PHOTONICS RESEARCH GROUP

OPTIMIZATION OF MULTI-BEAM SILICON PHOTONICS BASED LASER DOPPLER VIBROMETRY FOR MEASURING CARDIOVASCULAR SIGNALS ON BARE SKIN

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InSiDe

CARDIOVASCULAR DISEASE (CVD): THE BIGGEST KILLER

17.9 million (2016)
people die each year

from CVDs, an estimated 31% of all deaths worldwide.

World Health Organization

Easy-to-use screening tools are needed for early detection of CVDs

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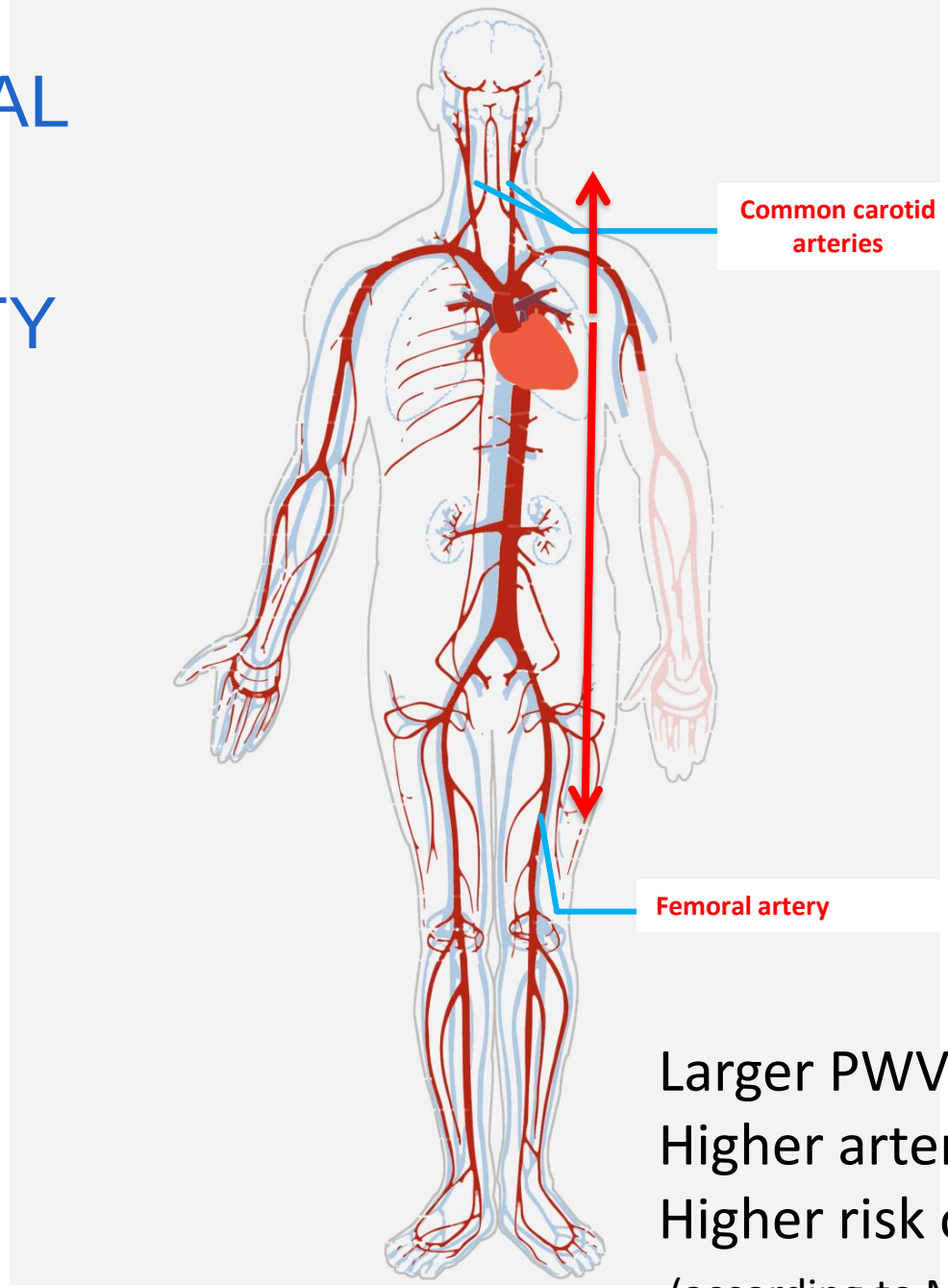
Marker for arterial stiffness: Pulse wave velocity (PWV)

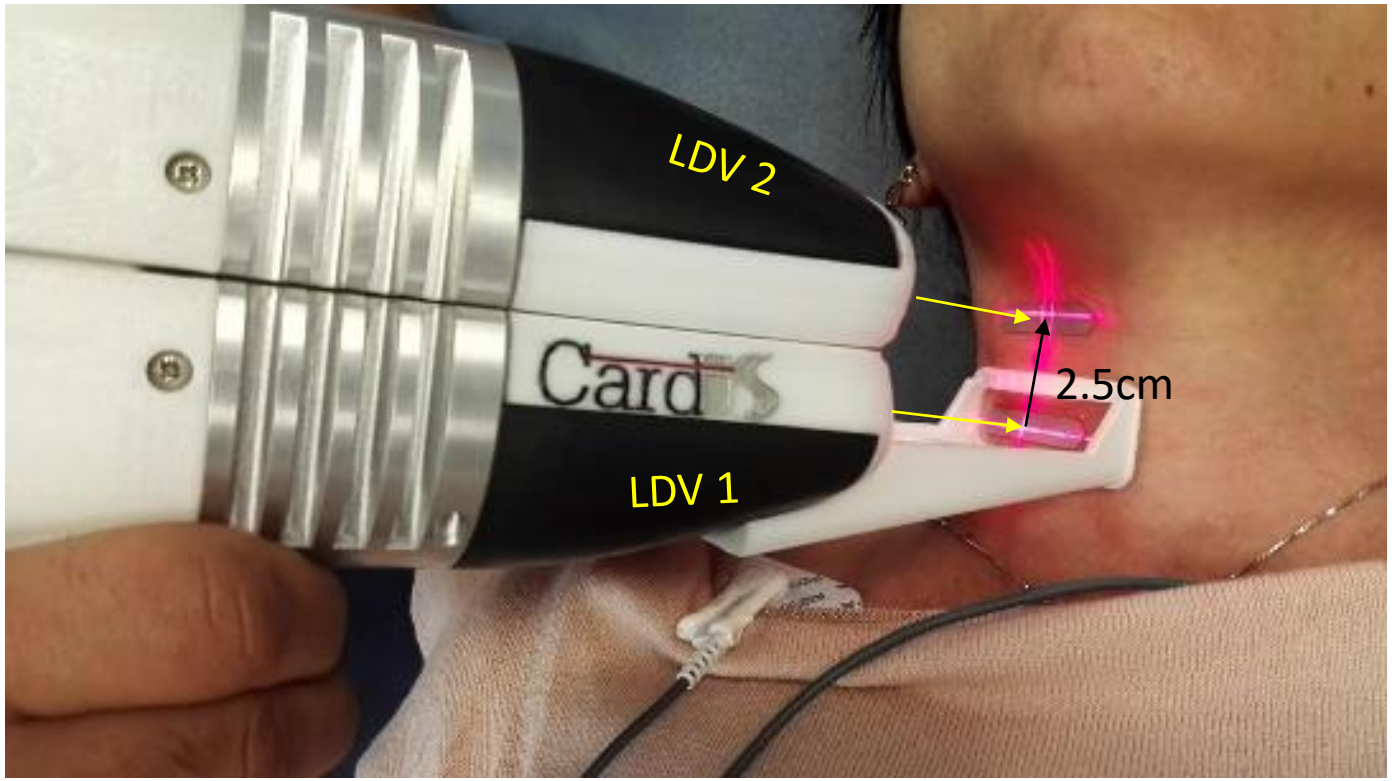
$$PWV = \frac{travel\ distance}{travel\ time}$$



Larger PWV ->
Higher arterial stiffness ->
Higher risk of cardiovascular events

(according to Moens–Korteweg equation)

CARDIS: HAND-HELD SENSOR FOR PWV MEASUREMENT



Use on-chip Laser Doppler Vibrometry (LDV) array

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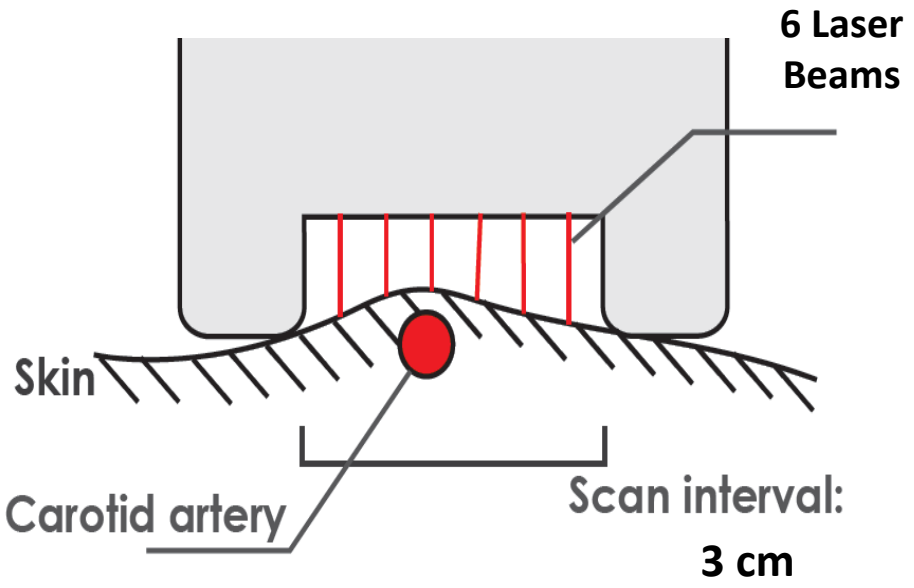
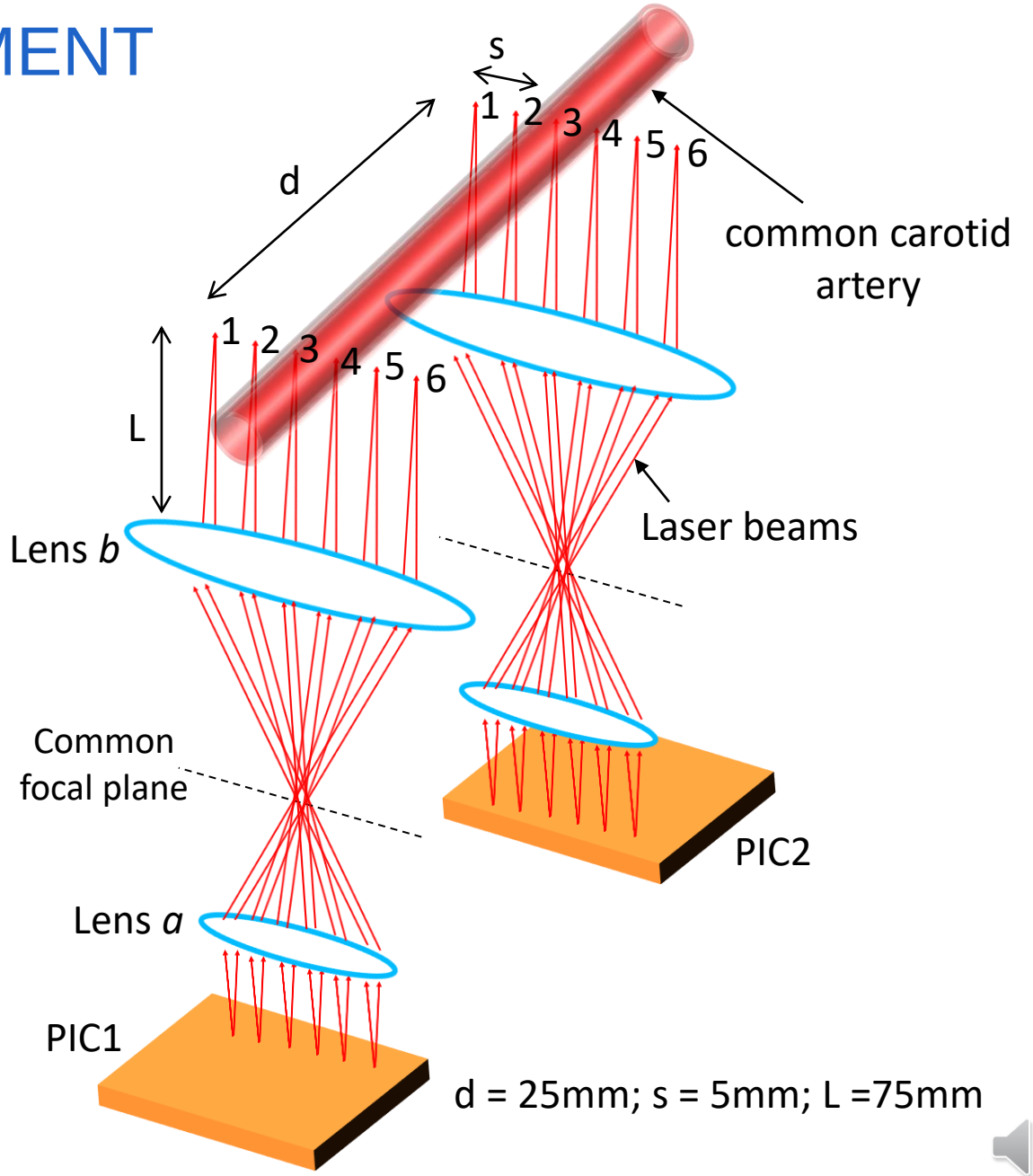
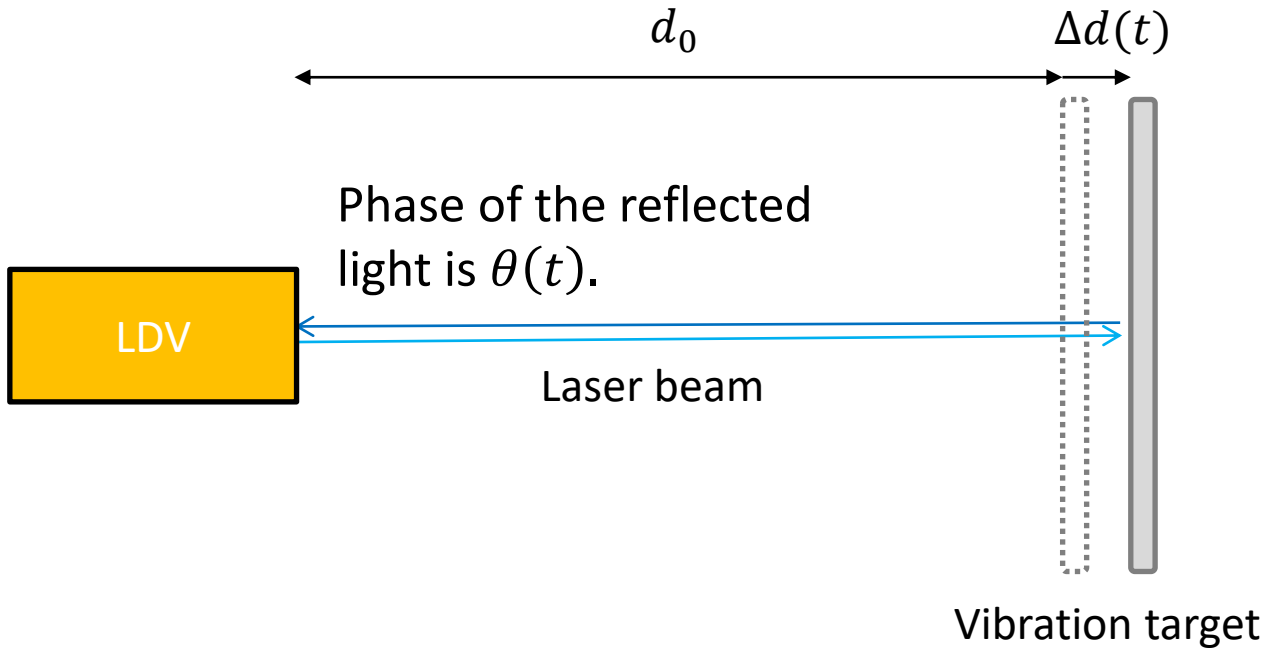
MULTIPLE LDVS: EASY ALIGNMENT





- To make the alignment easier, we use 2x6 beams instead of 2 beams.
- Thanks to the compact size of silicon photonic chips, the integration of 2x6 LDVs is possible.

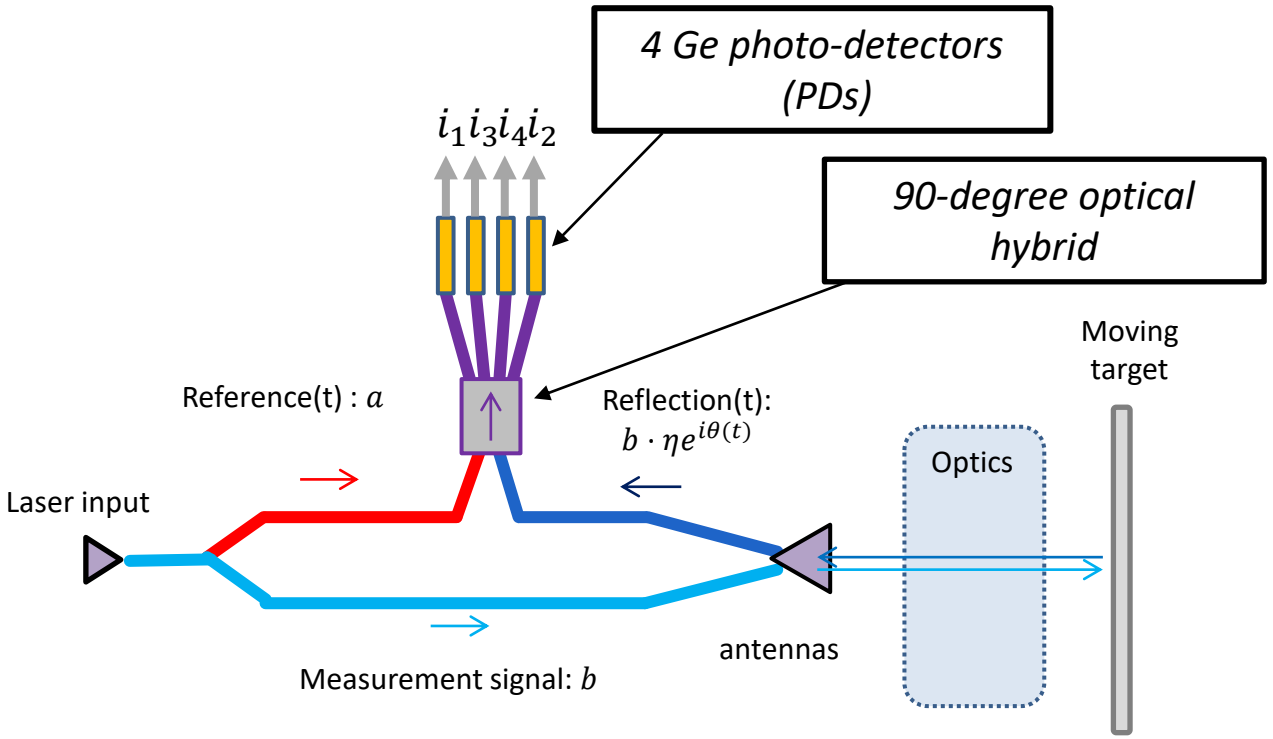
What is a Laser Doppler vibrometer

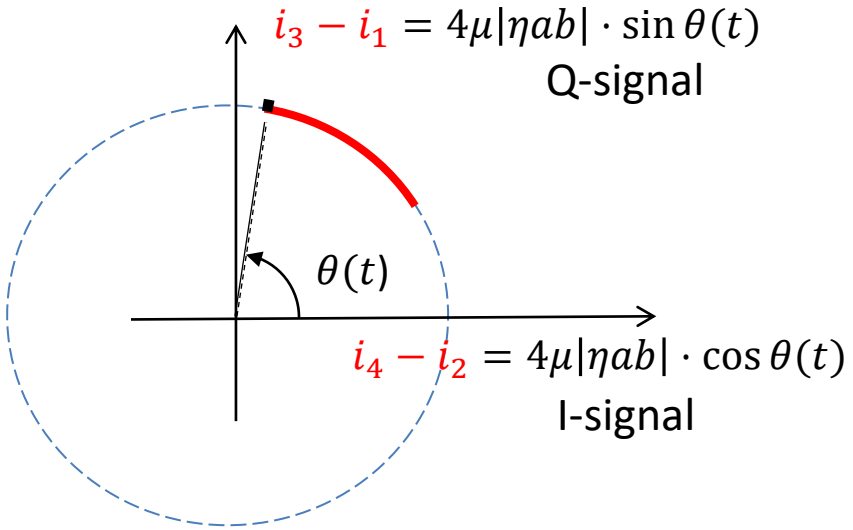


The displacement $\Delta d(t)$ can be retrieved by measuring $\theta(t)$, based on the relation

$$\theta(t) = \frac{2\pi}{\lambda_0} \cdot 2\Delta d(t) + \text{const.}$$

LDV SYSTEM: WORKING PRINCIPLE





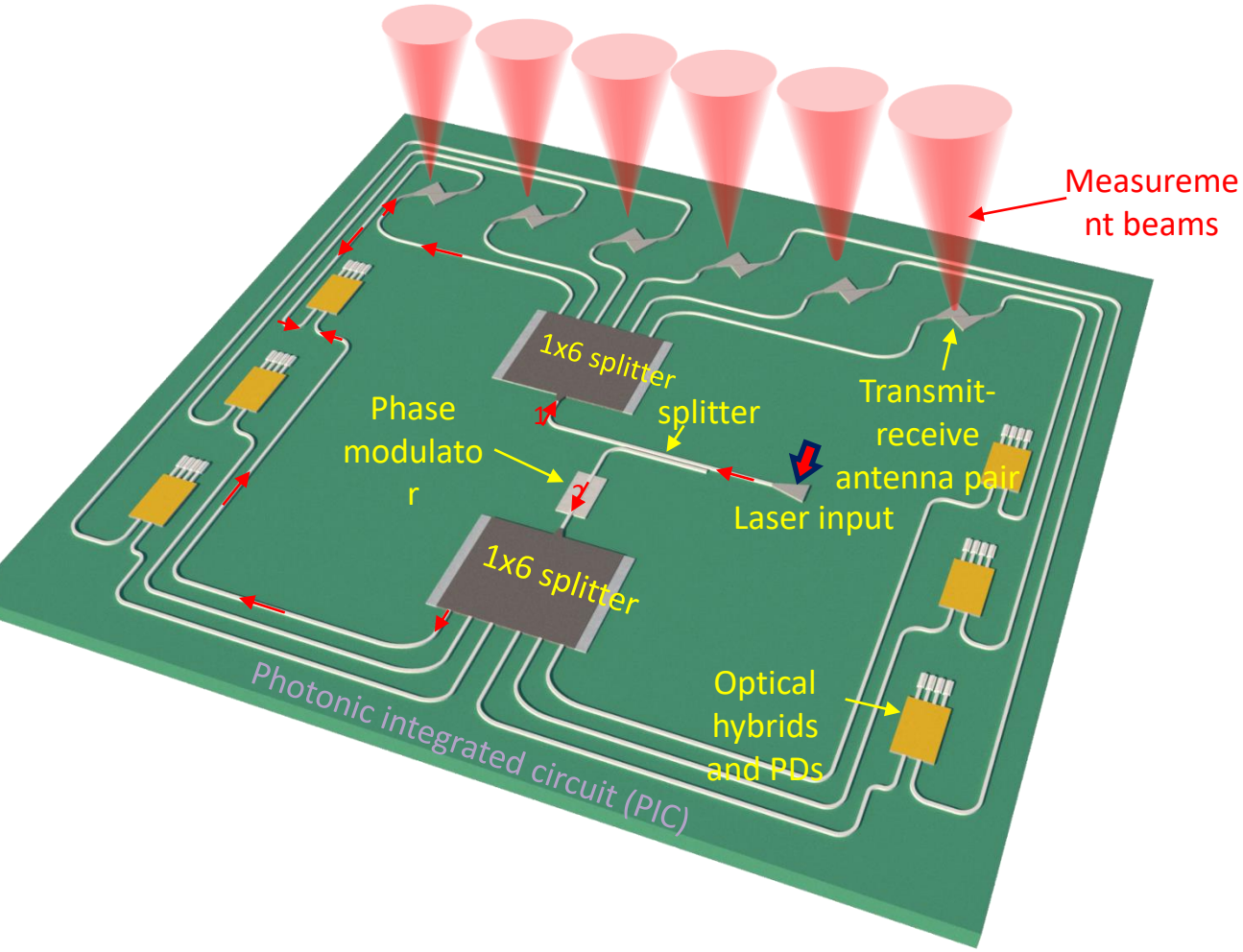
IQ curve (Lissajous curve)

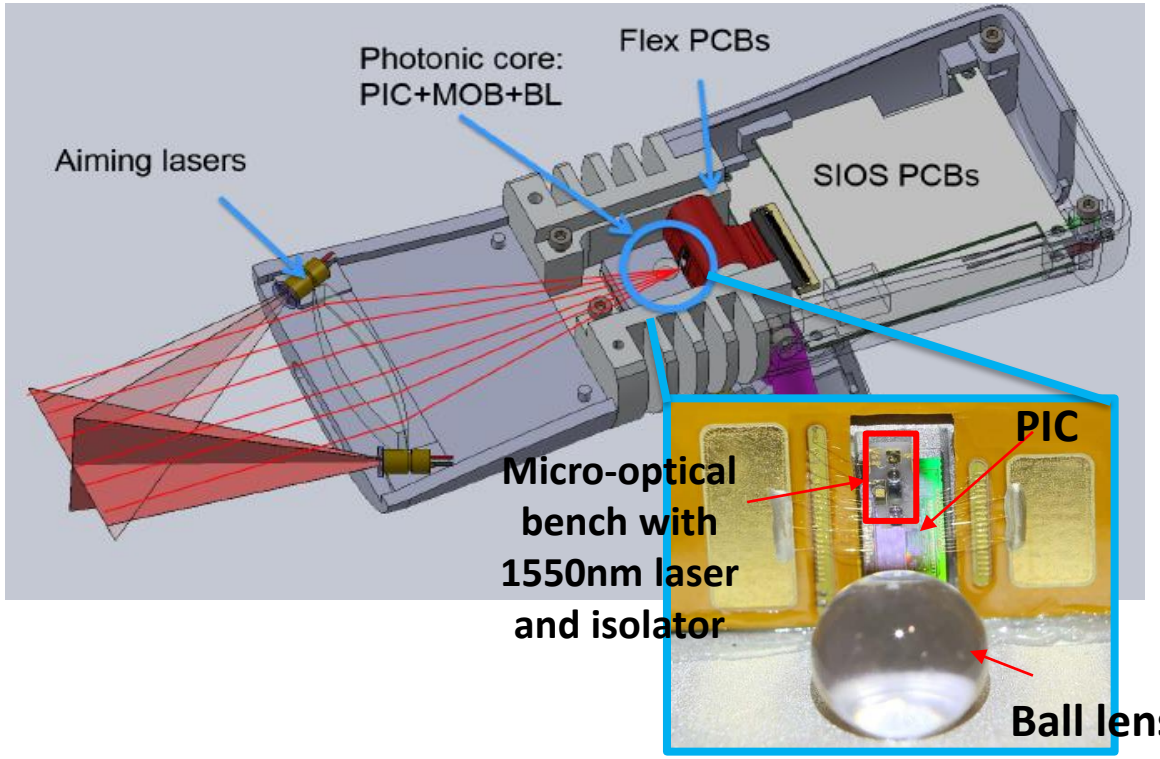
Demodulation method:

$$\theta(t) = \arctan\left(\frac{i_3 - i_1}{i_4 - i_2}\right)$$

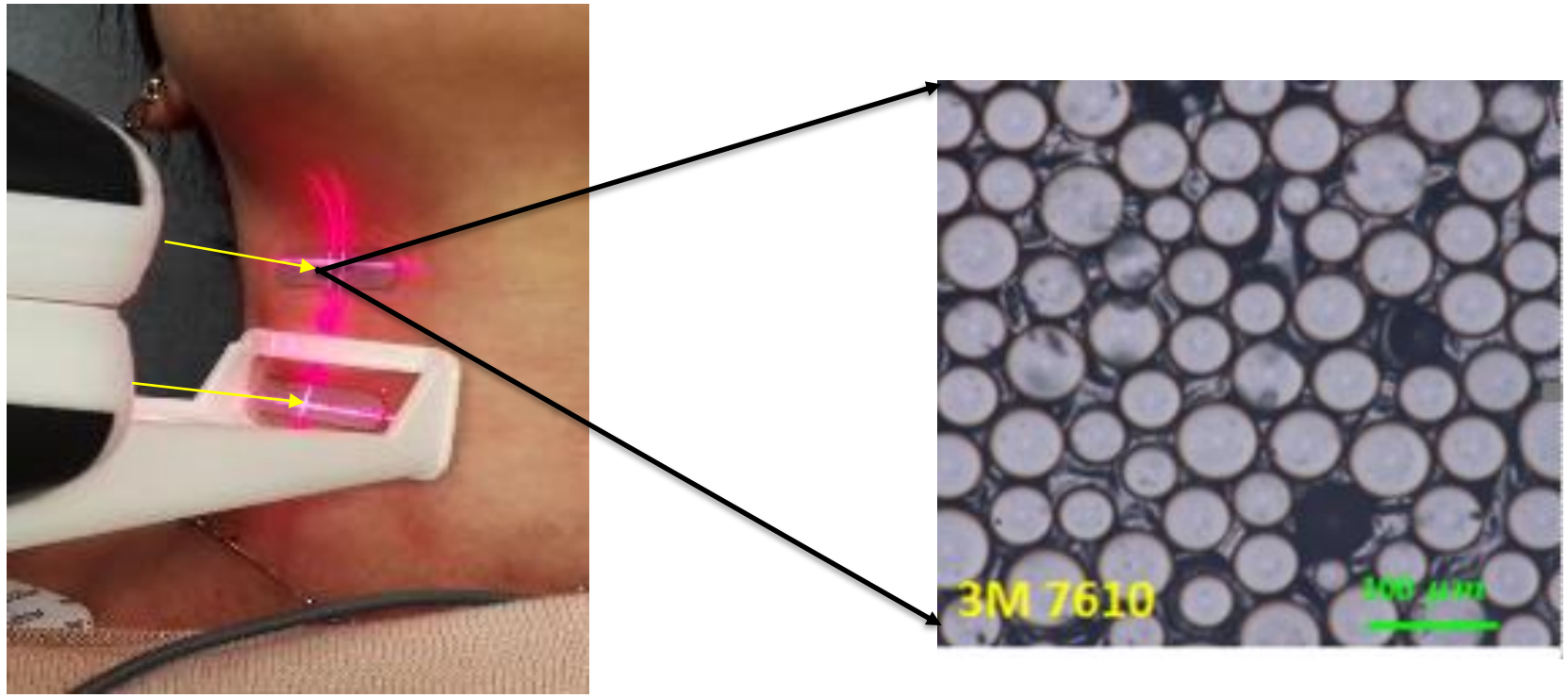
The signal demodulation is realized in PC in CARDIS demonstrator

REALIZATION OF A SIX-BEAM LDV ON SILICON CHIP



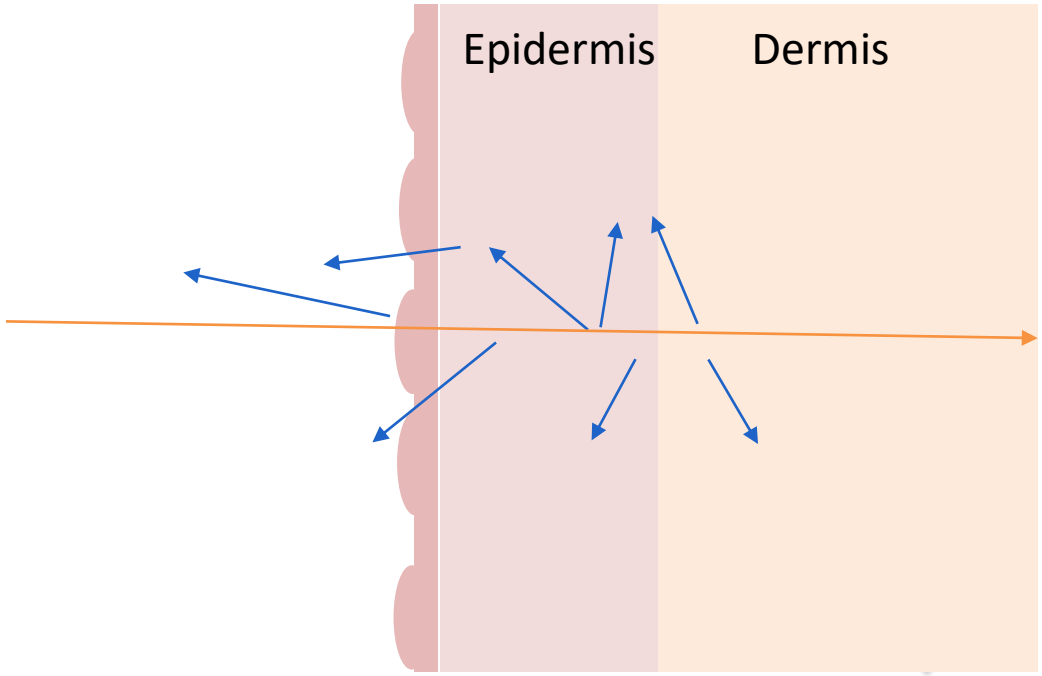


RETROREFLECTIVE (RR) PATCH



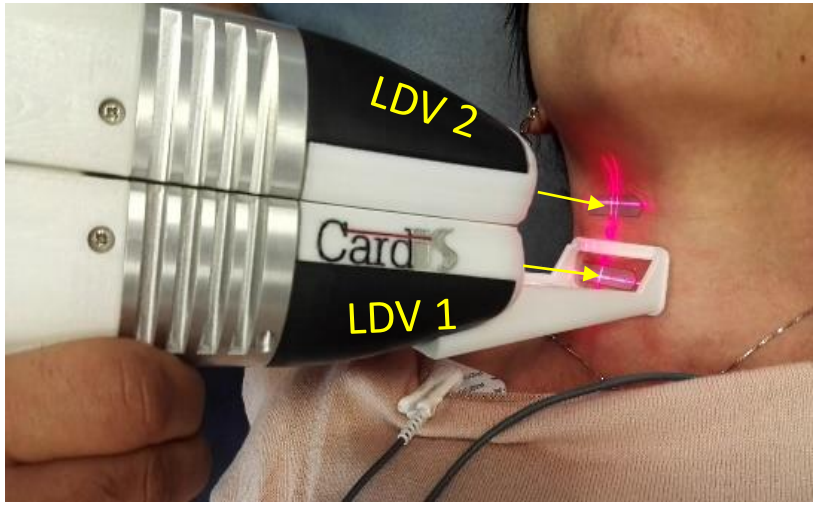
- Why do we use RR patches
  - Skin reflection is week, we use RR patches to enhance reflection.
- Why do we want to remove the RR patches:
  - Inconvenient to apply and remove RR patches for each measurement
  - The measurement locations are limited due to use of RR patches

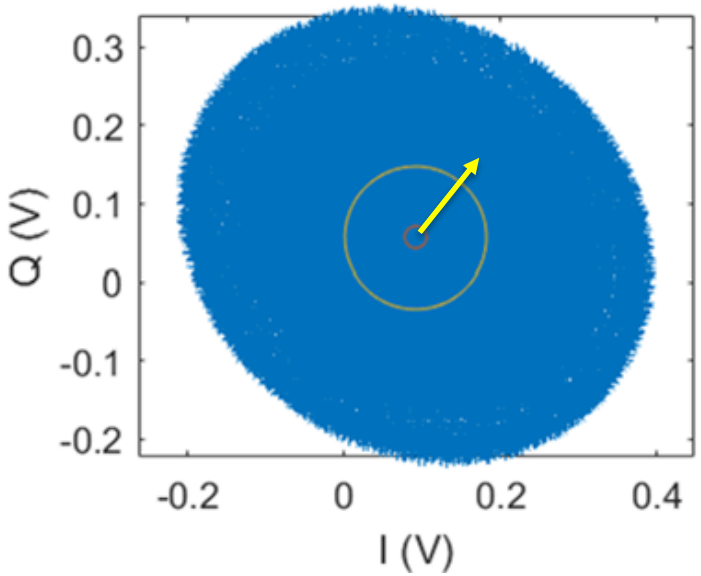
PROBLEMS WITH BARE SKIN REFLECTION

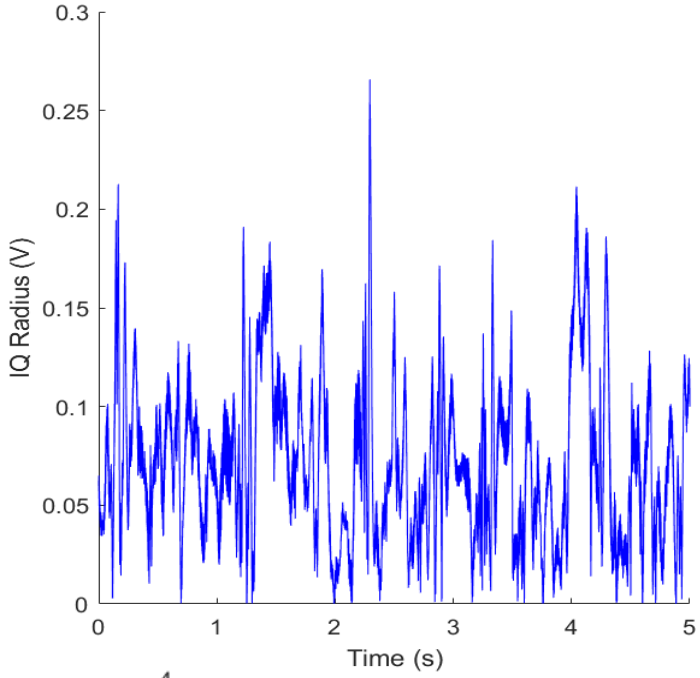


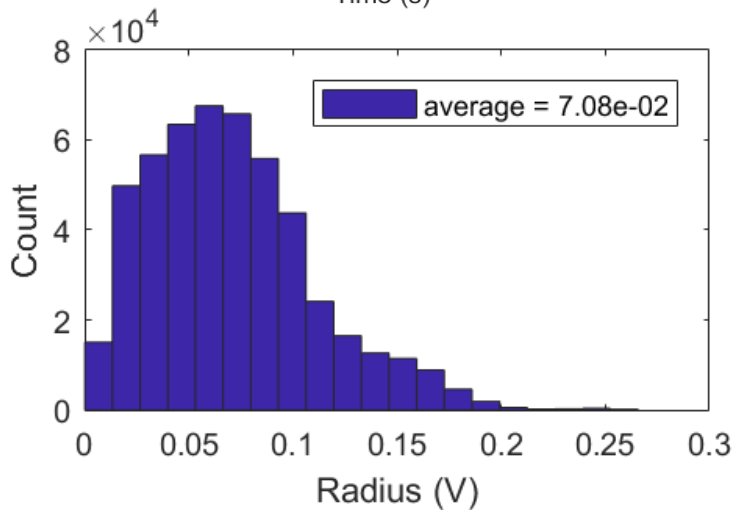
- Direct reflection at the skin boundary is 2.4% (neff = 1.37)
- Skin is also strongly scattered inside of skin
- Light is also strongly absorbed by water inside of the skin (8/cm).
- Total reflection from skin (all direction) measured by using spectro-photometer is only 5% for 1550 nm.

MEASUREMENT RESULTS WITH RR PATCHES









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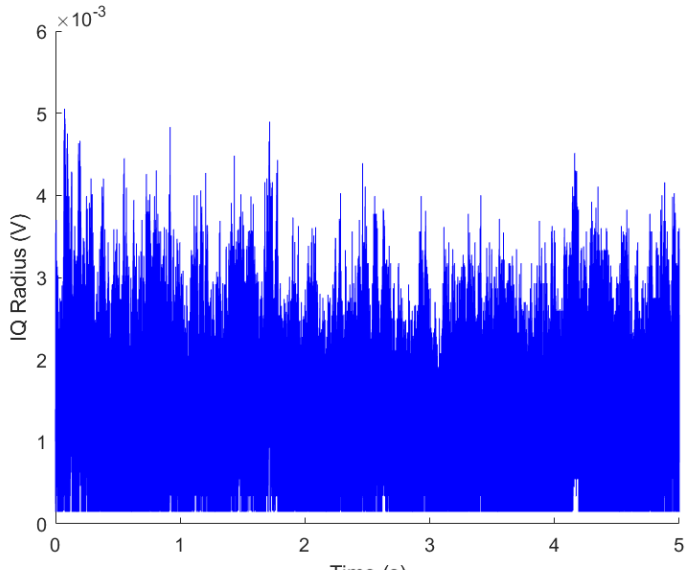
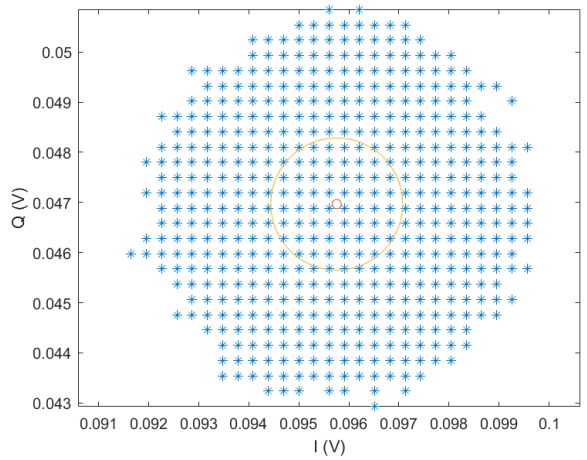
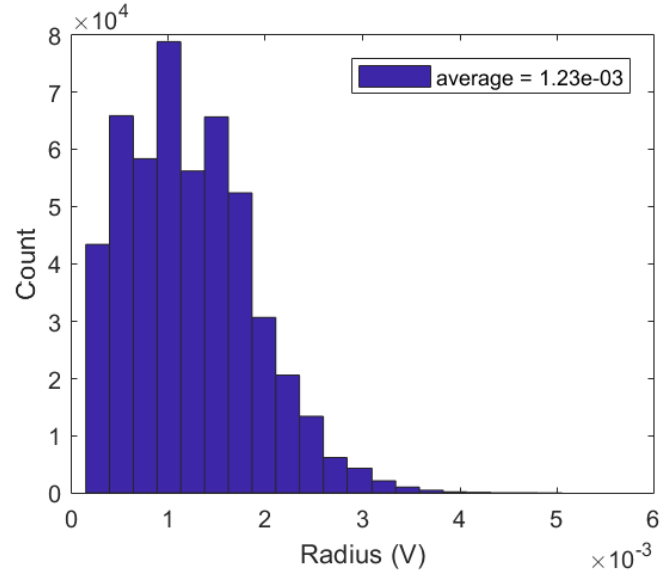
MEASUREMENT RESULTS WITHOUT RR PATCHES







Compared to with RR, directly measuring on bare skin:

- Radius is reduced by 58 times
- Reflection power is reduced by 3300 times

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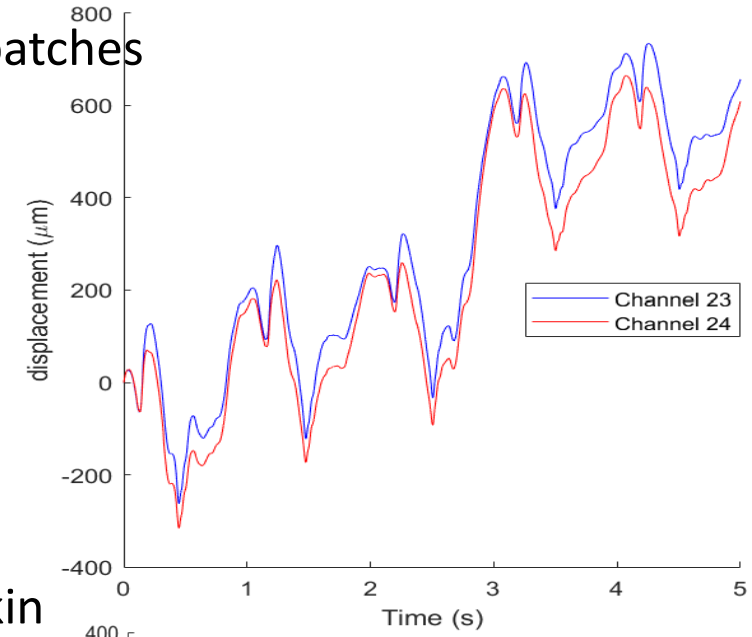
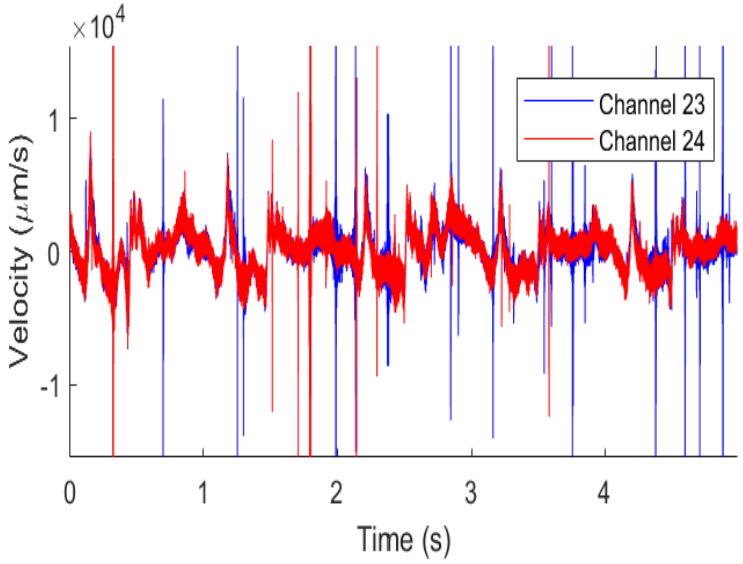
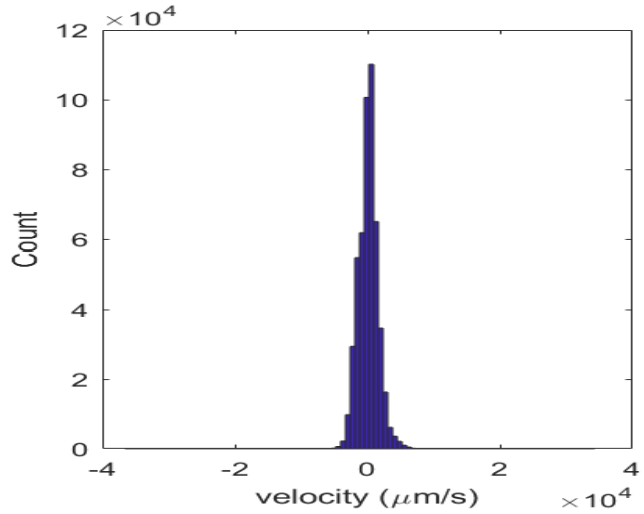
DEMODULATED SIGNALS

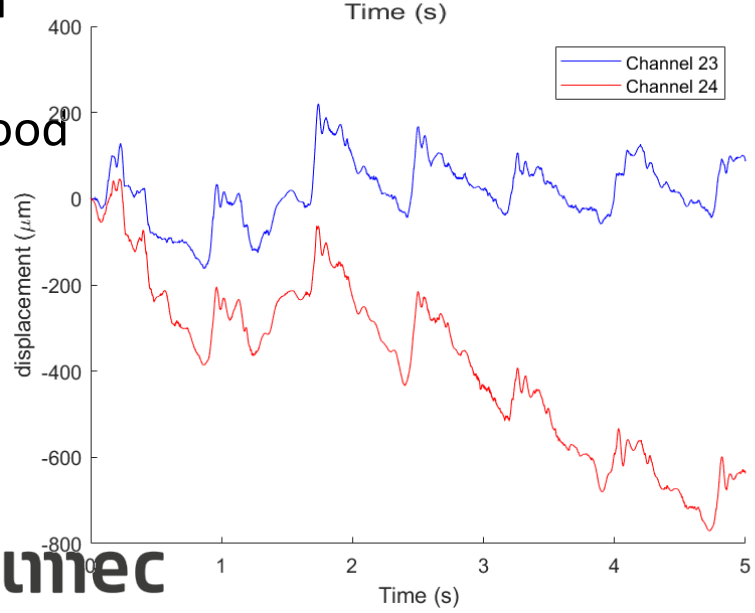
with RR patches

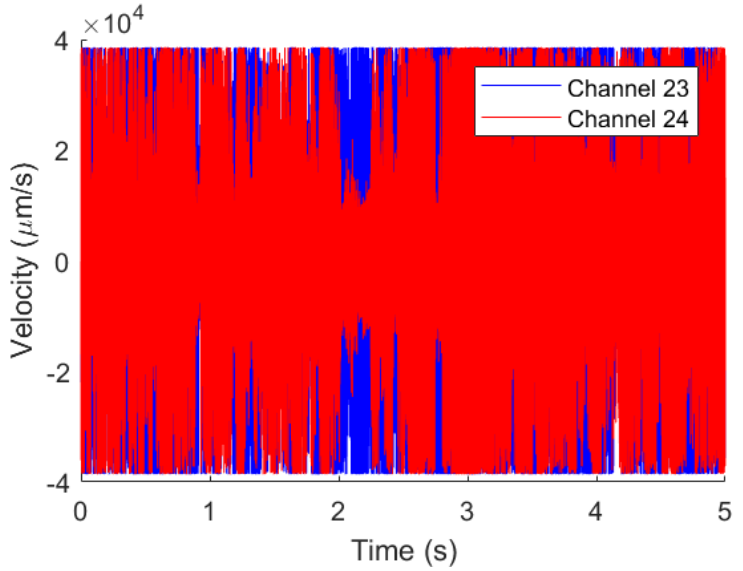


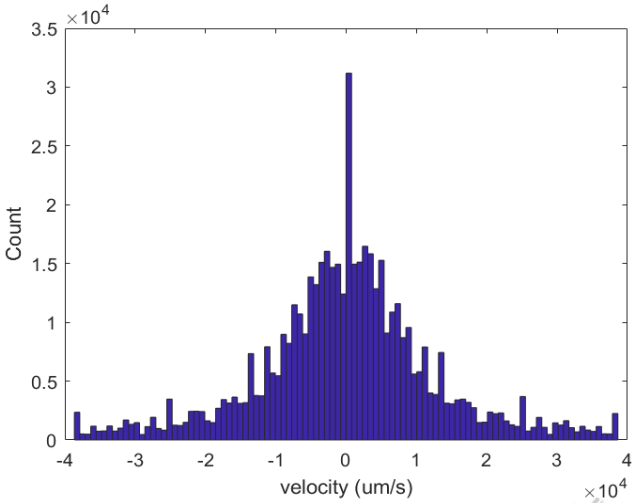




on bare skin (the special case with good enough reflection)







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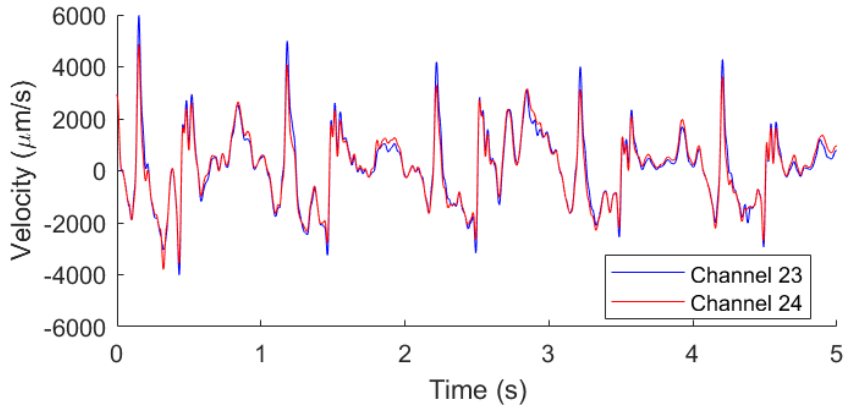
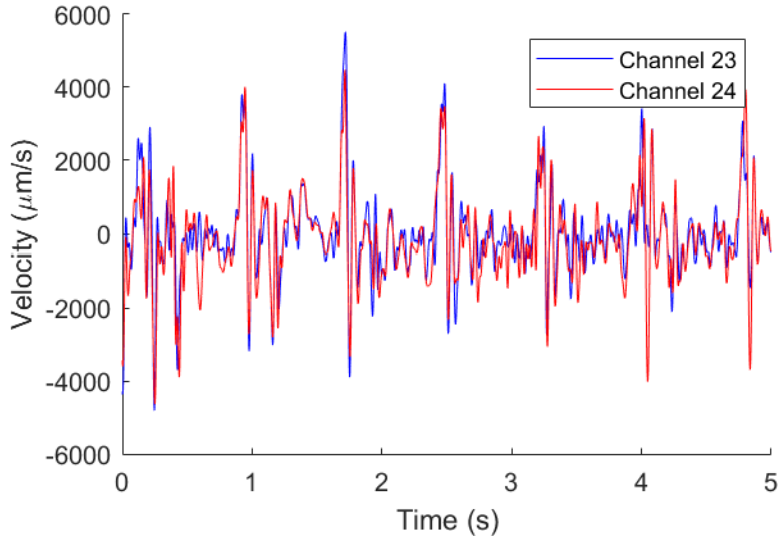
WITH POST FILTER 30 HZ FILTERS

with RR patches



without RR patches (the special case with good enough reflection)



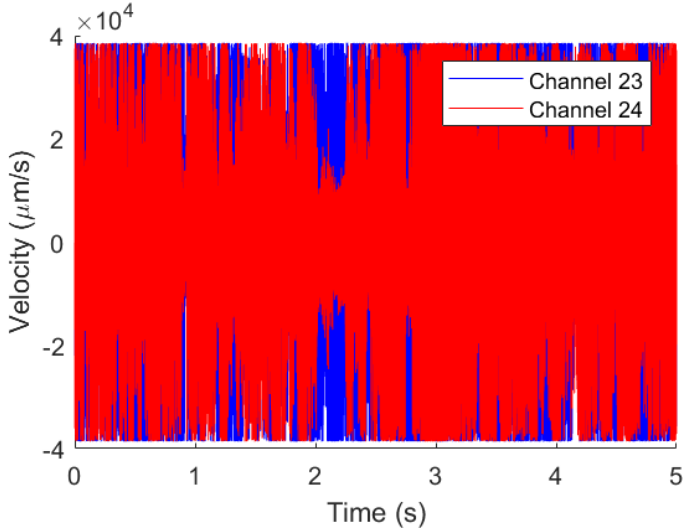
- Clear pulse peaks can be obtained on LDV measurement on bare skin.
- But this is only for the limited candidate with stronger skin reflections.

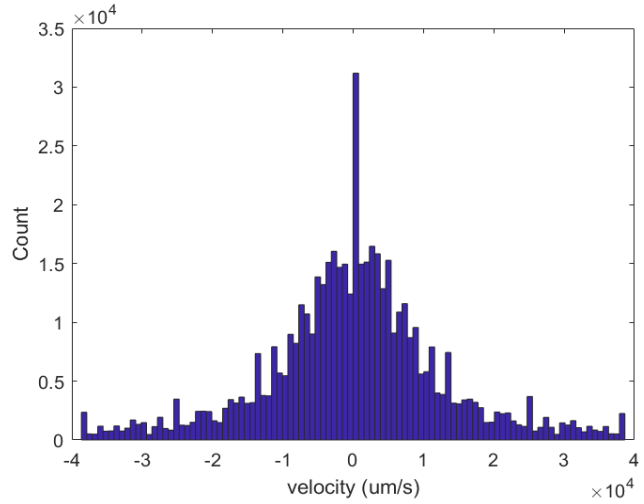
PRE-FILTERING IQ SIGNALS (MOVING AVERAGE)

Unfiltered velocity

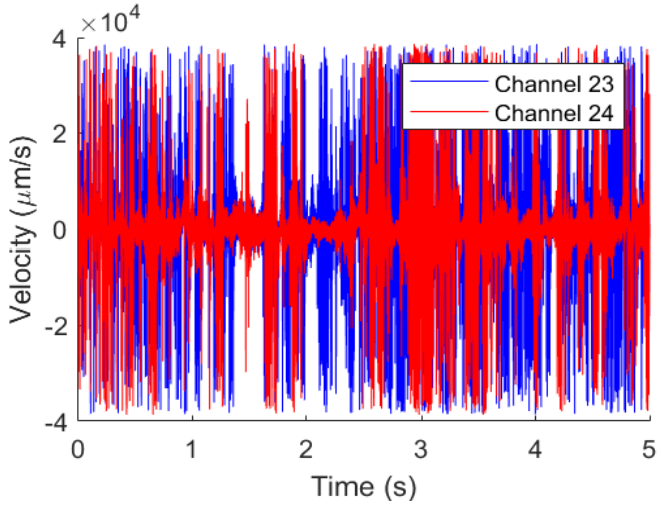
Histogram of the unfiltered velocity

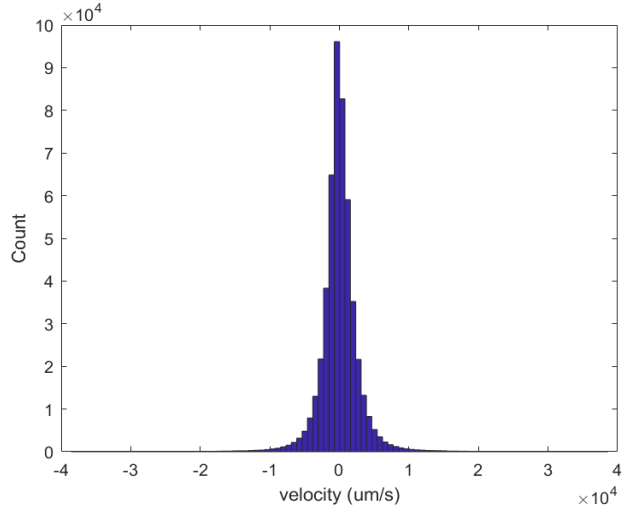
No moving average





Moving average over 7 samples





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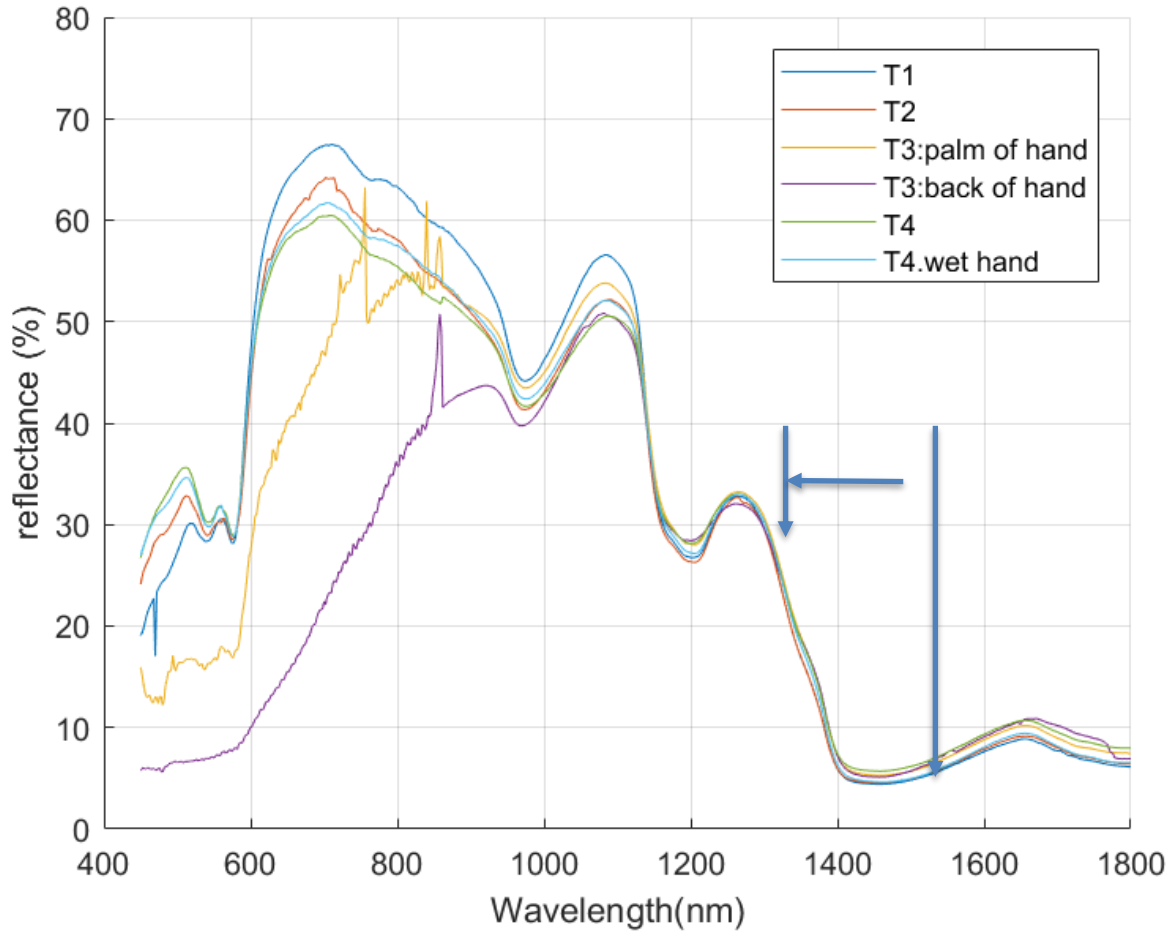
REFLECTION IMPROVEMENT NEEDED

- The measurement on bare skin doesn't work for most people
    - Skin reflectance of the selected candidate is close of the noise floor
    - Enhance the reflection power of the current bare skin reflection should be improved by 10 times.
- In new InSiDe project, we will improve the LDV to realize a measurement on bare skin.

How to improve reflection: different wavelength



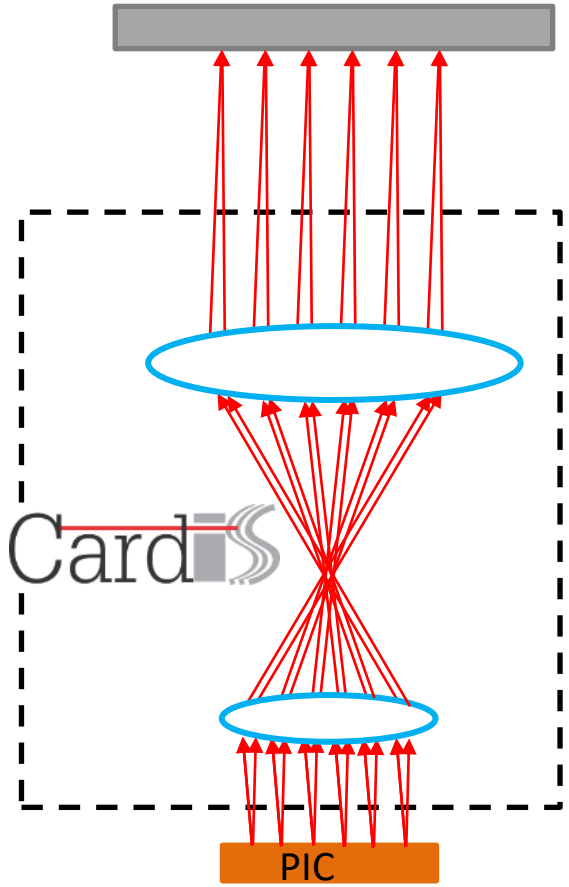
Human skin reflection measured with spectrophotometer

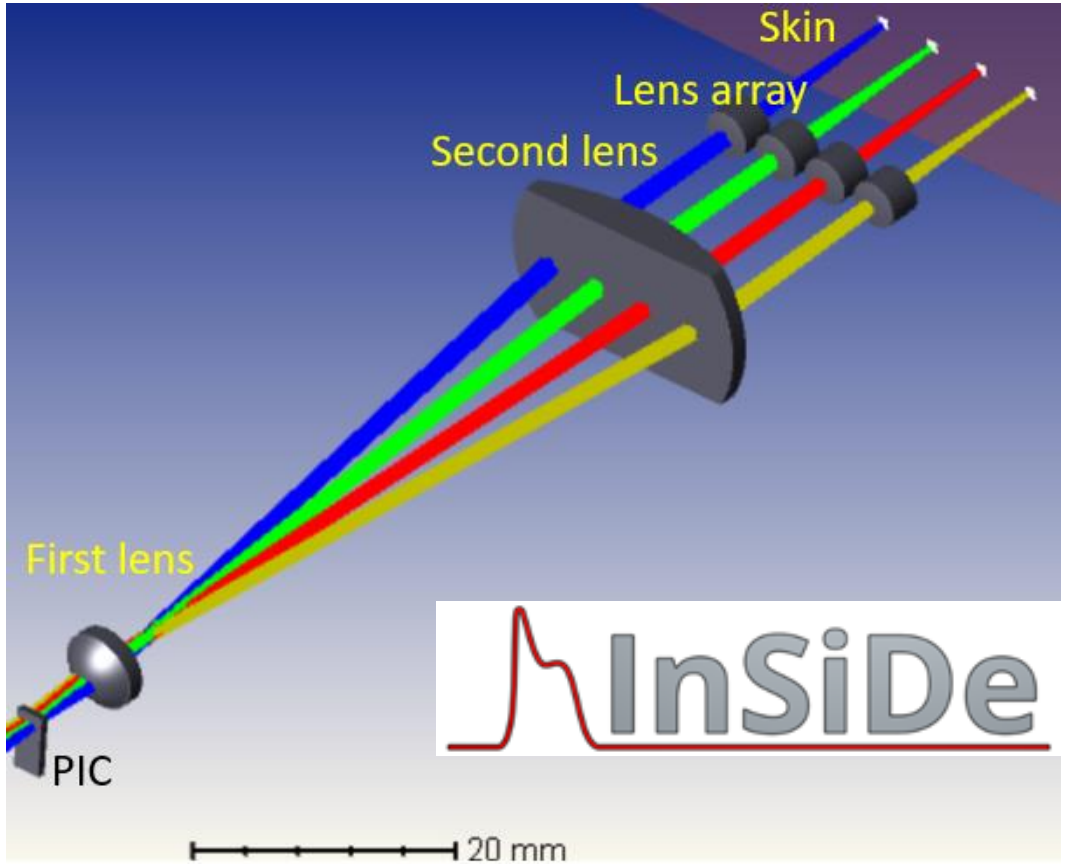
- Reflection at visible range can have strong reflection, but the reflection strongly depends on skin color
- Change to 1310 nm, reflection can be increased by 6 times
- We have a lot of components working in 1310 nm

How to improve reflection: strong output power

More input power: 2.5 – 5 times

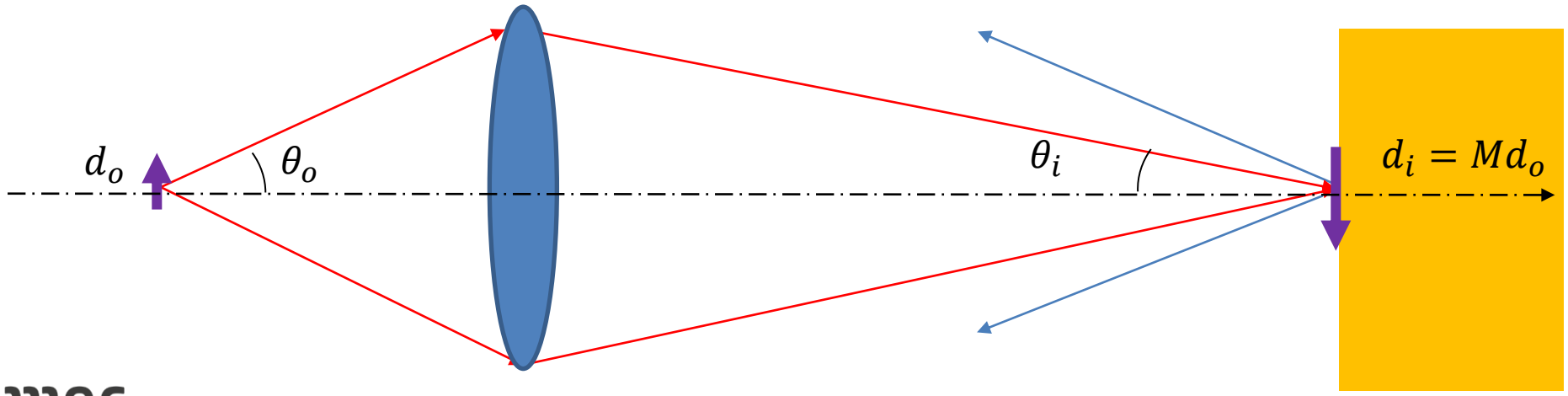
Less number of beams: 1.5 times.





How to improve reflection: Smaller magnification

- Use a smaller magnification to enhance reflection
    - A higher focus cone θ_i of the LDV beam corresponds to a higher collection of reflection power. $R \propto 1/M^2$
- However, a smaller depth of focus means reflection from inside of skin is reduced.
- *M* is change to from 16.7 (in CARDIS) to 2.8. We approximate that the reflection enhancement is between 6 and 36 times.



IMPROVEMENT METHODS

- Use a different wavelength (stronger reflection x6)
- Use stronger optical output power (x2.5 -> x5)
- Use less number of beams 6->4 (x 1.5)
- Use a smaller magnification 16.7 -> 2.8 (x6 -> x 36)

- In total: 135 times to 1620 times

SUMMARY

- We propose to use LDV to do CVD monitoring
- We need to avoid using RR patches
- We can measure pulse with old LDV device, but only on limited subjects
- We outlined how we will improve the LDV sensor:
    - By changing wavelength from 1550 nm to 1310 nm
    - By improving laser power and reducing the number of beams
    - By using a smaller magnification