The advantages of Avalanche Photodiode (APD) arrays in laser ranging applications

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Apache
Point
Observatory
Lunar
Laser-Ranging
Operation

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APOLLO Return Rates

$$\text{Link Efficiency, } \varepsilon = \eta^2 f Q \left(\frac{n d^2}{r^2 \Phi^2}\right)\left(\frac{D^2}{r^2 \phi^2}\right)$$

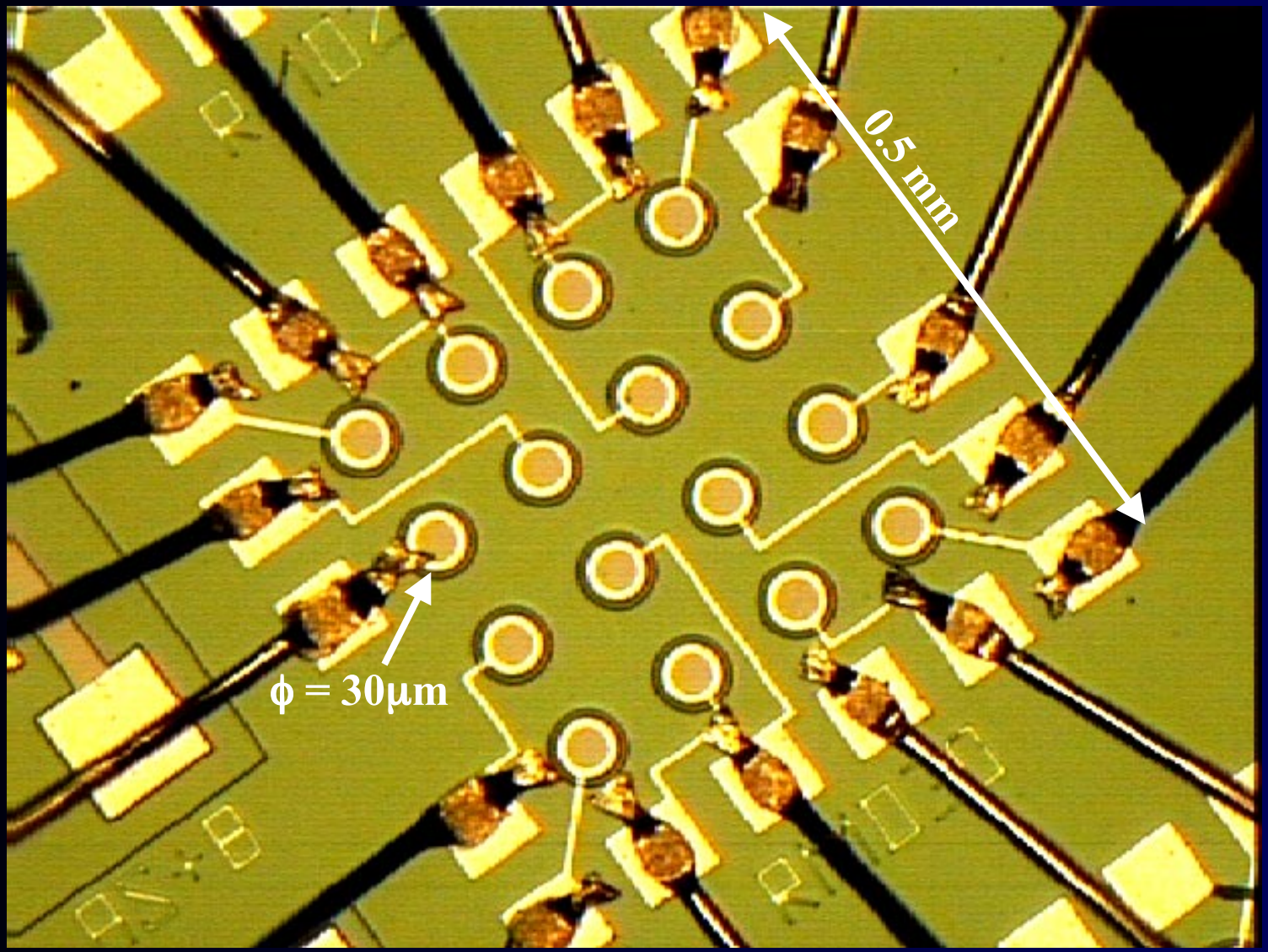
η = telescope/atmospheric efficiency
f = receiver throughput
Q = detector efficiency
n = number of corner cubes in array
d = diameter of corner cubes
r = distance to the moon
Φ = atmospheric divergence
D = diameter of telescope
ϕ = corner cube divergence

- With 1 arcsecond seeing, 40% telescope efficiency, 25% receiver efficiency, and 30% detector efficiency, the link efficiency is **1.7×10^{-17}**.
- A 115 mJ laser pulse at 532 nm contains **3.1×10^{17}** photons.

APOLLO should receive
5 – 10 photons per pulse

Complications of multiple photons

- Most detectors would only detect the first photon reliably
  - Would bias data to shorter times/ranges
- Need a way to time-tag each individual return photon or determine the centroid of the return pulse
  - Fibers or beam splitters to individual detectors
  - ???



-Courtesy of Lincoln Labs

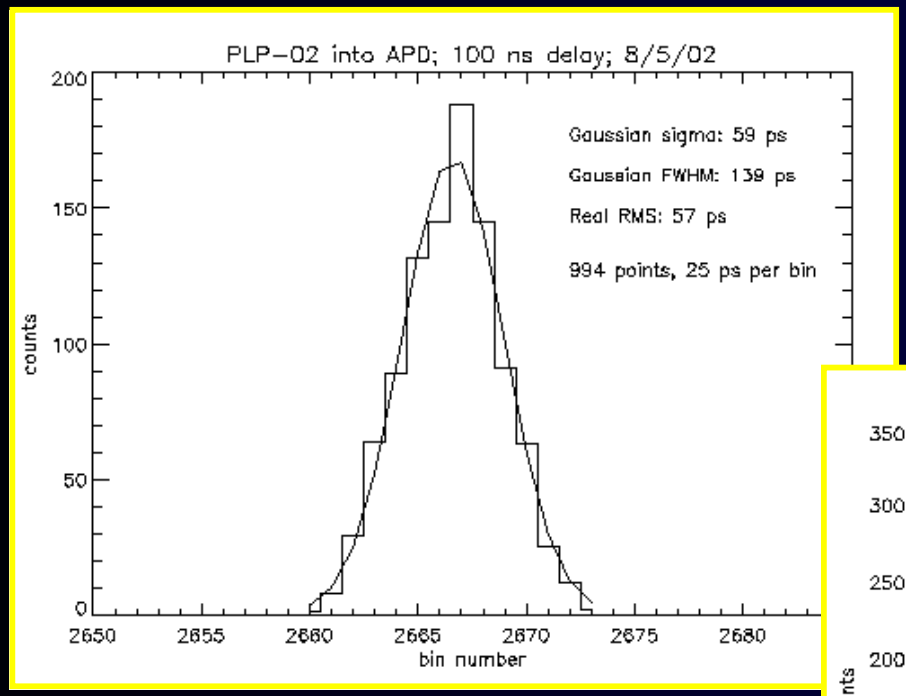
Lincoln Labs
APD array characteristics

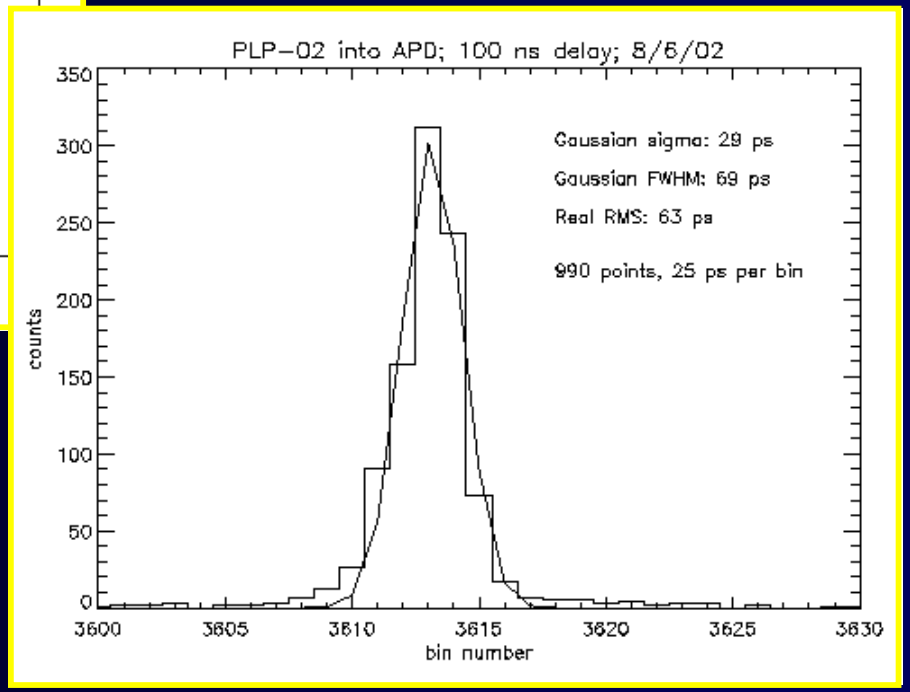
Element Spacing	100 μm
Active Diameters	20, 30, 40 μm
Device Thickness	~ 20 μm
Formats Produced	4 × 4 and 32 × 32
Breakdown Voltage	~ 25 V
Photon Detection Efficiency	30% (> 50% with AR coating)
Dark Count Rate	~ $2400e^{0.106T}$ s^{-1}, T in °C
Effective Resistance	25 kΩ
Effective Capacitance	< 2 pF

Lincoln Lab APD arrays

- Oversample the return pulses
  - Less than one photon detected per given element
- Involve low bias voltages and relatively simple readout electronics
- Demonstrate very high time precision of 30 ps RMS

Timing Results

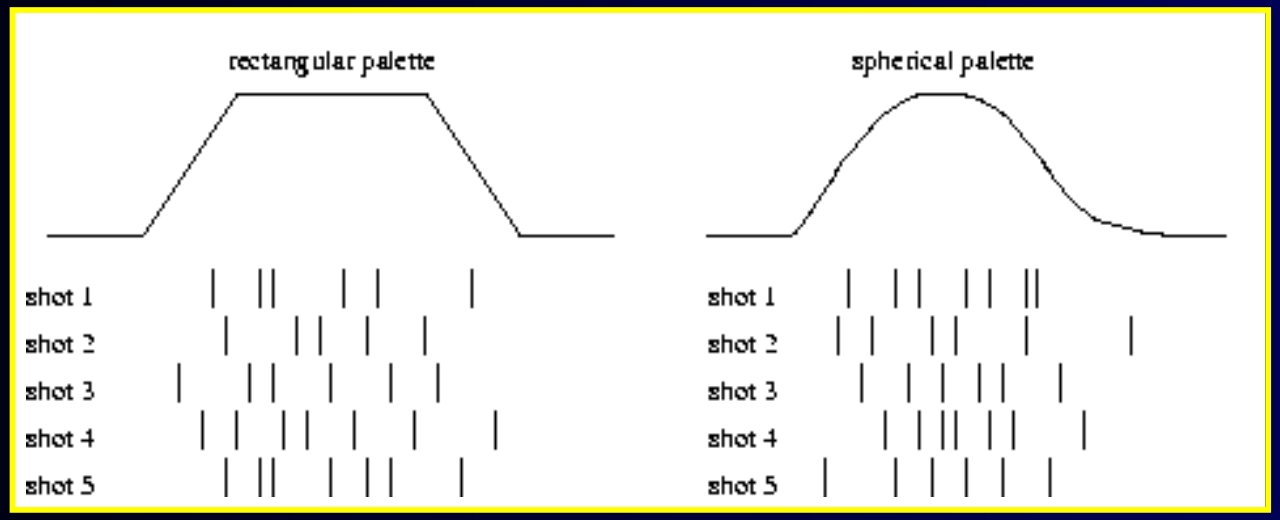




Advantages of oversampled APD arrays

- Can detect multiple return photons per pulse
  - Creates a range profile with each shot

Range Profile

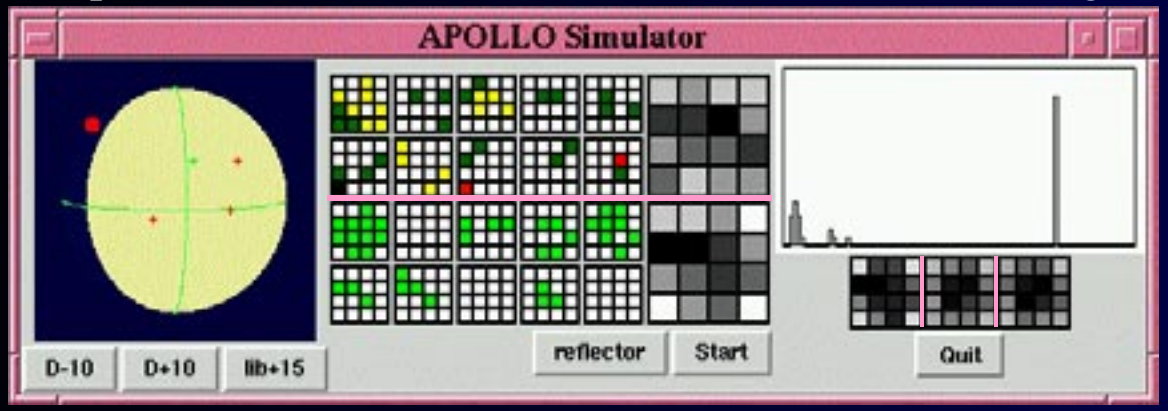


- Can improve centroiding by more than $\sqrt{N}$ if the general shape of the profile is known

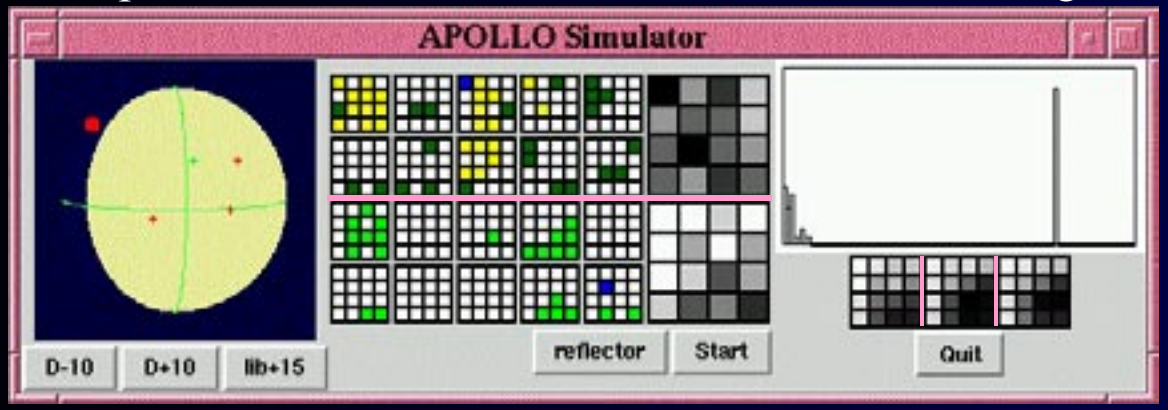
Advantages of oversampled APD arrays

- Can detect multiple return photons per pulse
  - Creates a range profile with each shot
- Spatial information is preserved
  - Facilitates closed-loop tracking and acquisition
  - Permits the evaluation of systematic errors such as beam focus and transmit/receive co-alignment based on the 2D footprint
  - Allows for the imaging of standard stars to monitor long-term throughput

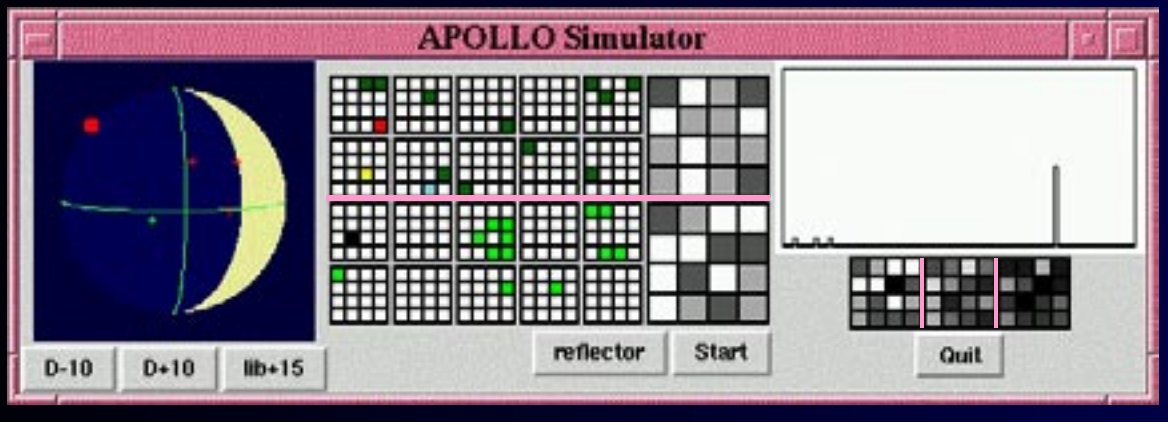
Apollo 15 with centered return and 1 arcsecond seeing



Apollo 15 with offset return and 1 arcsecond seeing



Apollo 14 with centered return and 1.5 arcsecond seeing



Legend

- Calibration return
- Box scatter
- Optics scatter
- Lunar background
- Dark count
- Twilight background
- Lunar return

Summary

- APD arrays have high timing resolution of at least 30 ps RMS
- Array format …
  - Allows for detection of multiple photons
    - Creates a range profile with each shot
  - Preserves spatial information
    - Facilitates closed-loop tracking and acquisition
    - Permits the evaluation of systematic errors based on 2D footprint