Utilizing Switched Capacitors in a SPAD-Based Pixel for dToF
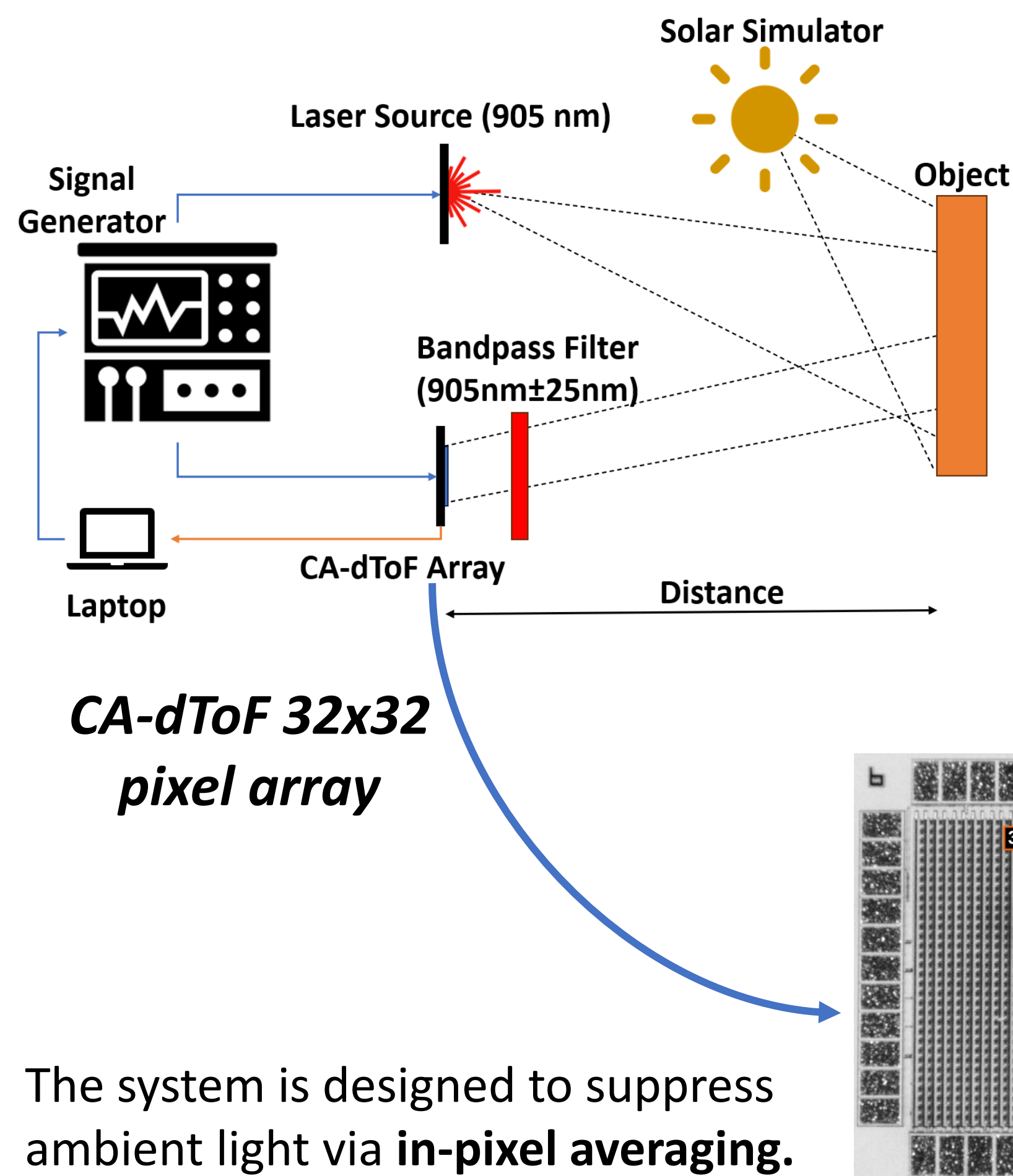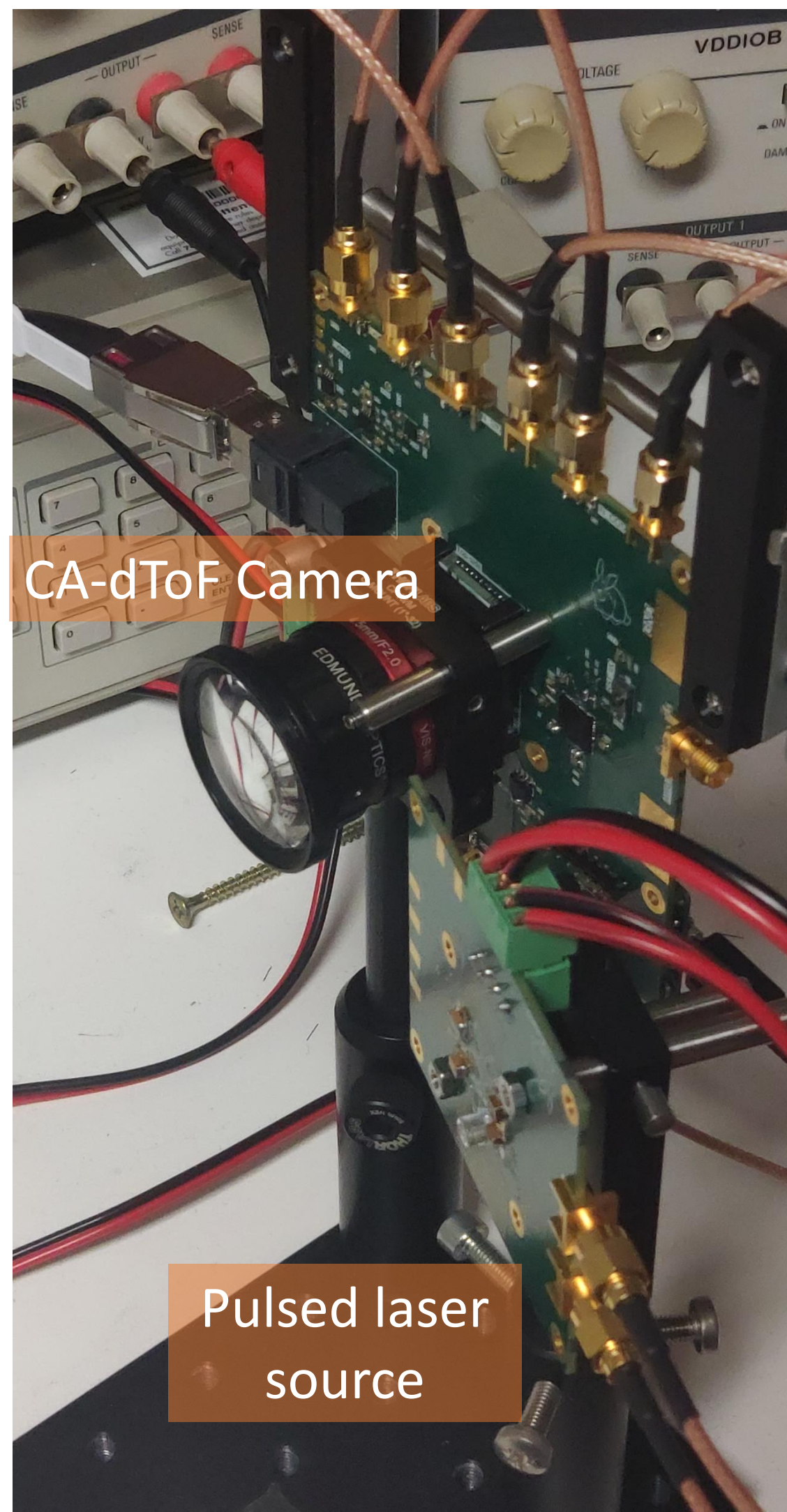
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The goal is a proof of concept for our SPAD-based dToF camera to suppress ambient light in a pixel.

CA-dToF Camera

Pulsed laser source

CA-dToF 32x32 pixel array

The system is designed to suppress ambient light via **in-pixel averaging.**

Pixel operation:

1) A laser pulse is synchronized with sinusoidal signals.

2) When a SPAD is triggered, a non-overlapping signal is generated.

3) Sinusoidal voltages "at the time of arrival" are captured and averaged via SC1 and SC2.

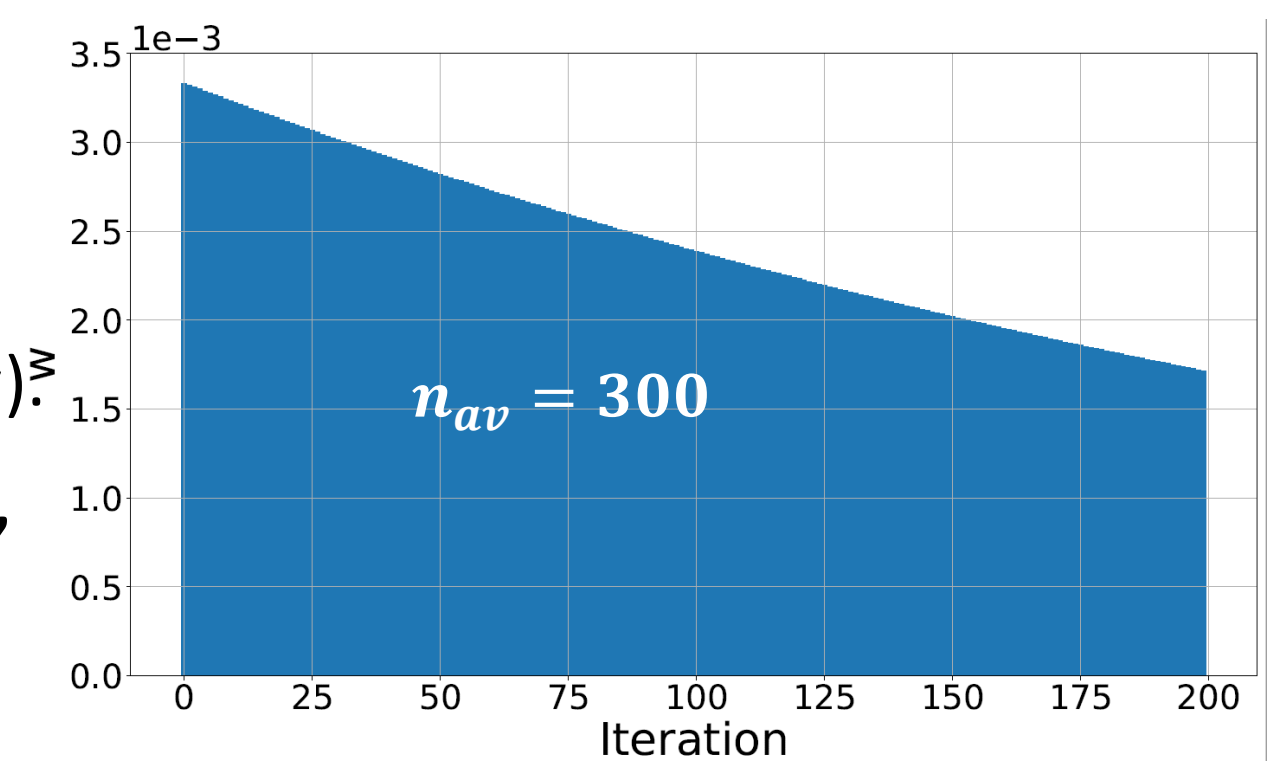4) Accumulated voltages evolve via the equation:

$$V_{out}[i+1] = \frac{V_{in}}{n_{av}} + \left(1 - \frac{1}{n_{av}}\right) V_{out}[i]$$

$$n_{av} \approx \frac{C_2}{C_1} \approx \frac{C_4}{C_3} \qquad C_1, C_3 \ll C_2, C_4$$
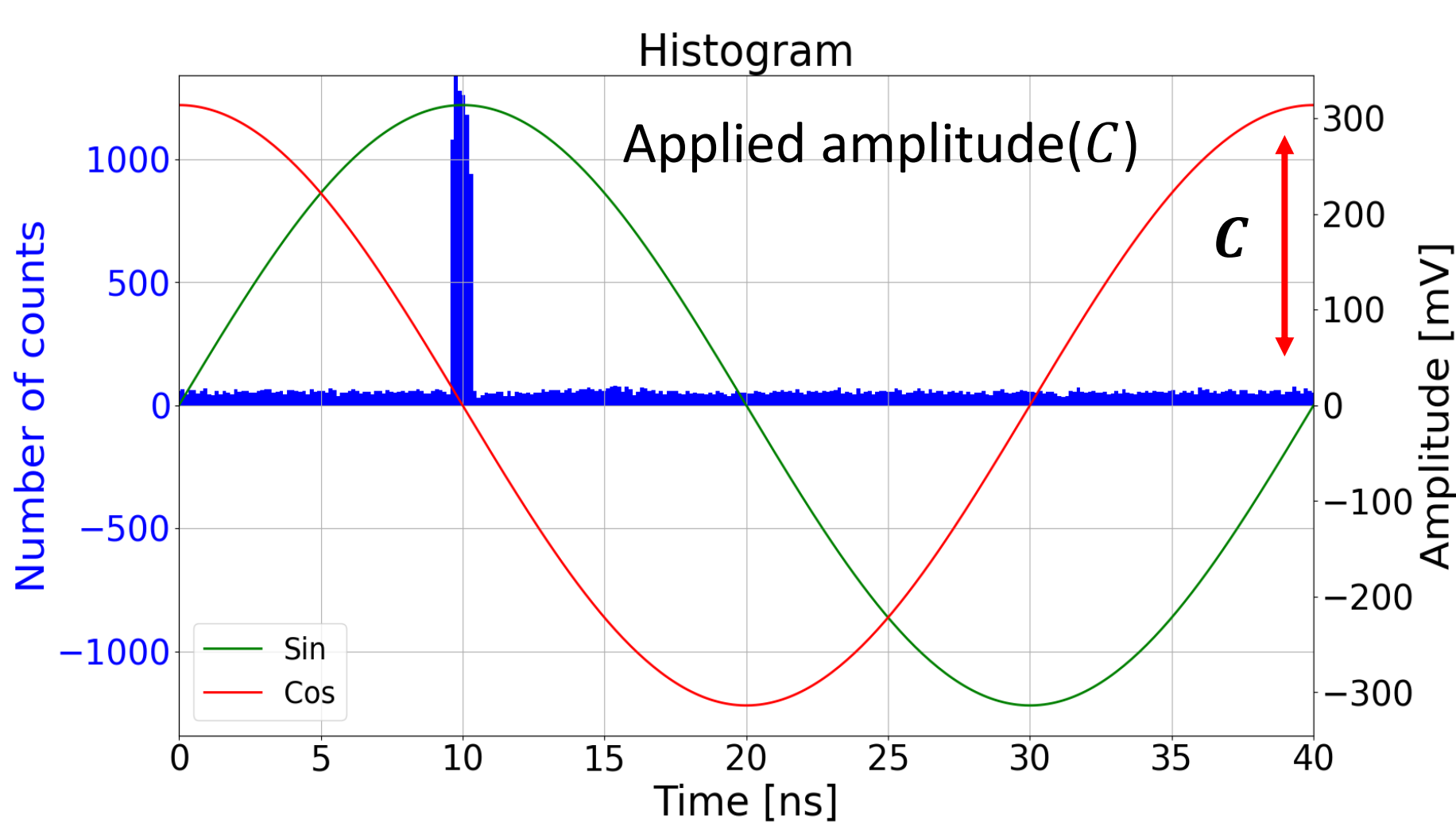
Pixel schematic
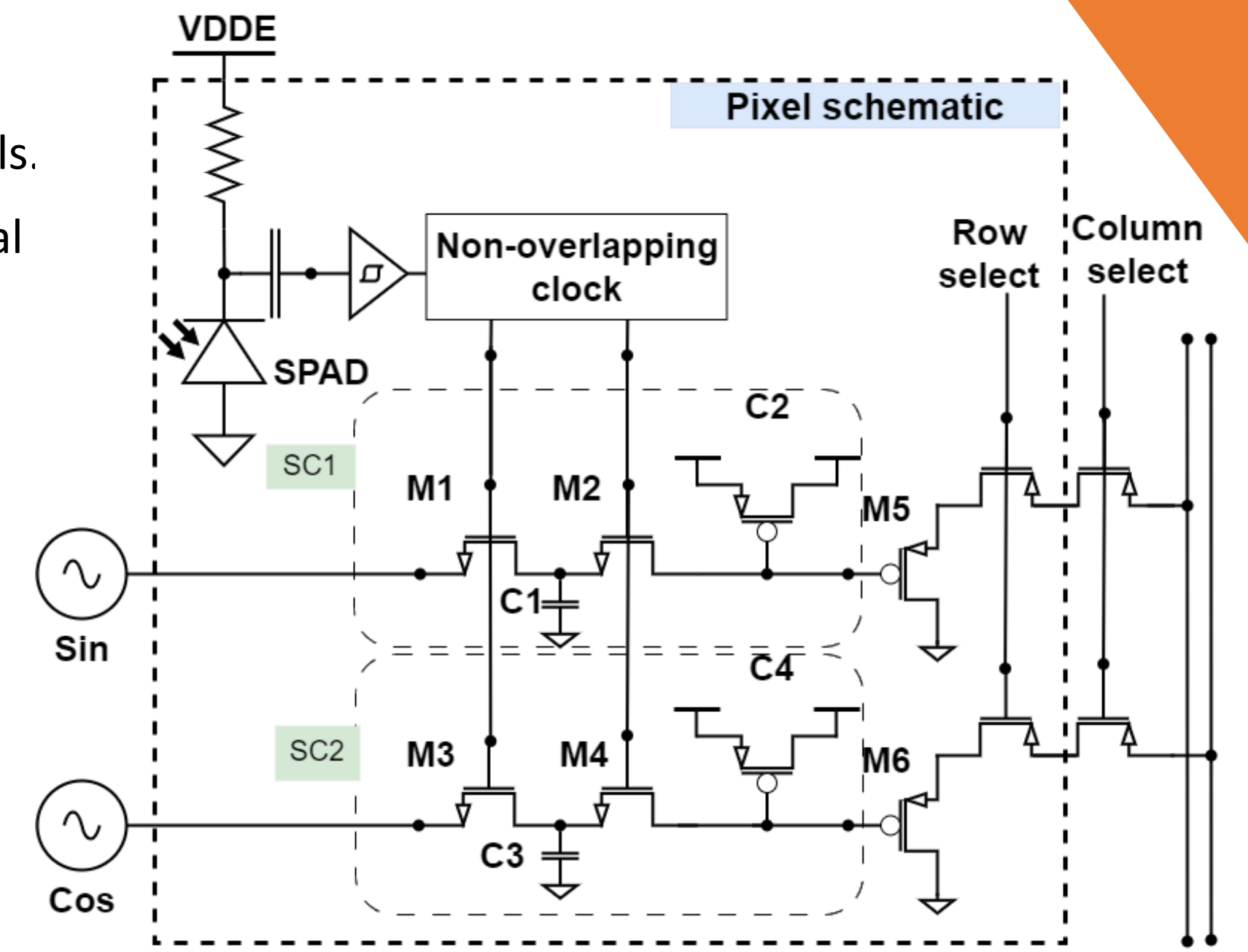
Exponential Weighted Moving Averaging (EWMA):
Every measurement has a weight (w).

For a large integration length (n_{av}), the weight reduction is negligible.

$n_{av} = 300$

For a large (n_{av}), every new V_{in} is linearly averaged with pervious $V_{out}[i]$.

Working Principle
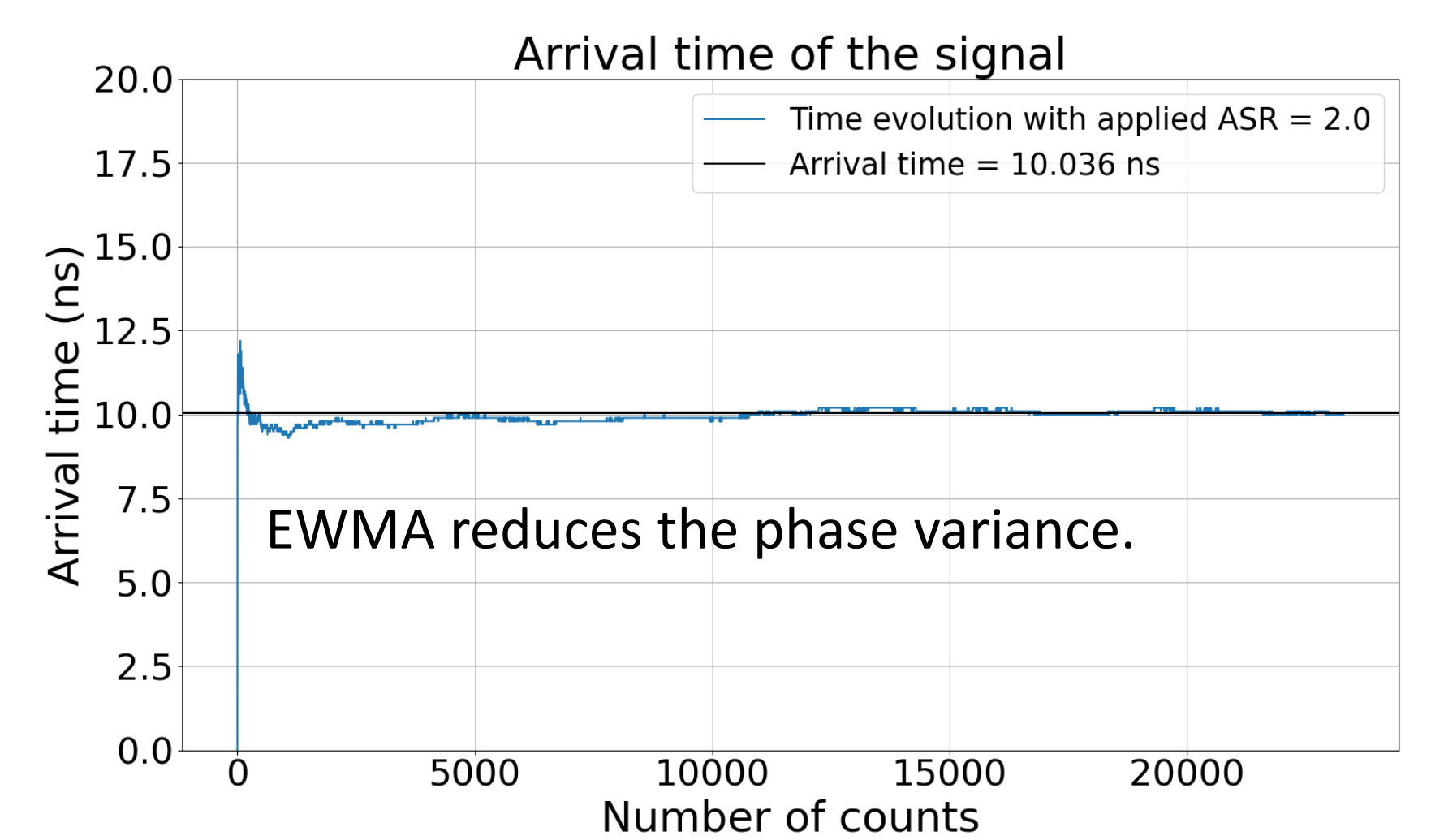
1. Laser arrival time histogram

Applied amplitude(C)

C

Ambient-to-signal ratio (ASR) = 2

2. Sin/Cos evolution

Sin and Cos accumulated signal

Ambient light averaging

At equilibrium, confidence $(\hat{C})$

$n_{av} = 4000$

$\hat{C} = \sqrt{I(t)^2 + Q(t)^2}$

Ambient light averaging

$I(t)$

$Q(t)$
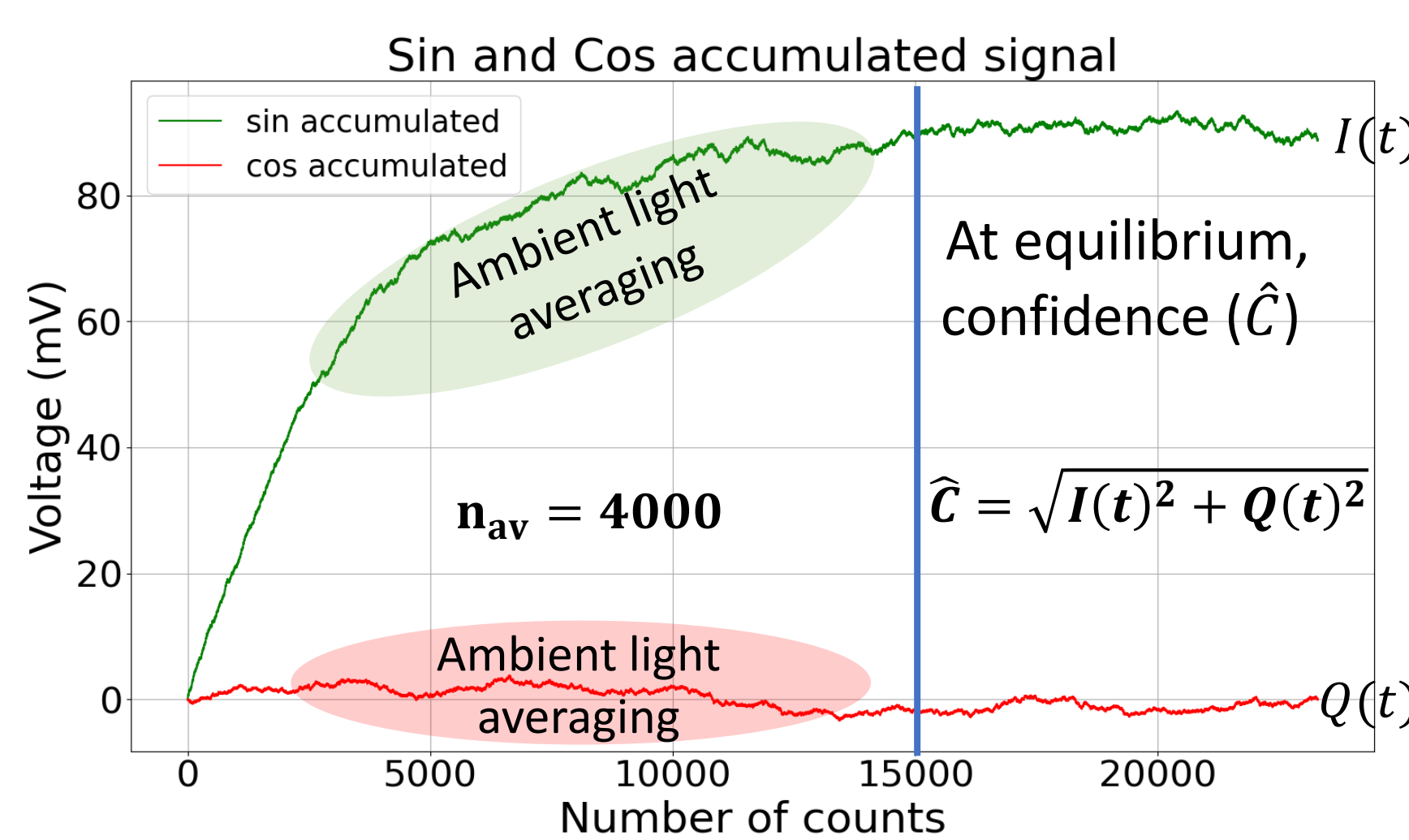
3. Arrival time calculated

Arrival time of the signal

Time evolution with applied ASR = 2.0
Arrival time = 10.036 ns

EWMA reduces the phase variance.

Properties

1) At equilibrium, the higher ASR, the lower the confidence.

ASR

$$\hat{C} \approx \frac{C}{1 + ASR}$$
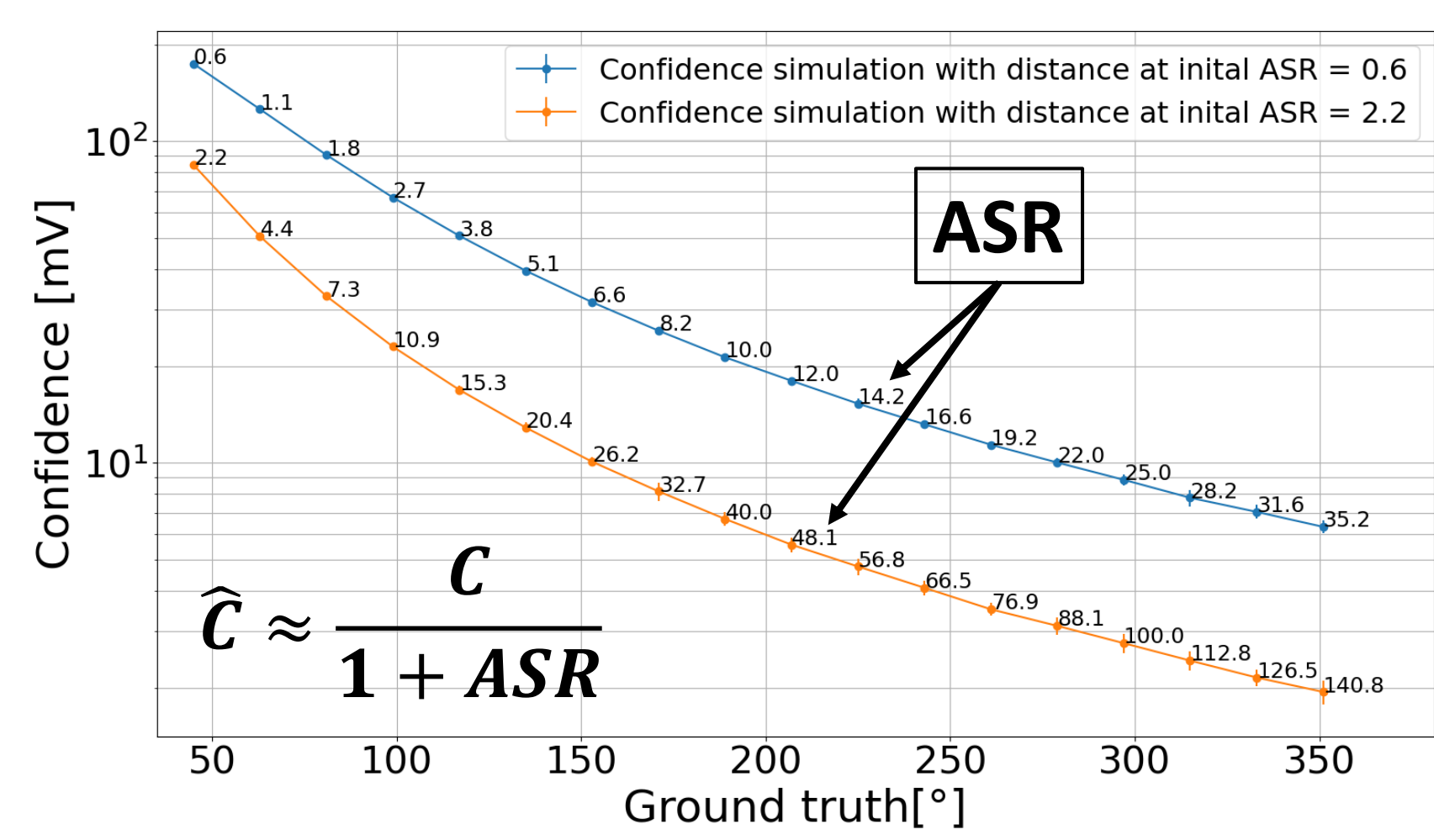
2) Phase accuracy is minimally influenced by ASR. Phase variance, however, is suppressed via (n_{av})

$n_{av} = 10^6$
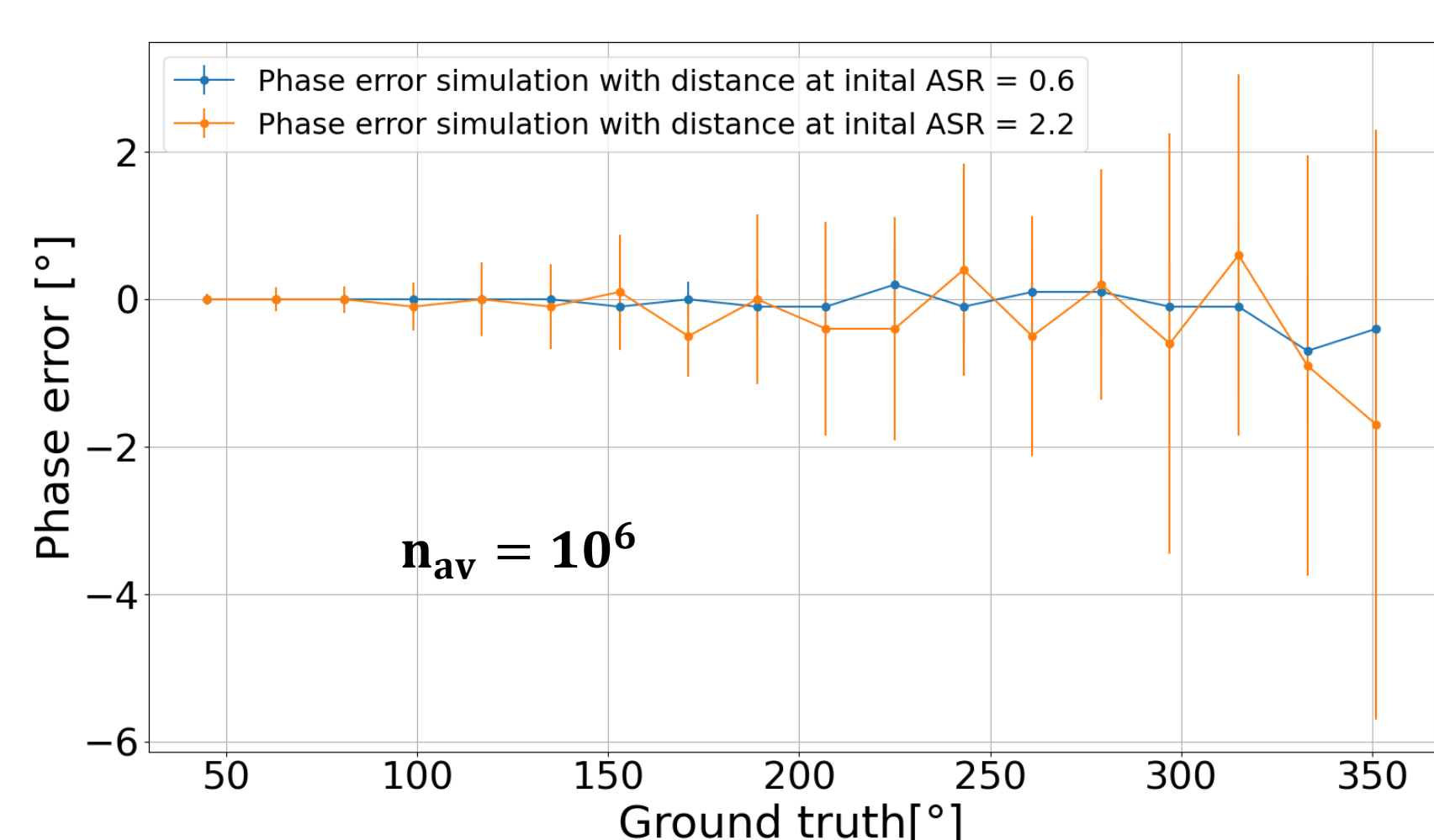
Measurement

For a fixed ASR (Fixed distance of detection)

Fixed distance from an object, No ambient light
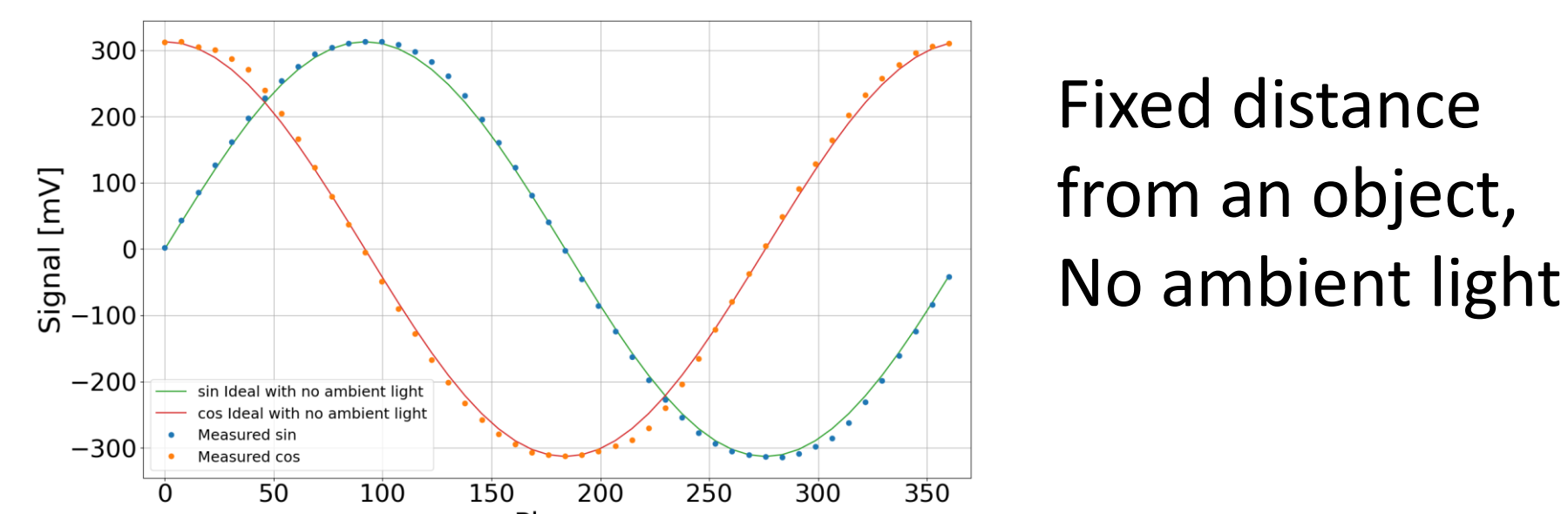
Applying Solar emulator to the system (ASR = 41,1)

$n_{av} \approx 300 \cdot 1024 \approx 307 \cdot 10^3$

Measuring five frames
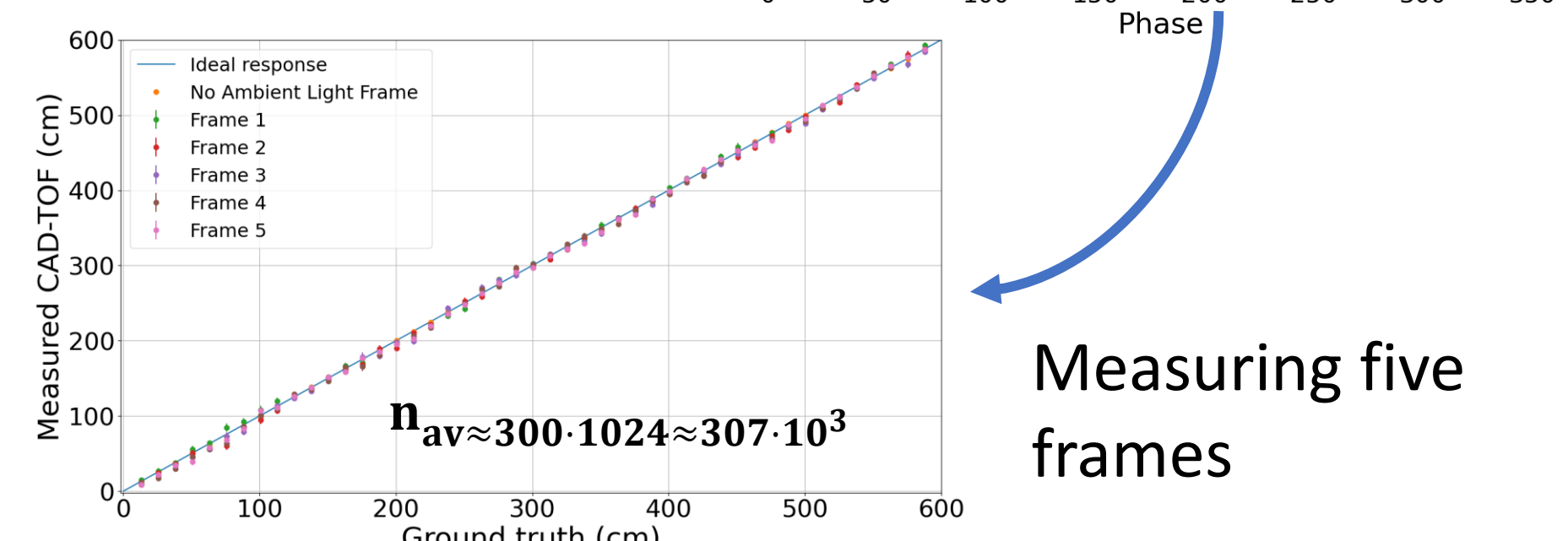
Max accuracy error 3,3% over 6 m range with precision of 0,7%.
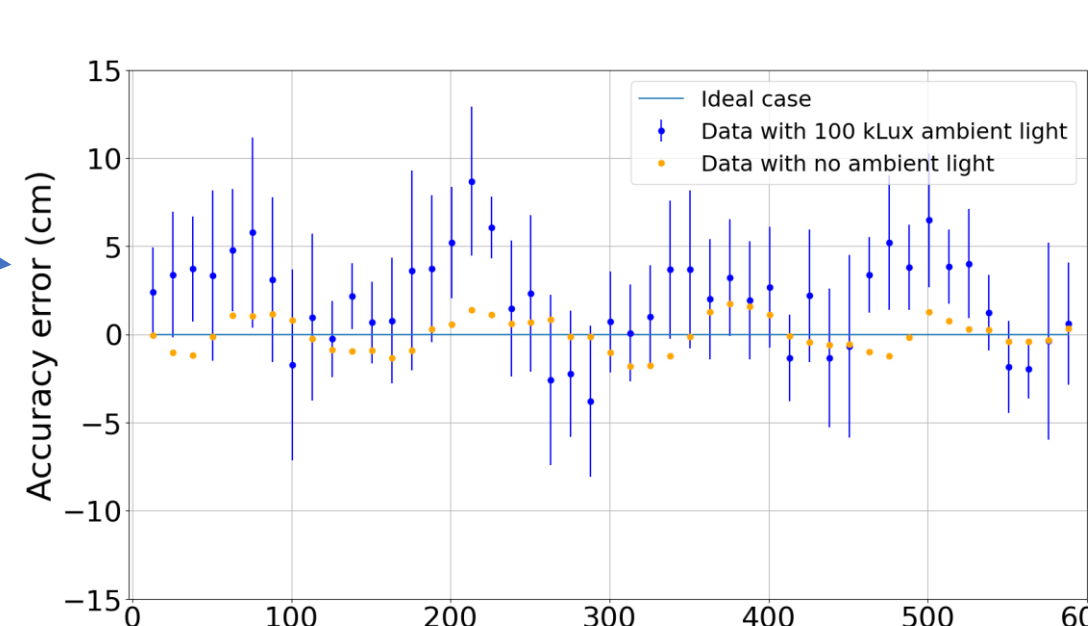
Conclusion and discussion
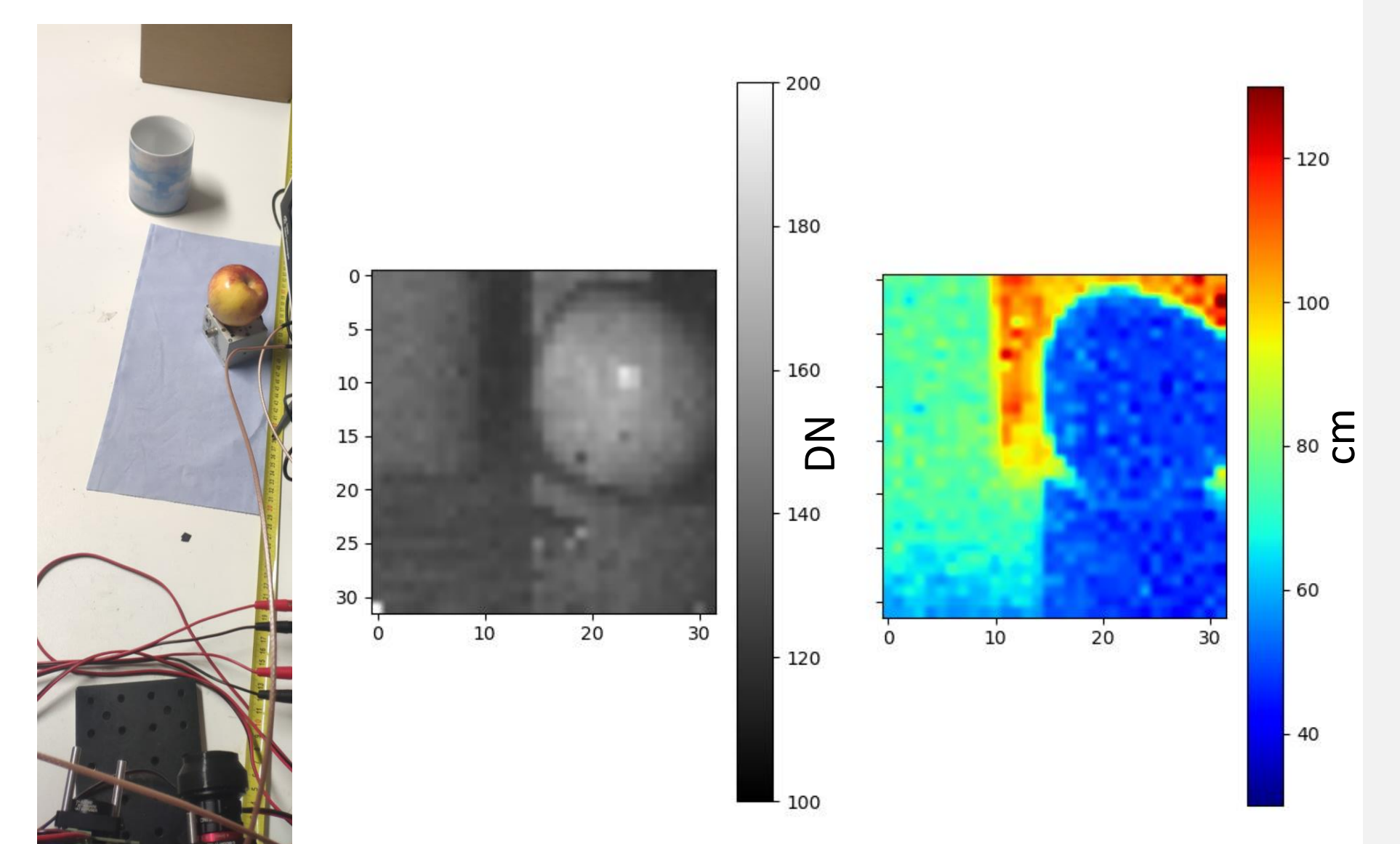
1. The proposed CA-dToF pixel can suppress ambient light with an in-pixel averaging.

2. CA-dToF pixel operation showed consistent results with the statistical simulation.

3. Pixel average power consumption was around 40 μW, including the SPAD average power.

Upcoming work:

The pixel is challenged by:

- leakage current for smaller technologies,
- SPAD deadtime, • and multi-path reflections.

We are in the process of publishing possible techniques to overcome those challenges.

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