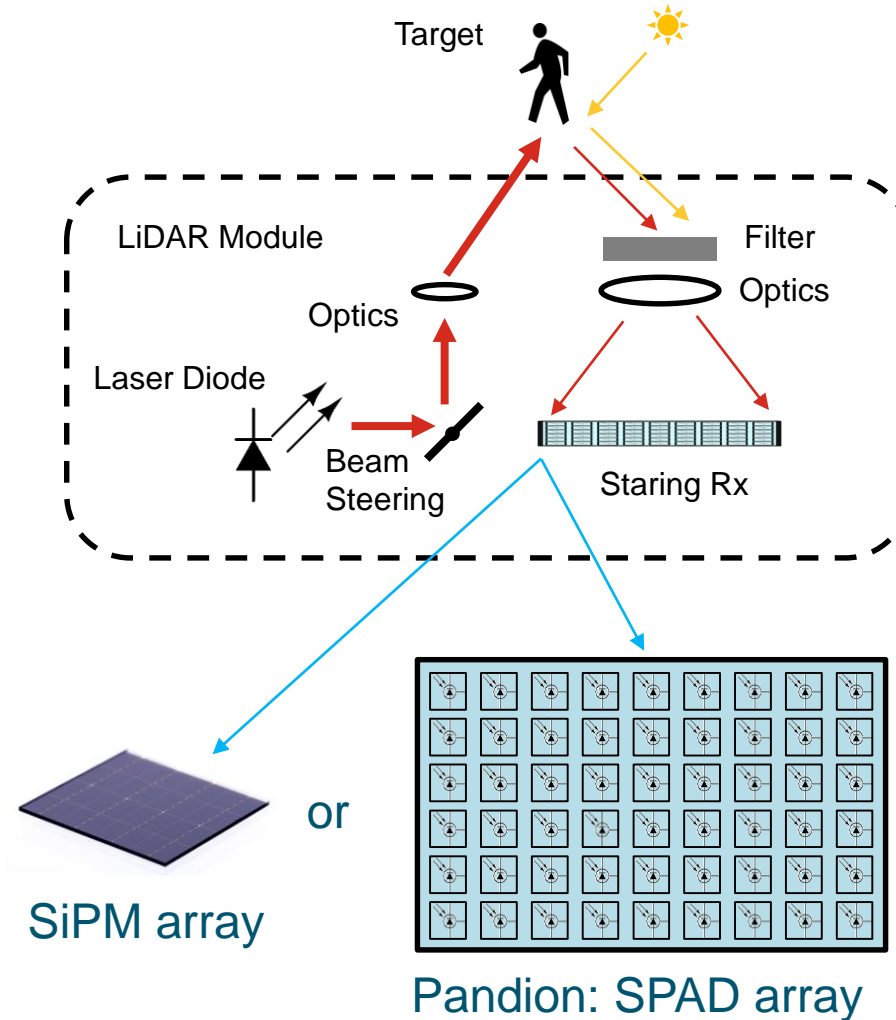
# Challenges with Today's LiDAR Systems?



1. Poor angular resolution in the y-direction
2. Steering the received light onto the sensor

# Future LiDAR Design with SPAD or SiPM Arrays

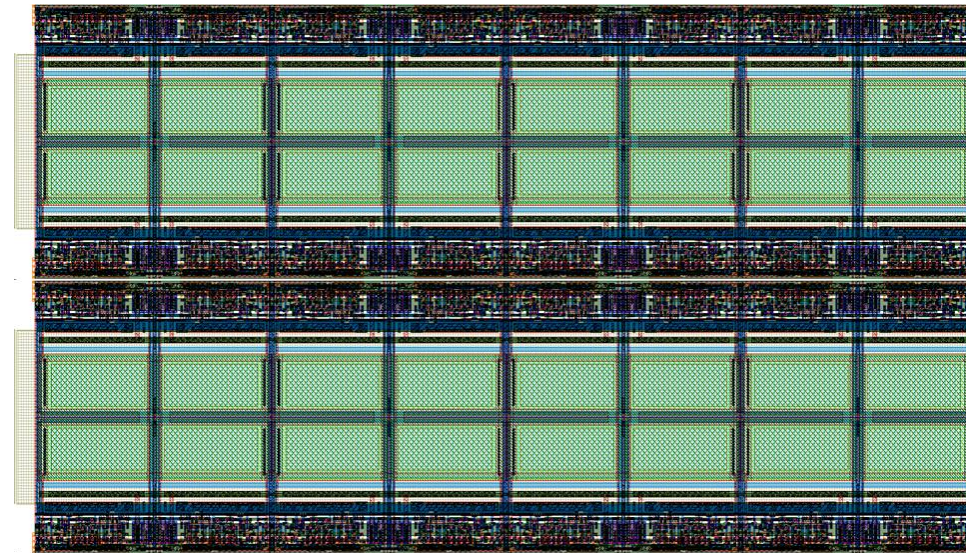
- Beam Steering
  - TX scanner
    - MEMS, optical phase array, other
  - Ultra compact LiDAR solution
    - No RX beam steering required
- Laser Diode
  - High peak power (1000s W)
  - High pulse rep. rate (100s kHz)
  - Short pulse width (1ns or less)
- Optics
  - TX can be miniaturized
  - RX optimized for SPAD or SiPM array
    - Small AoV per pixel



# SensL Pandion SPAD Array for Next Generation LiDAR System

- 400×100 SPAD array
- High dynamic range
- High raw data output rate
- Optimised for vertical line scanning
- 0.1° x-y angular resolution
- Suitable for >100m ranging at 10% reflectivity in full sunlight

Pandion  
pixels



...

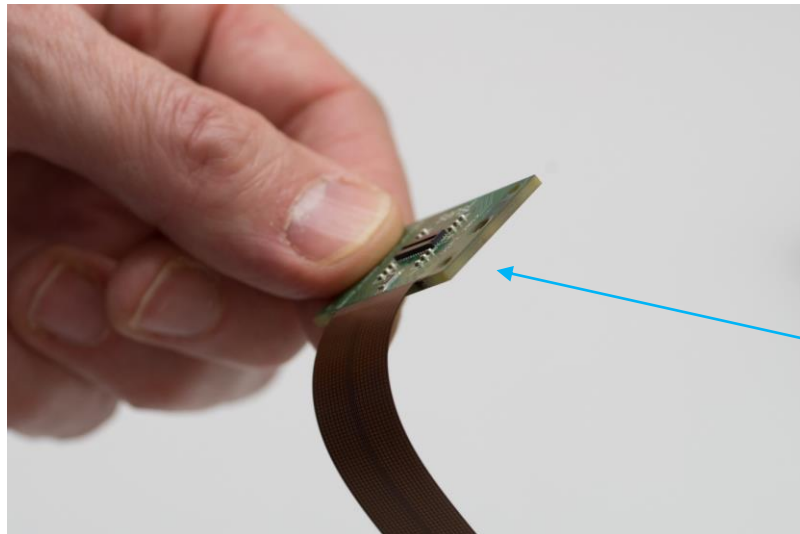
Sampling  
Q2 2019

# Gen 3 Imaging LiDAR Demonstrator

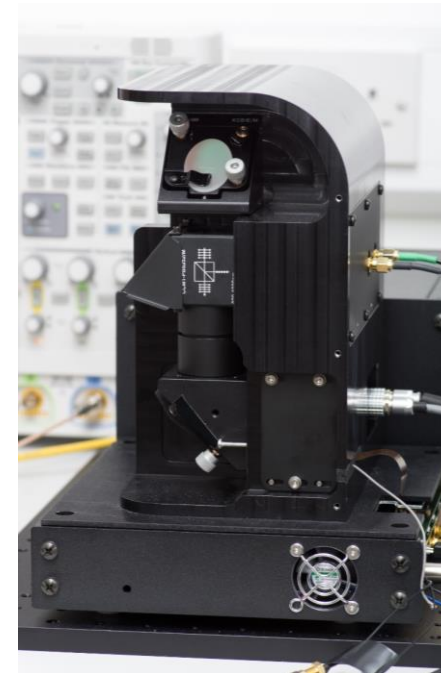
# Anatomy of the Gen 3 Imaging LiDAR System

Parameter	Value
AoV	80° x 5.53°
Pixel AoVx	0.1°
Pixel AoVy	0.325°
Aperture Rx	22 mm
Image Size	800 x 16 pixels
Data Rate	6 Mbits / s
Num. Laser Diodes	16
Pulse Width	1 ns
System Peak Power	400 W (Internal)
System Size	22cm x 18cm x 13cm

## Specifications Summary

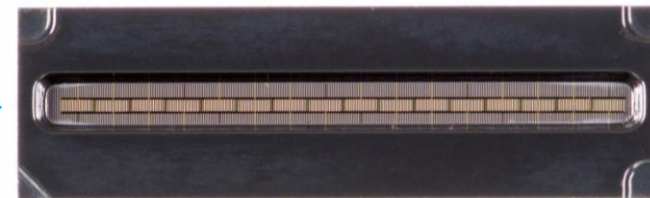


1x16 SiPM Array on flexible PCB



22 cm

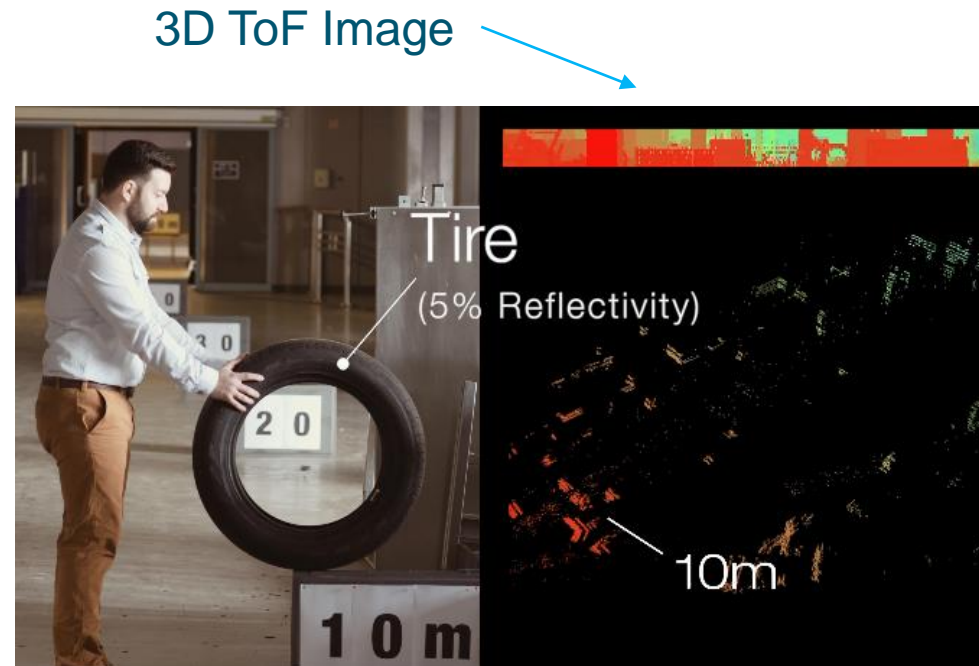
Gen 3 Scanning LiDAR



1x16 Monolithic SiPM Array

# 3D ToF Imaging LiDAR with SiPM Gen3 Demonstration Video

- Demo Objectives:
  - Demonstrate SiPM advantages
  - Long distance low reflective target ranging
  - Imaging
- 1x16 SiPM Array
  - Monolithic SiPM array
  - Compact Rx
- System overview
  - 80° x 5° AoV
  - 16 channels acquired simultaneously
  - Imaging and depth displayed simultaneously



CMOS Camera Image

Full Video Link

<https://www.youtube.com/watch?v=Lg2L7v5vb7M>



# Thank You

More information can be found at [www.sensl.com](http://www.sensl.com)

Contact us at [sales@sensl.com](mailto:sales@sensl.com)