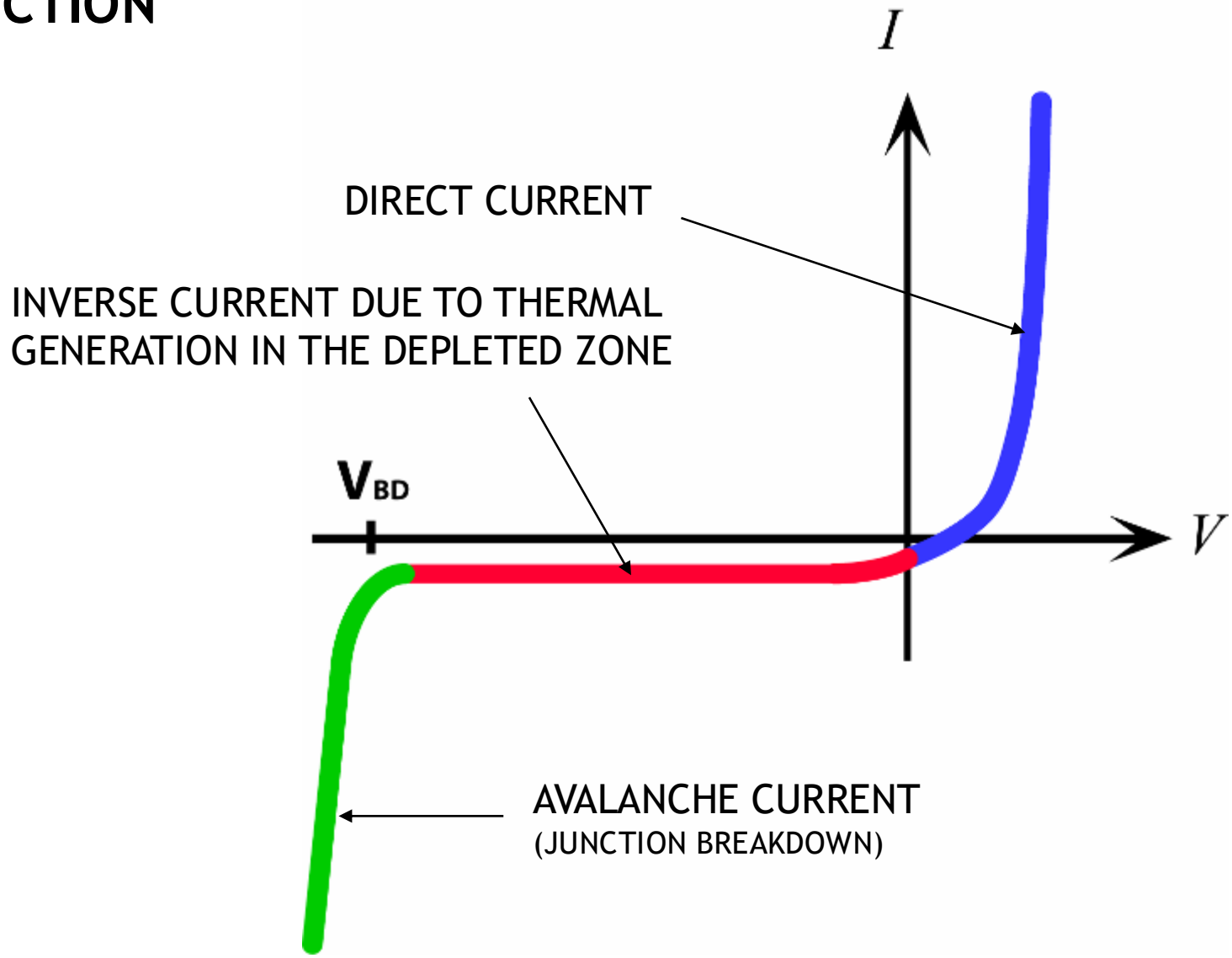
SINGLE-PHOTON AVALANCHE DIODE DEMYSTIFIED

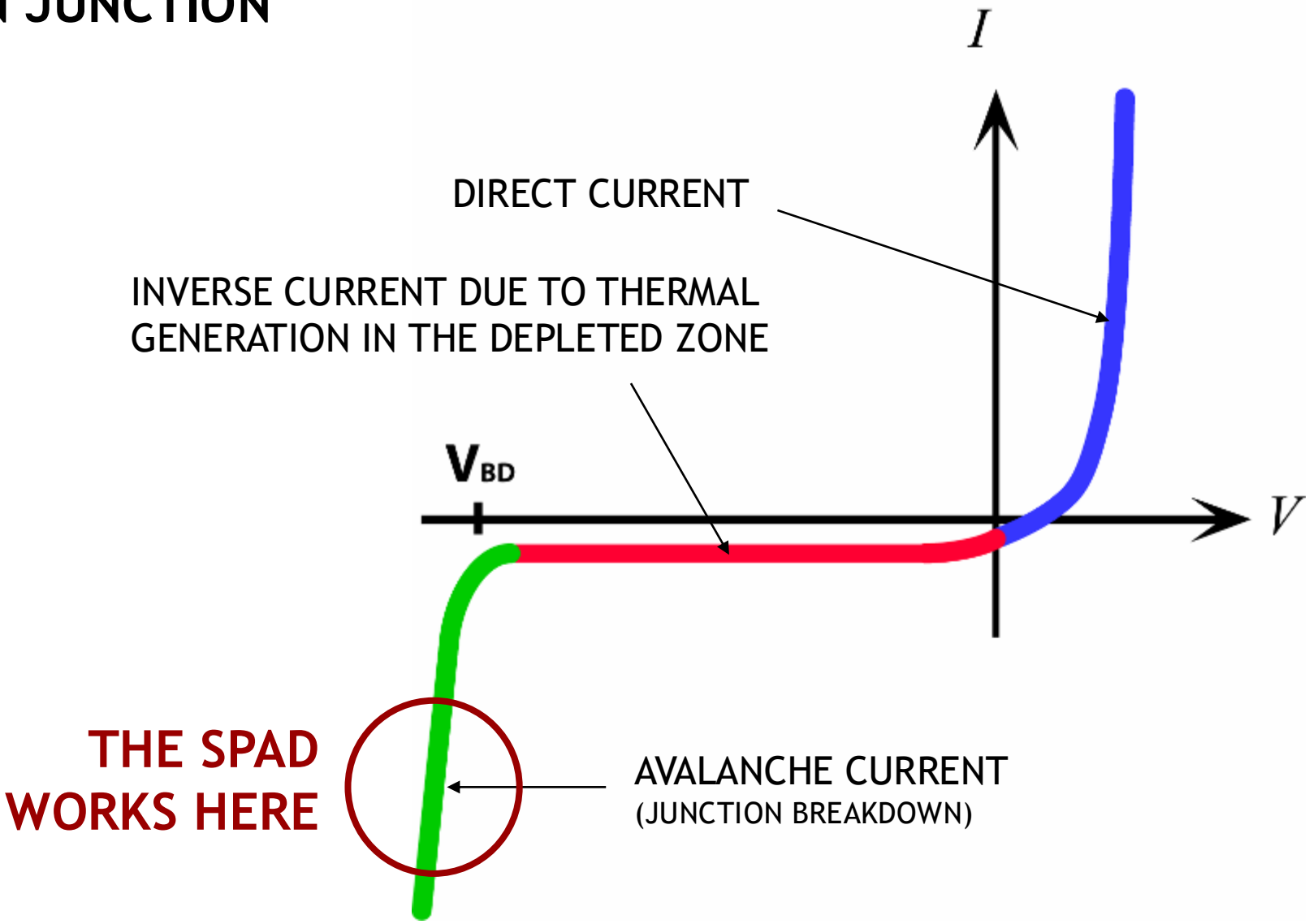
Fabrizio Guerrieri

LET'S CONSIDER THE TYPICAL PN JUNCTION I-V CHARACTERISTICS…

PN JUNCTION

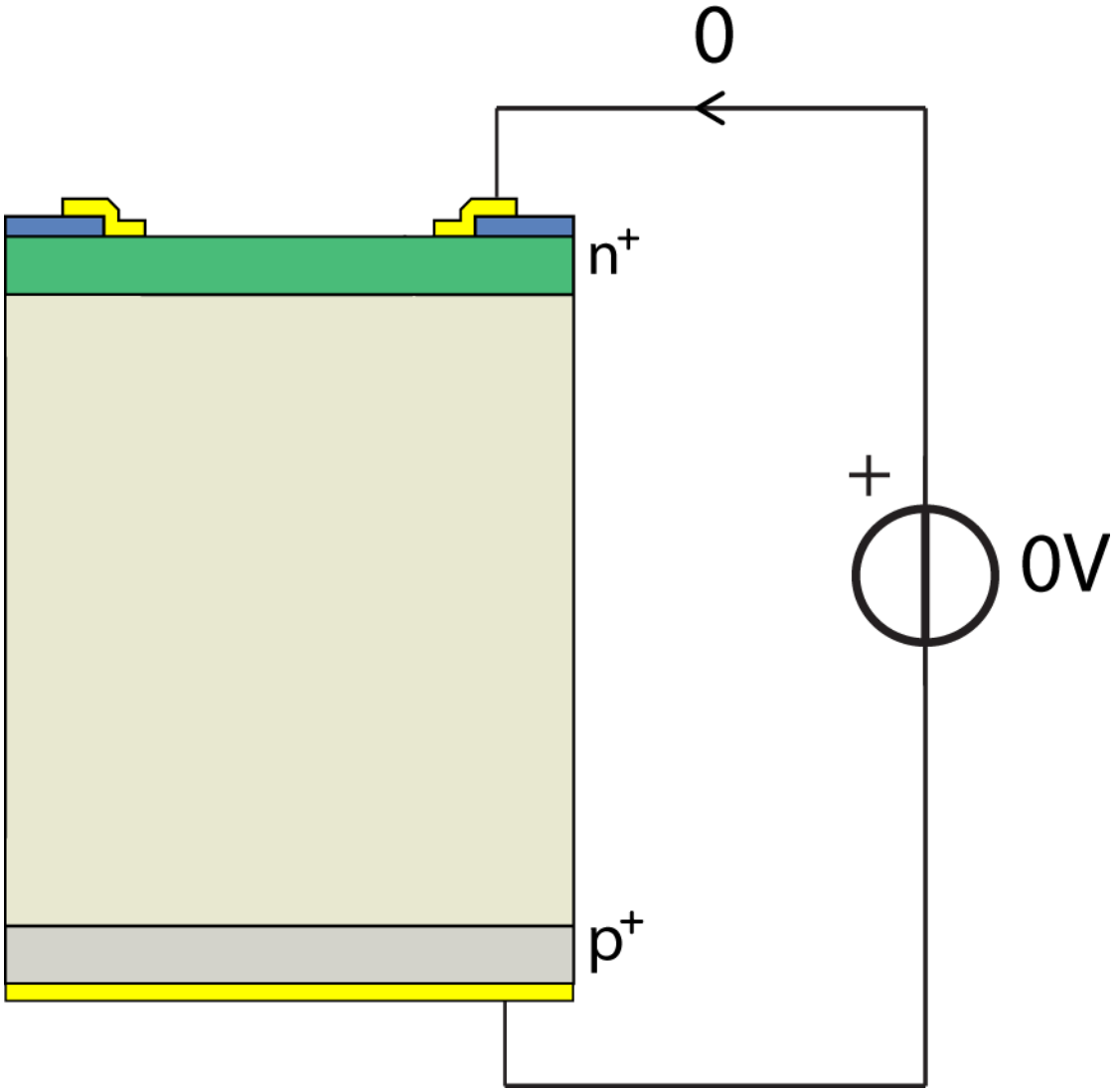

I
DIRECT CURRENT
INVERSE CURRENT DUE TO THERMAL
GENERATION IN THE DEPLETED ZONE
VBD
V
AVALANCHE CURRENT
(JUNCTION BREAKDOWN)

PN JUNCTION


I
DIRECT CURRENT
INVERSE CURRENT DUE TO THERMAL GENERATION IN THE DEPLETED ZONE
VBD
V
THE SPAD WORKS HERE
AVALANCHE CURRENT
(JUNCTION BREAKDOWN)

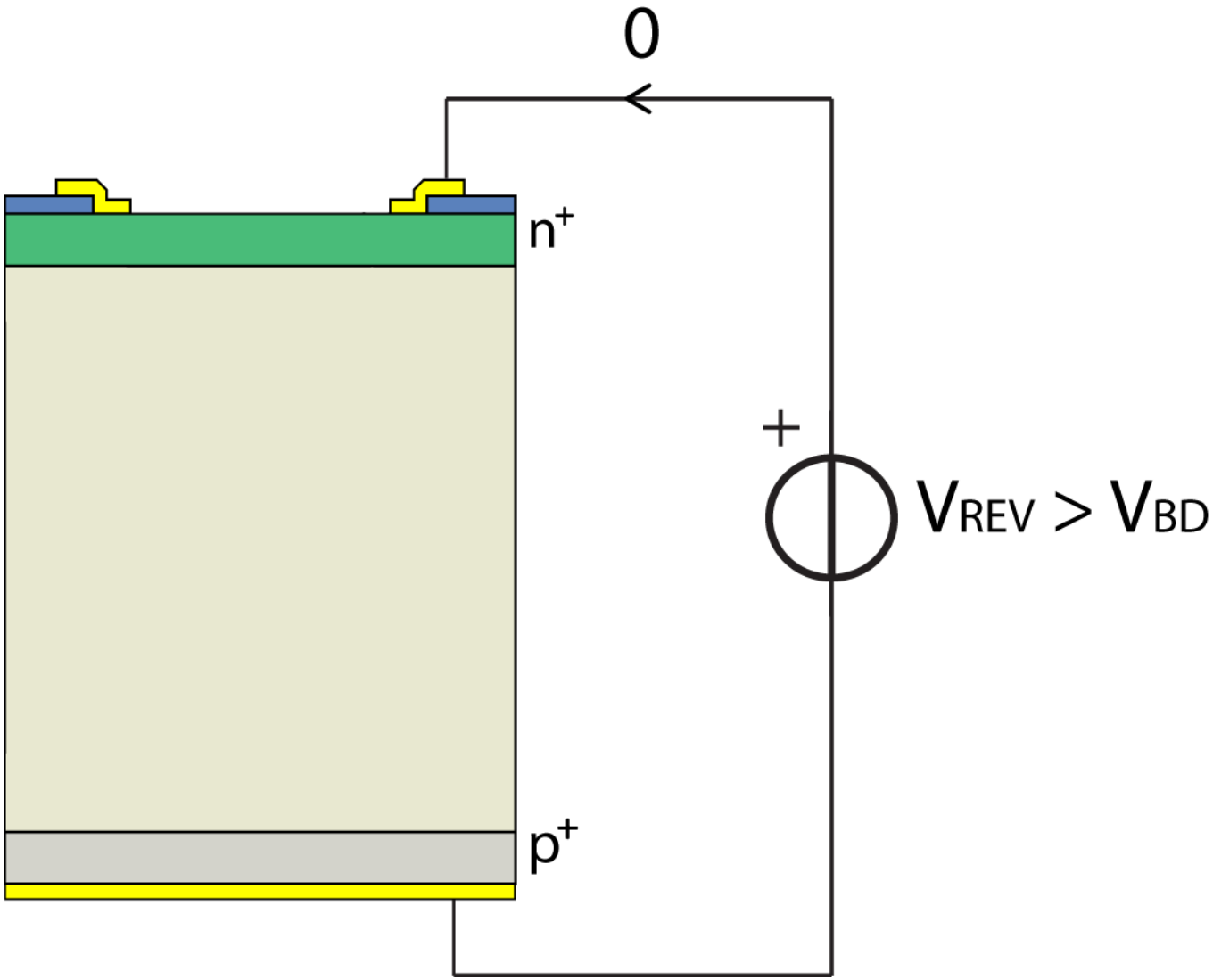
HOW DOES A SPAD WORK?

WITH A REVERSE VOLTAGE BELOW BREAKDOWN NO CURRENT FLOWS

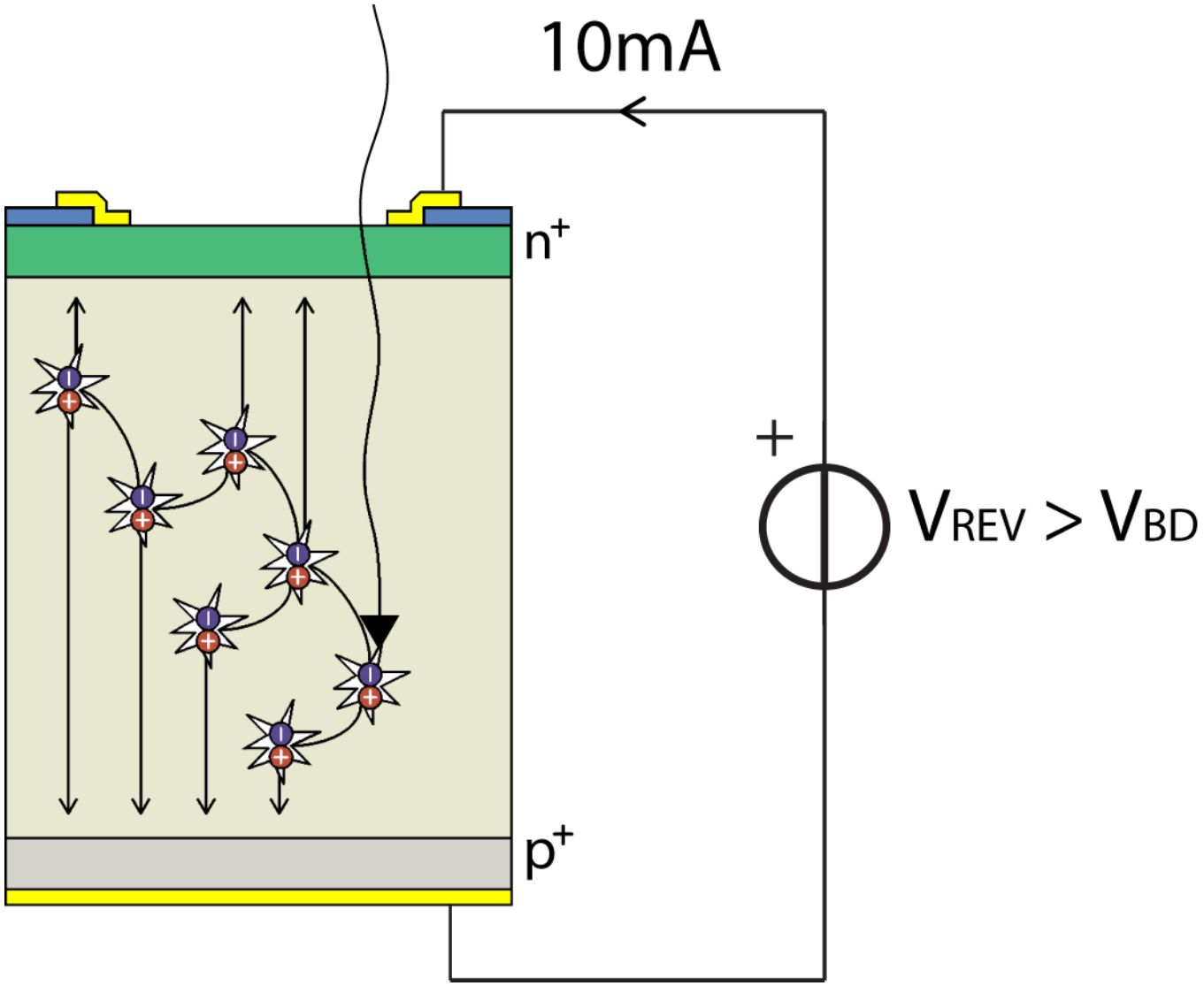

0
n+
+
0V
p+

AT THE BEGINNING,

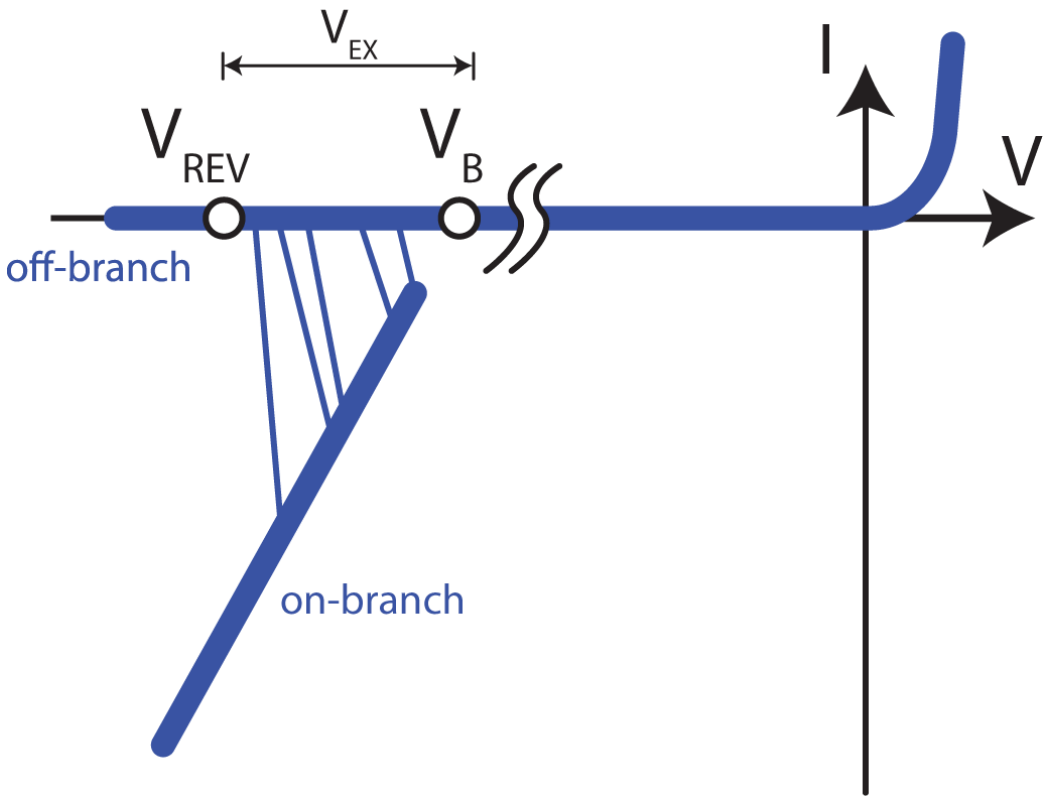
NO CURRENT FLOWS EVEN WITH
A REVERSE VOLTAGE ABOVE BREAKDOWN


0
n+
+
VREV > VBD
p+

AN AVALANCHE CURRENT IS TRIGGERED BY THE FIRST PHOTON GENERATING AN ELECTRON/HOLE PAIR IN THE DEPLETED REGION


10mA
n+
p+
+
VREV > VBD

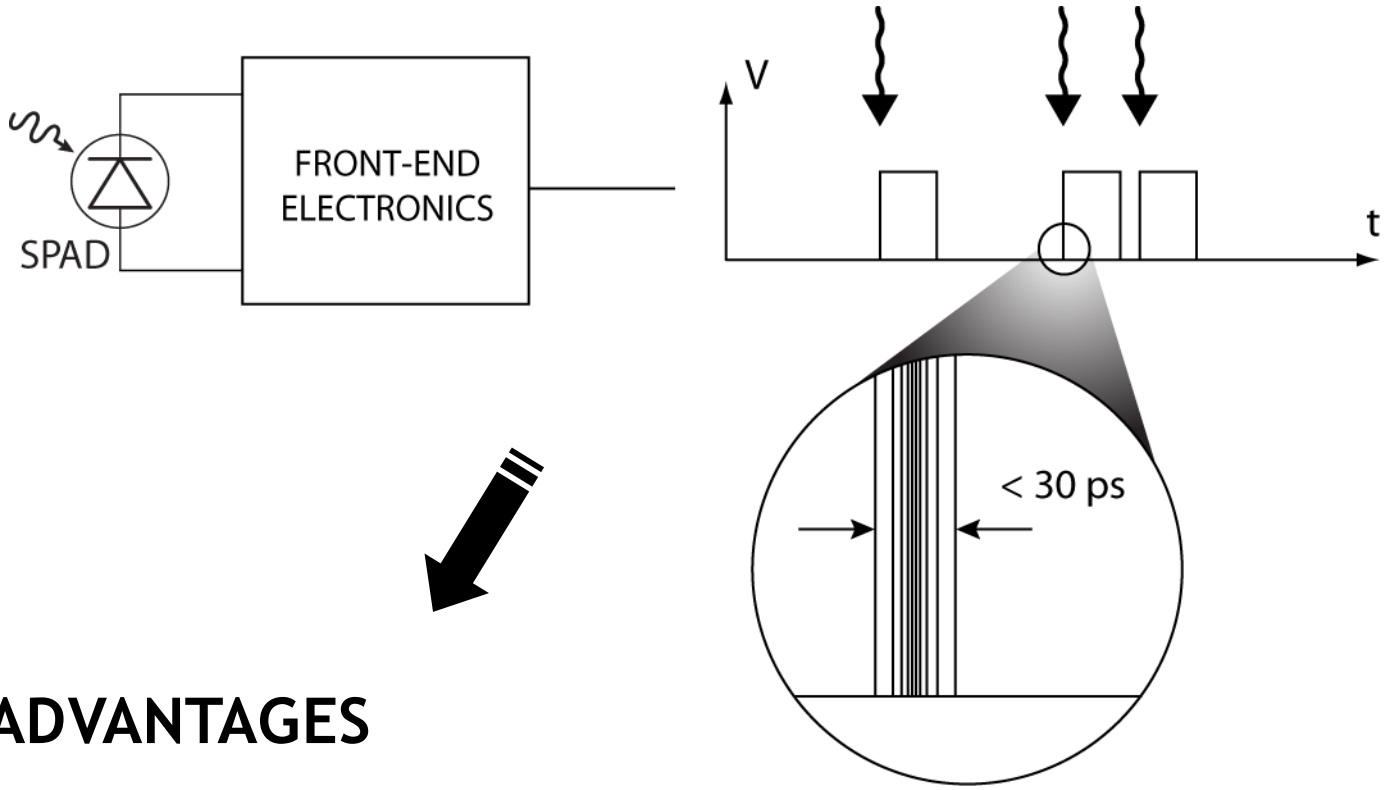
THE BRANCHED CHARACTERISTIC OF A SPAD



OBVIOUSLY A FRONT-END CIRCUIT (WE CALL IT QUENCHING CIRCUIT) IS NEEDED IN ORDER TO:

1. ENABLE THE SPAD RISING THE REVERSE VOLTAGE ABOVE BREAKDOWN
2. DETECT THE AVALANCHE CURRENT
3. QUENCH THE AVALANCHE CURRENT LOWERING THE REVERSE VOLTAGE BELOW BREAKDOWN

HOW CAN I USE A SPAD?



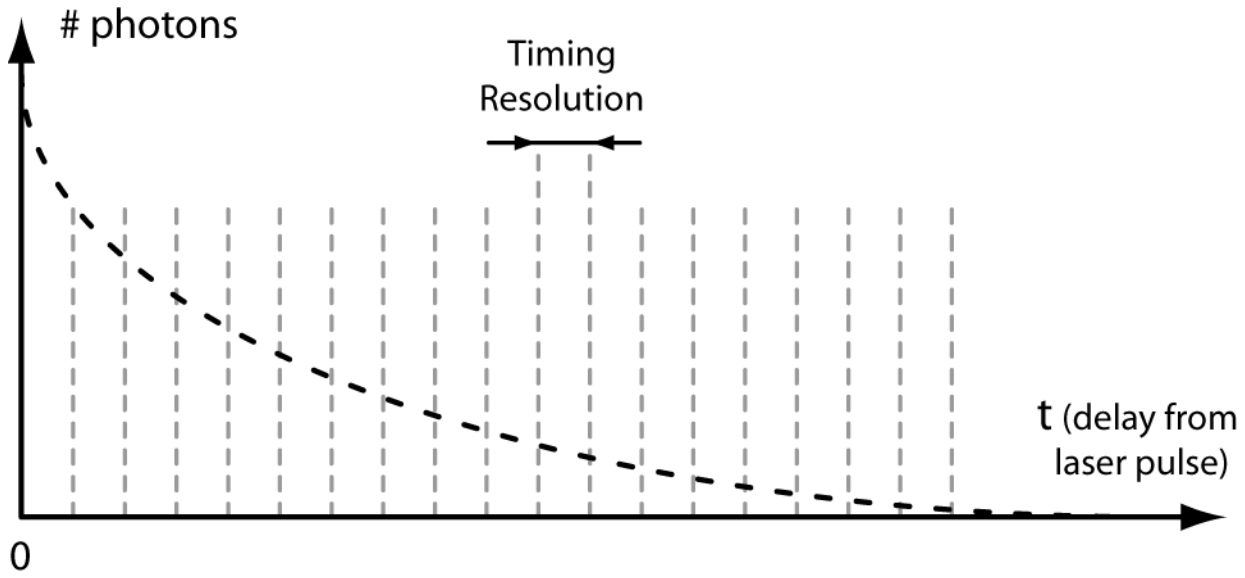
TWO MAIN ADVANTAGES

1. SINGLE-PHOTON LEVEL SENSITIVITY
2. ELECTRONIC PULSE'S RISING EDGE WITH VERY LOW TIME JITTER (30 ps OR BETTER)

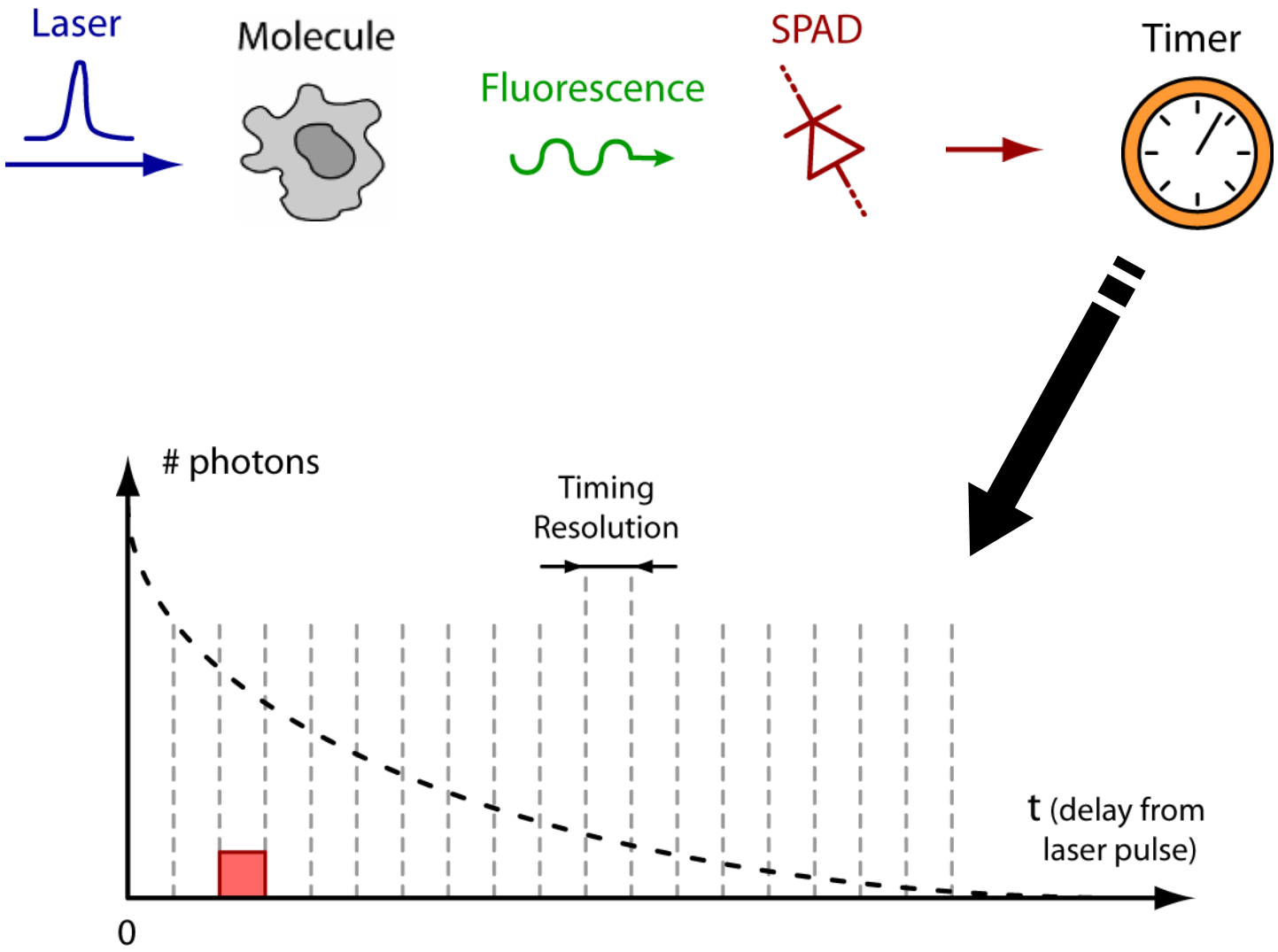
HOW CAN I USE A SPAD?

1. TIME CORRELATED SINGLE-PHOTON COUNTING (TCSPC)
   (WE INFORMALLY CALL IT "PHOTON TIMING")
2. TIME OF FLIGHT (TOF)
3. PHOTON-COUNTING

1 - PHOTON TIMING



1 - PHOTON TIMING



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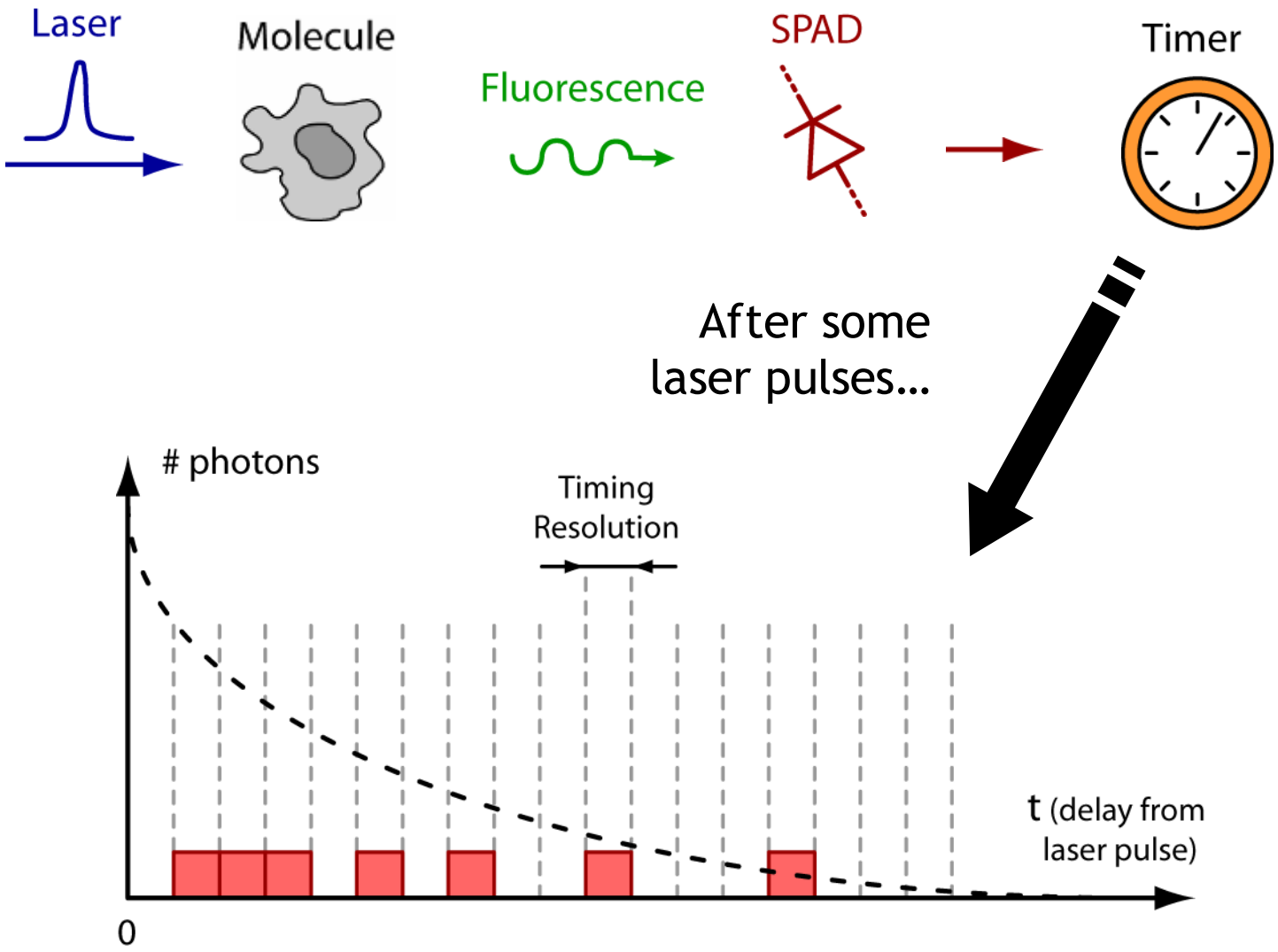

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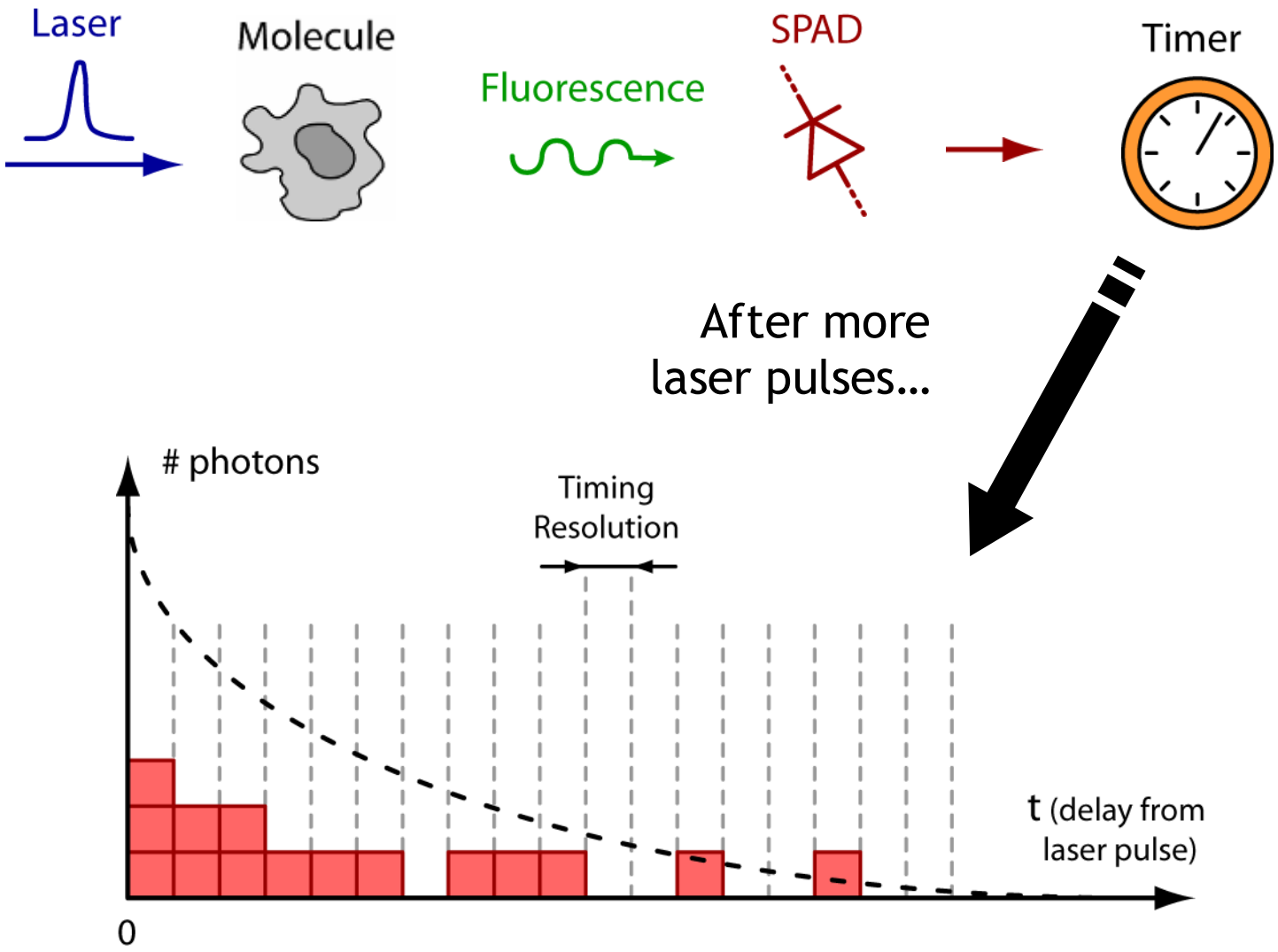

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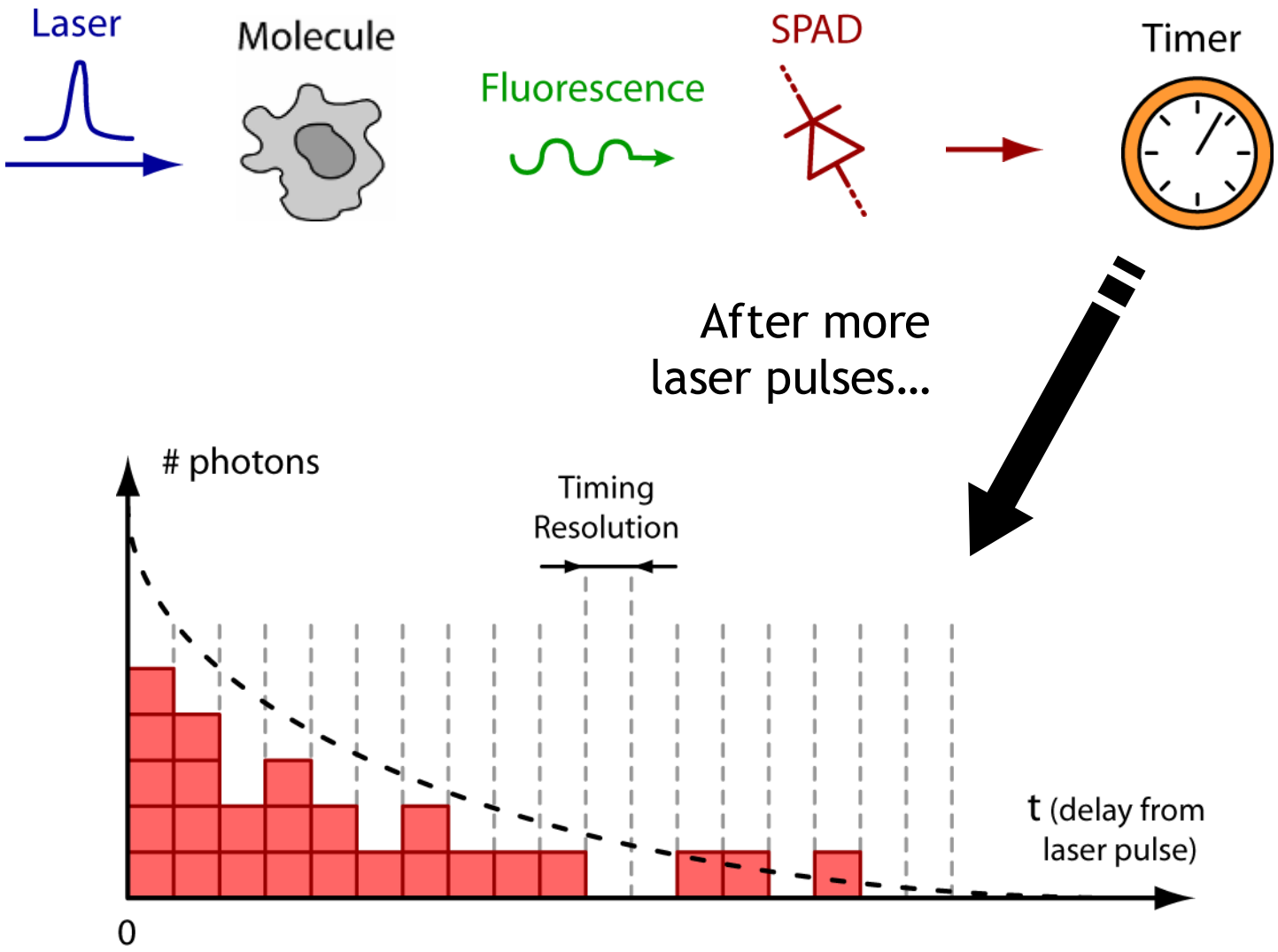

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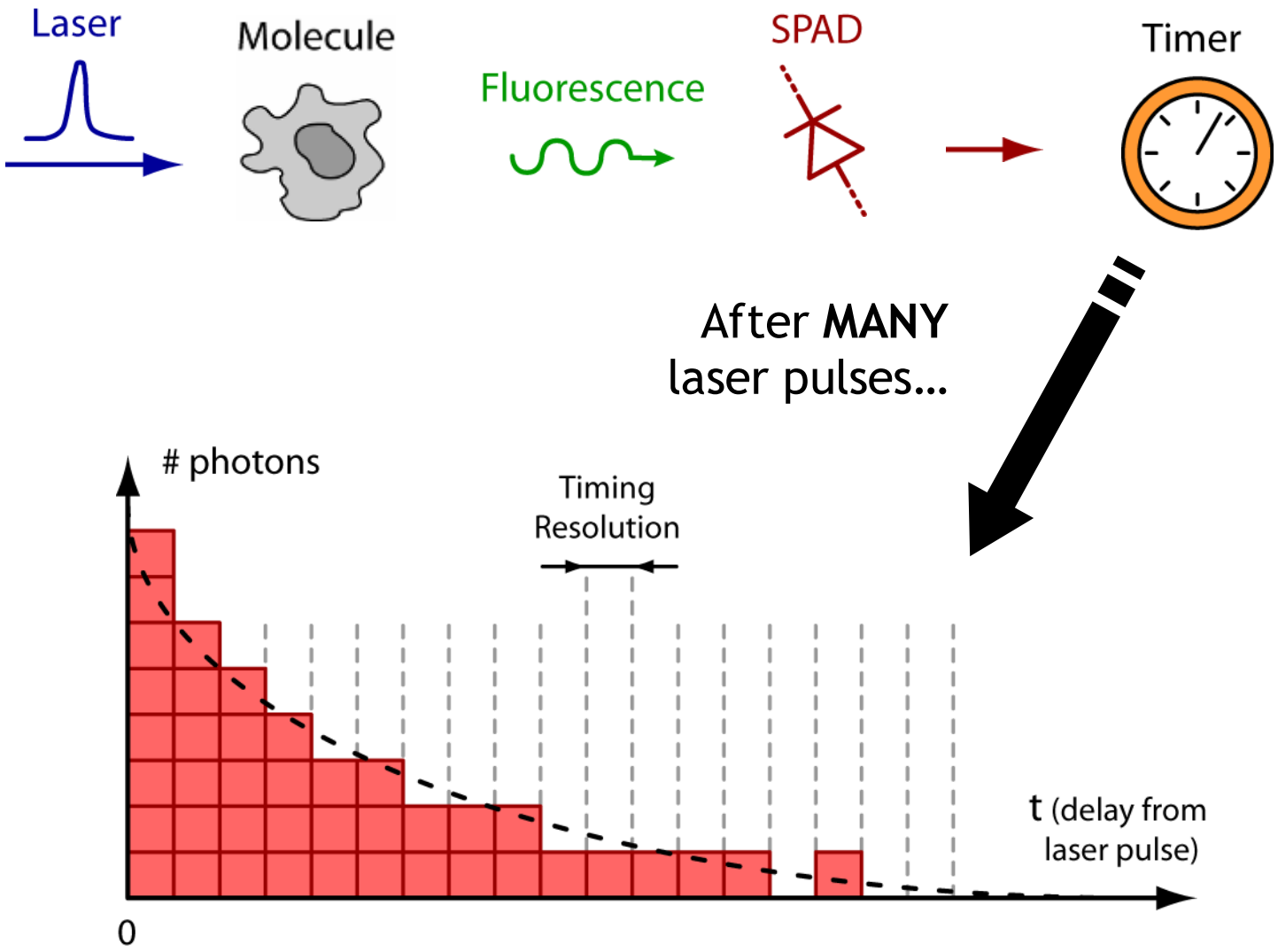
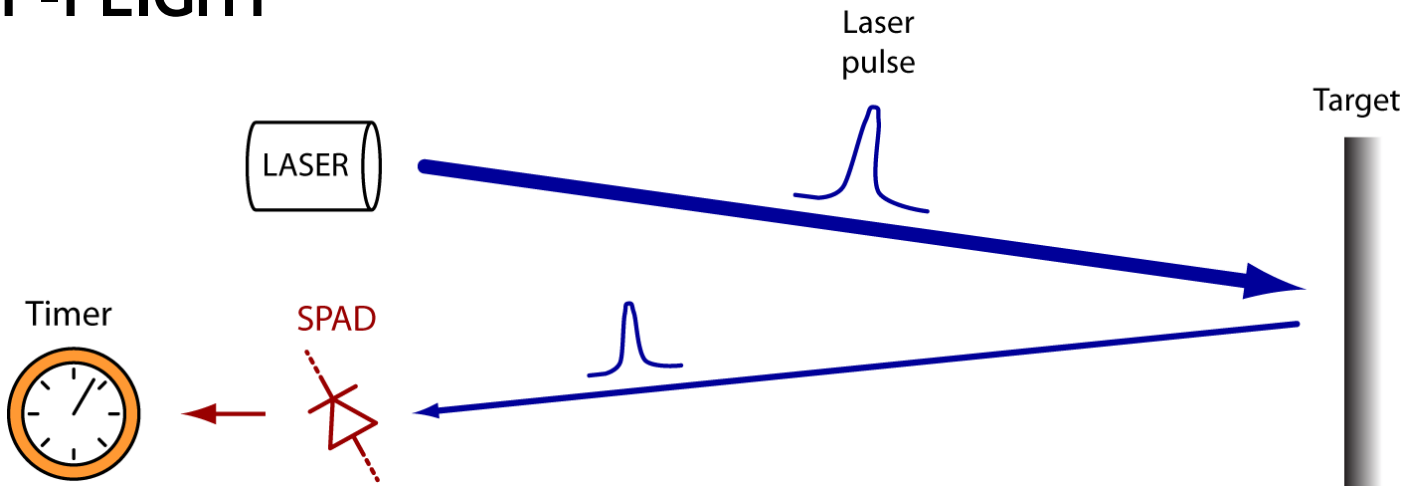
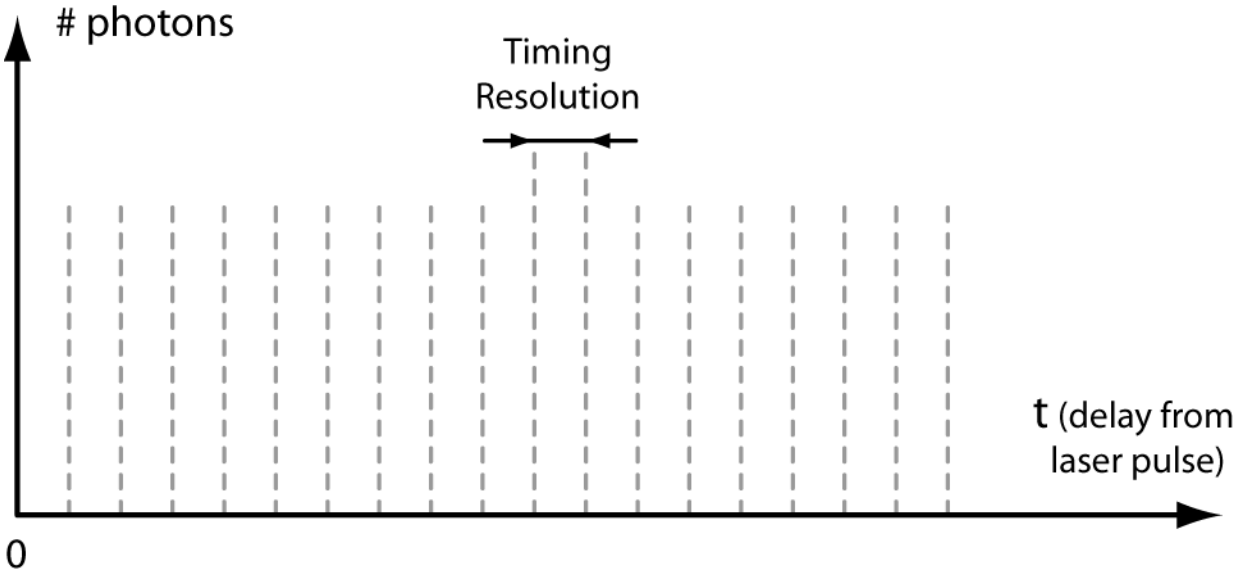


2 - TIME-OF-FLIGHT





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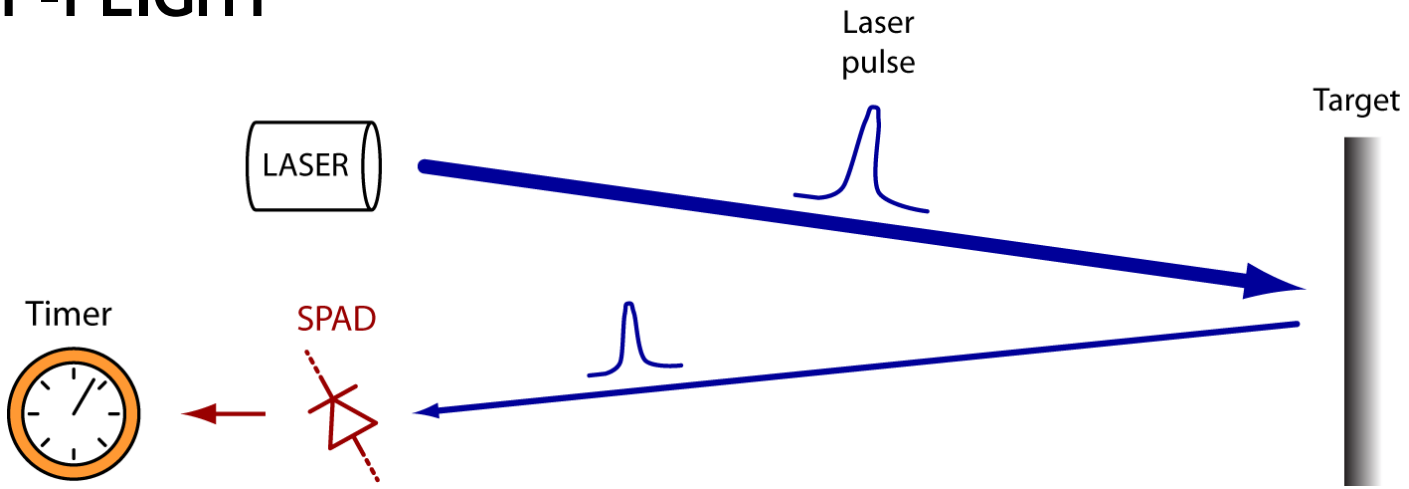

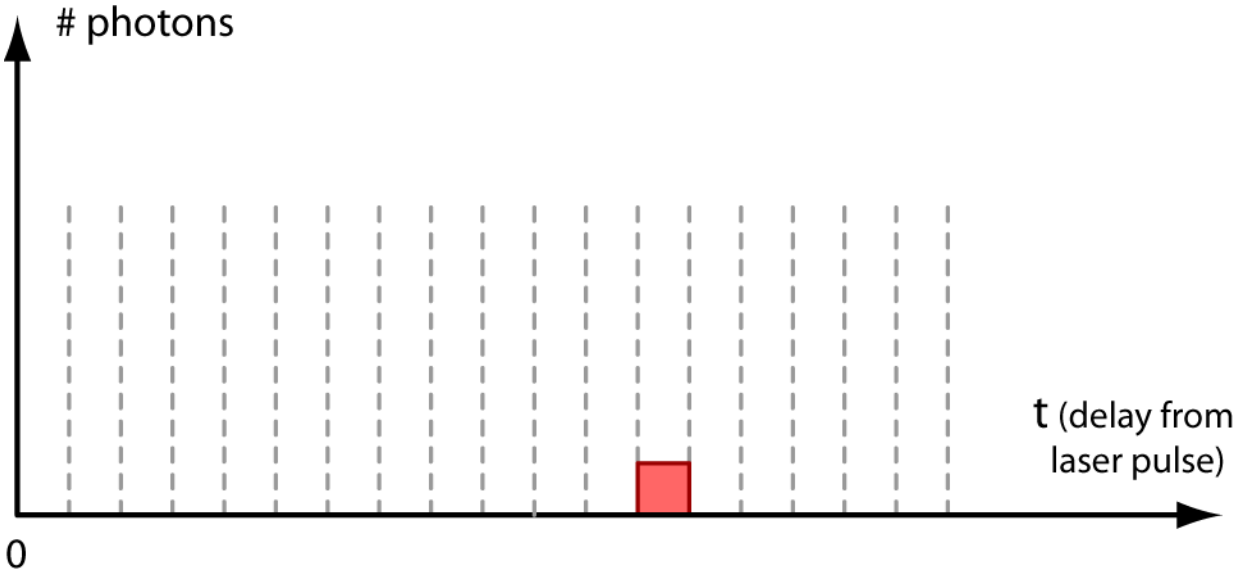

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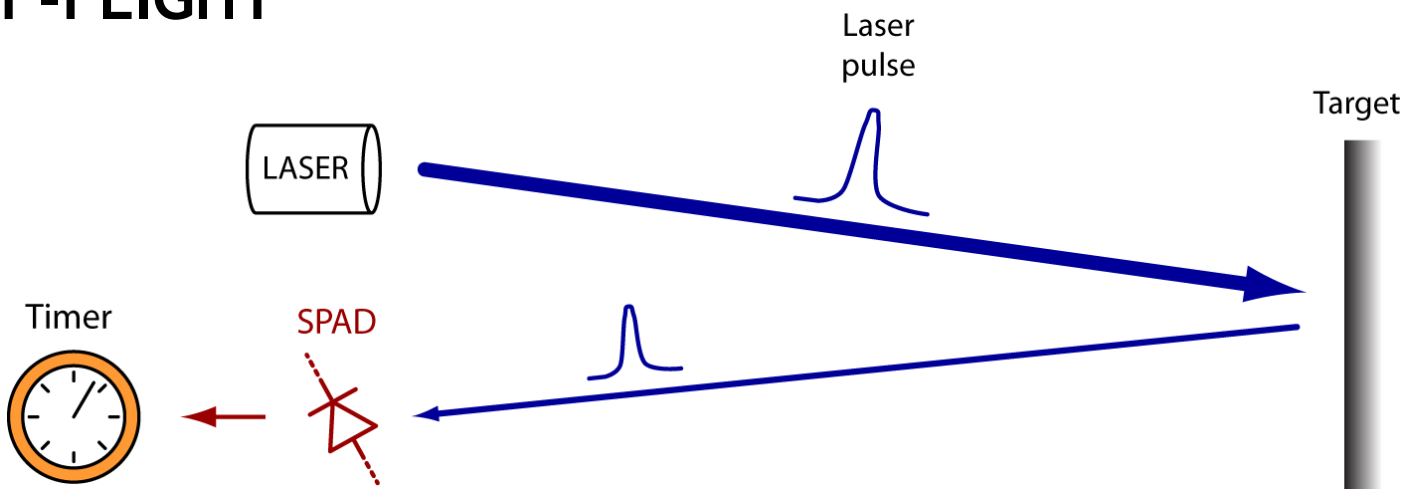

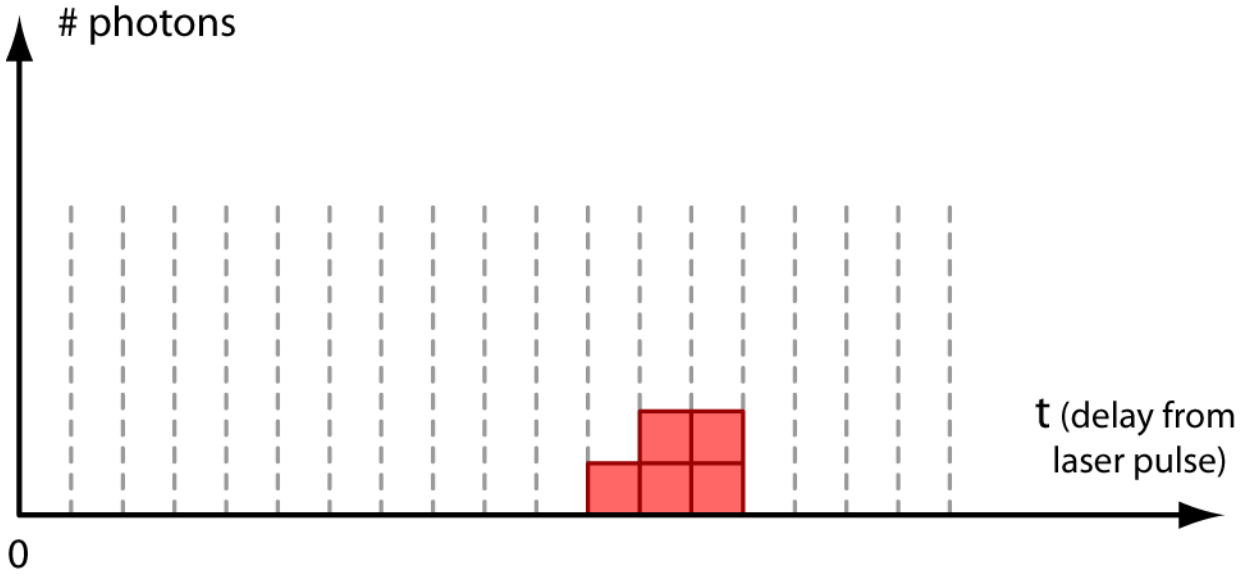

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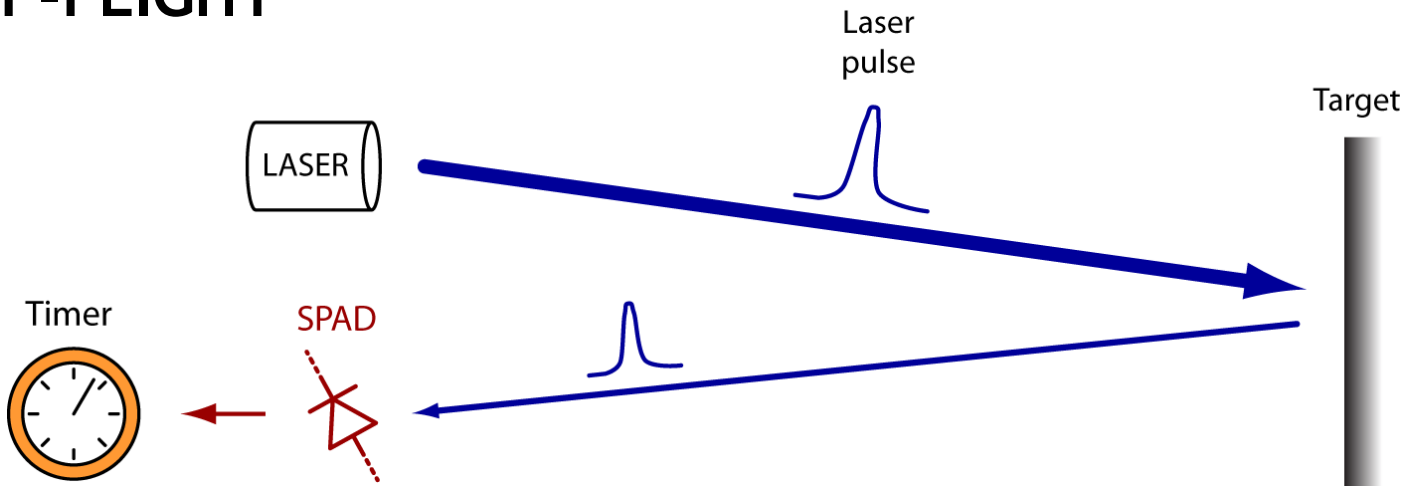
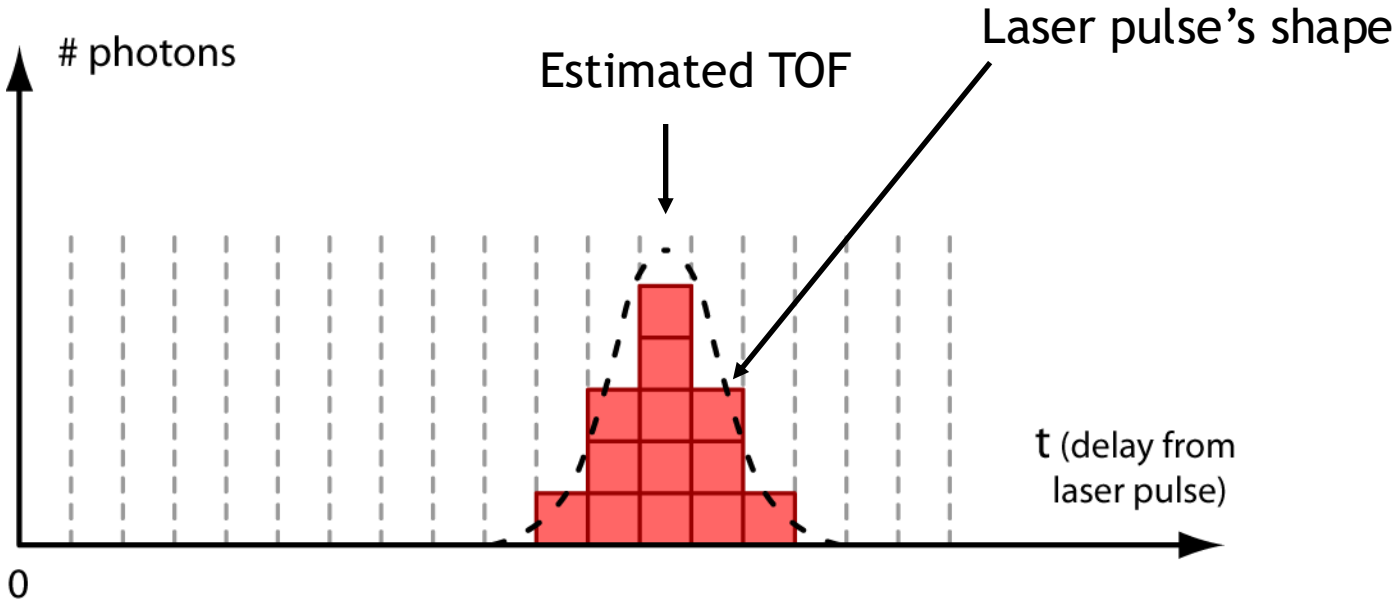
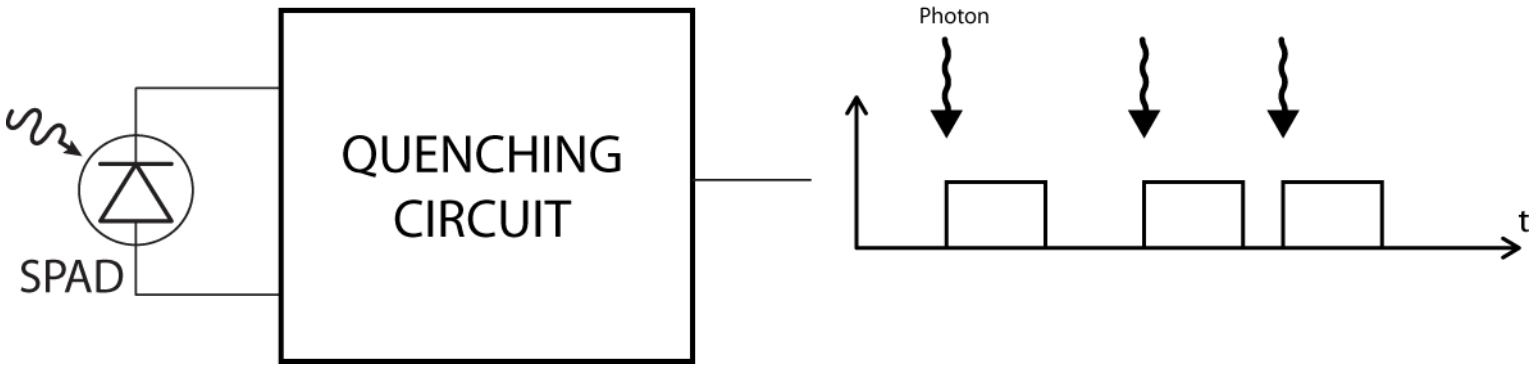




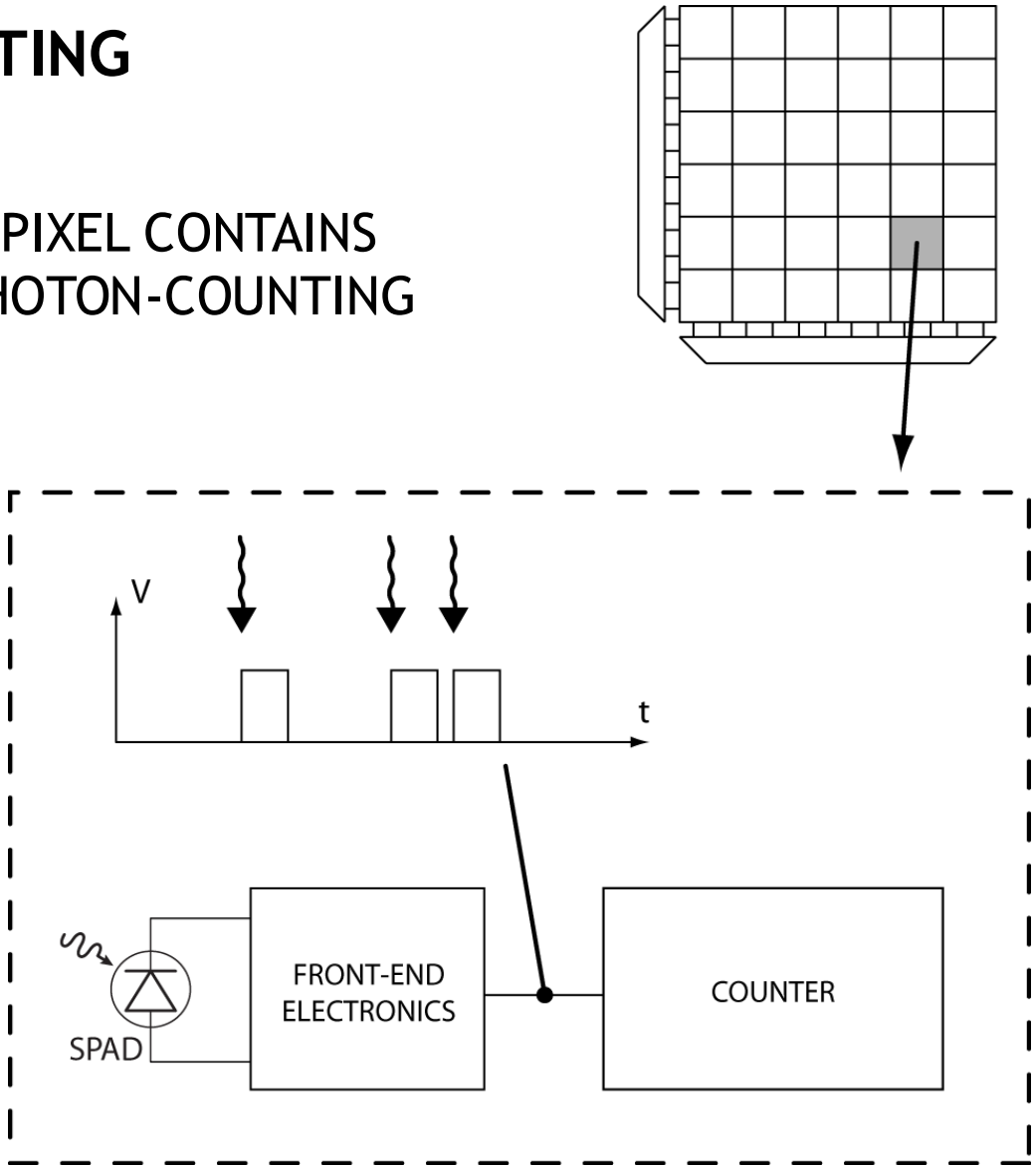
3 - PHOTON COUNTING

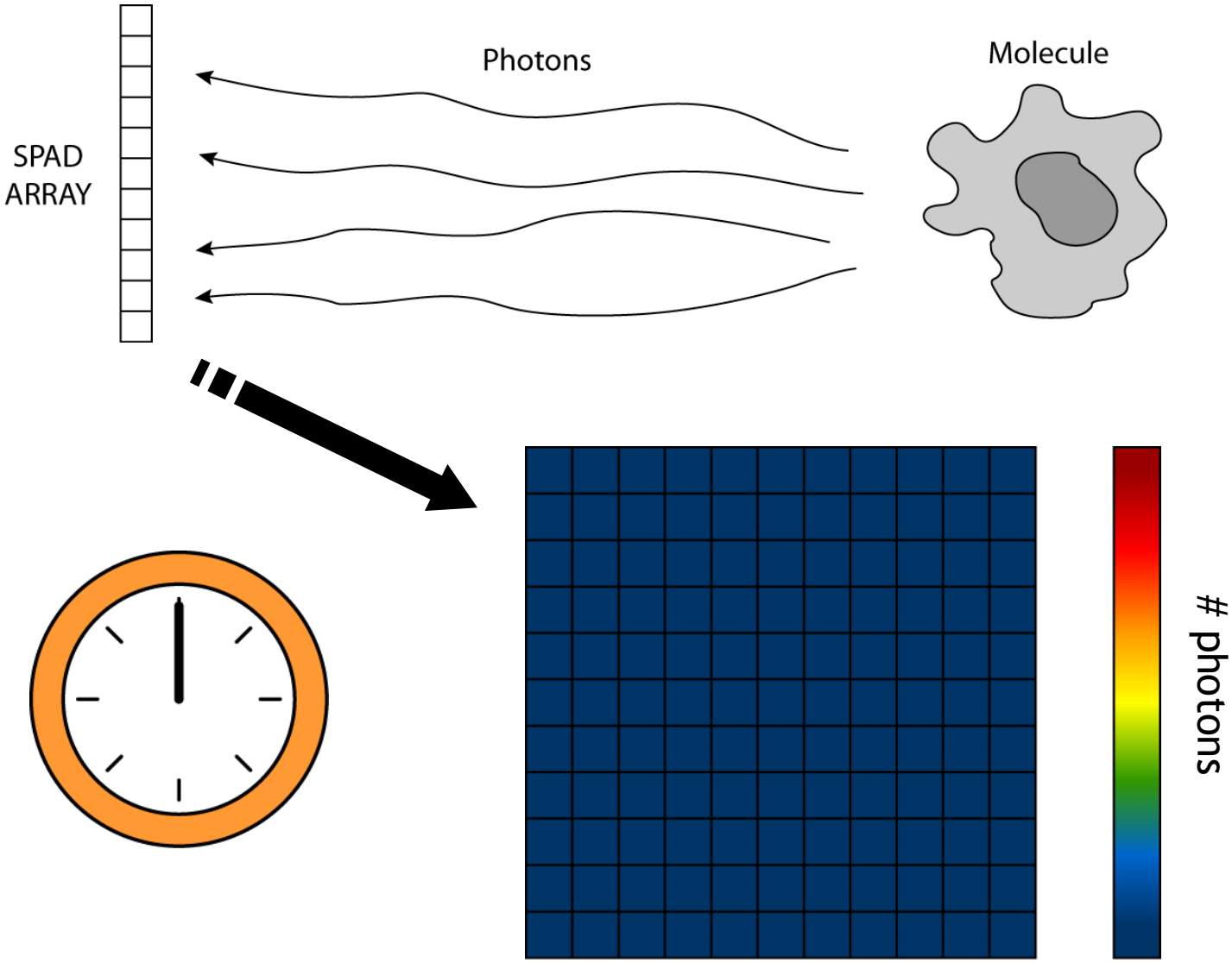


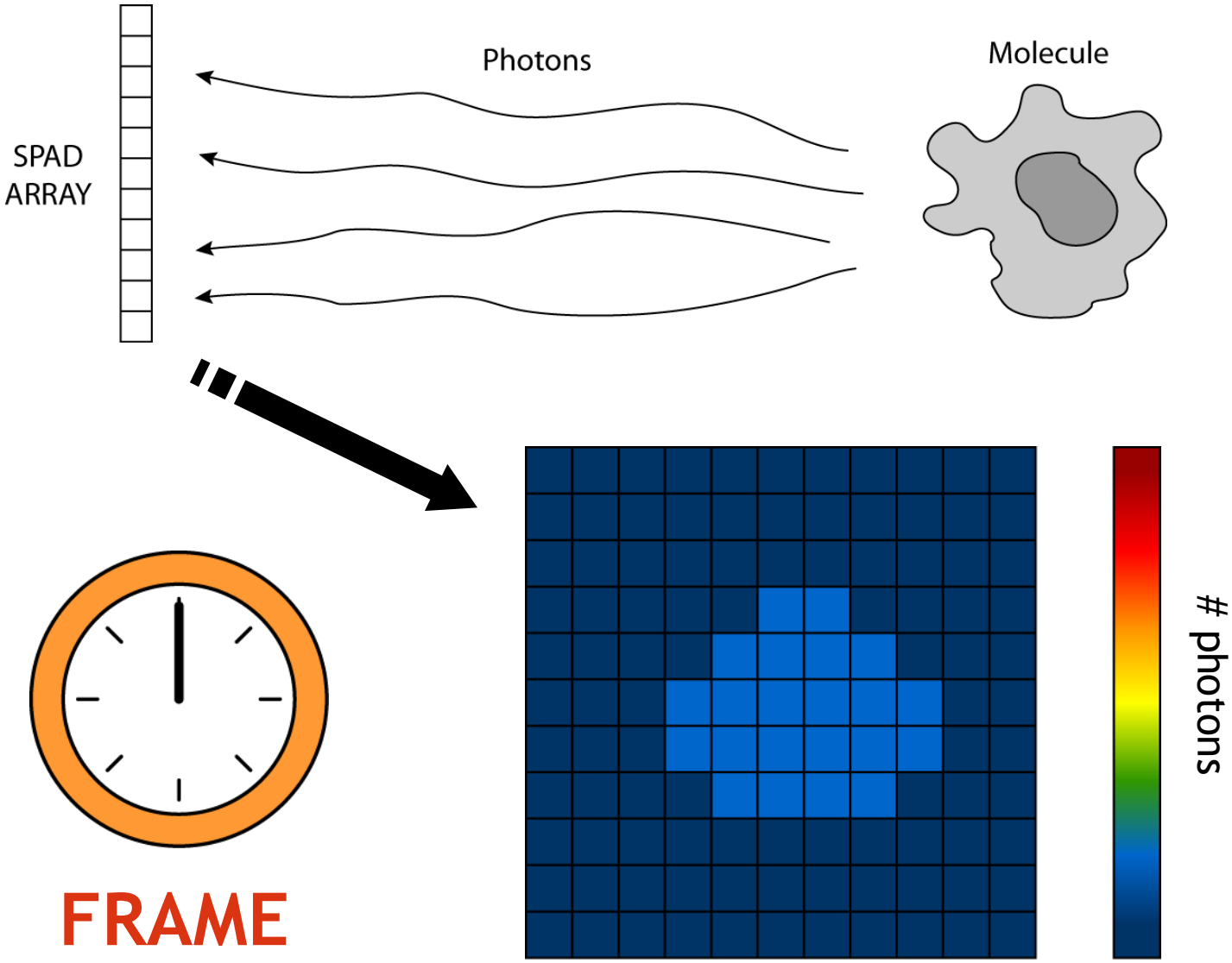
THE QUENCHING CIRCUIT DELIVERS AN OUTPUT PULSE EVERYTIME THE SPAD DETECTS A PHOTON

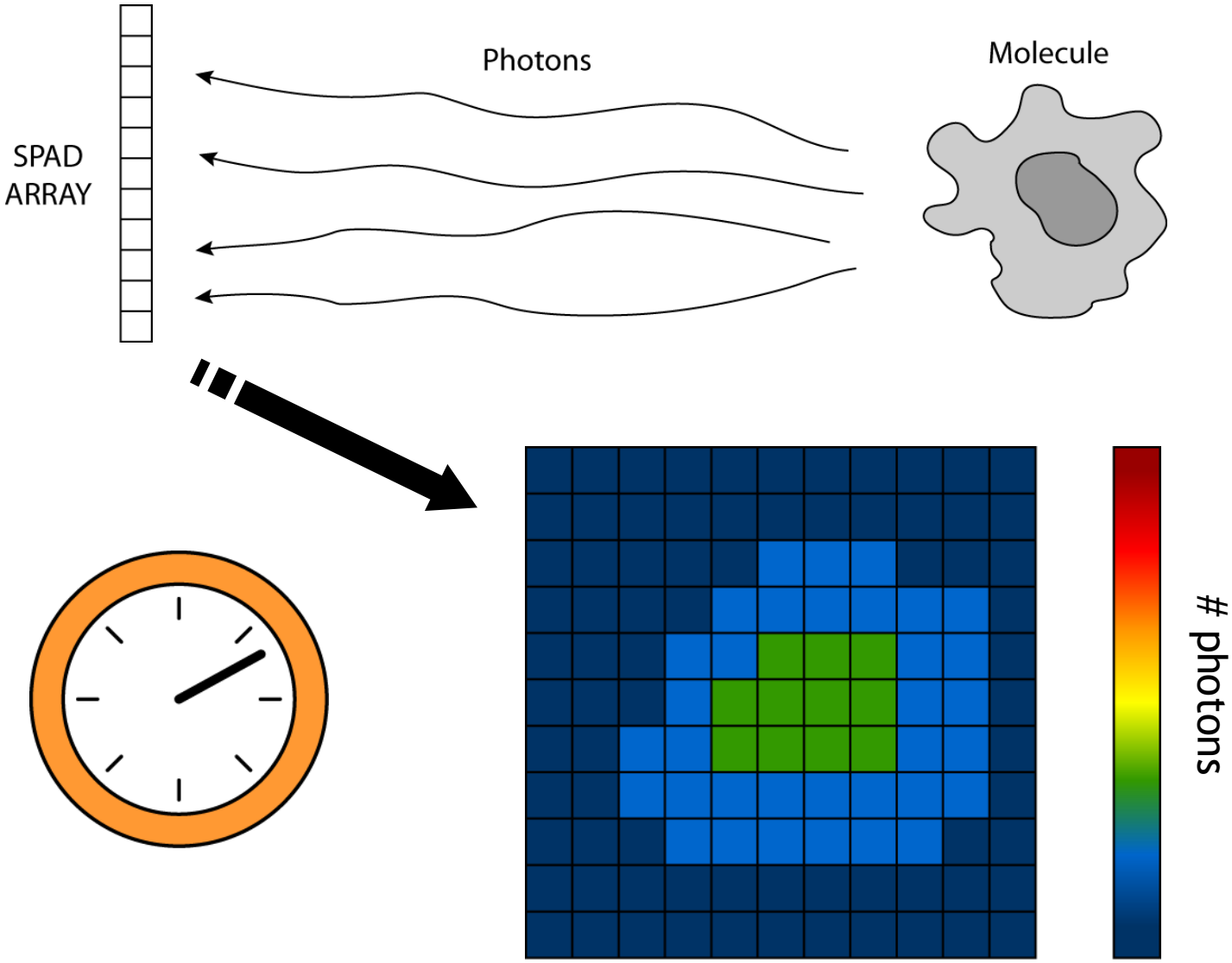
3 - PHOTON COUNTING

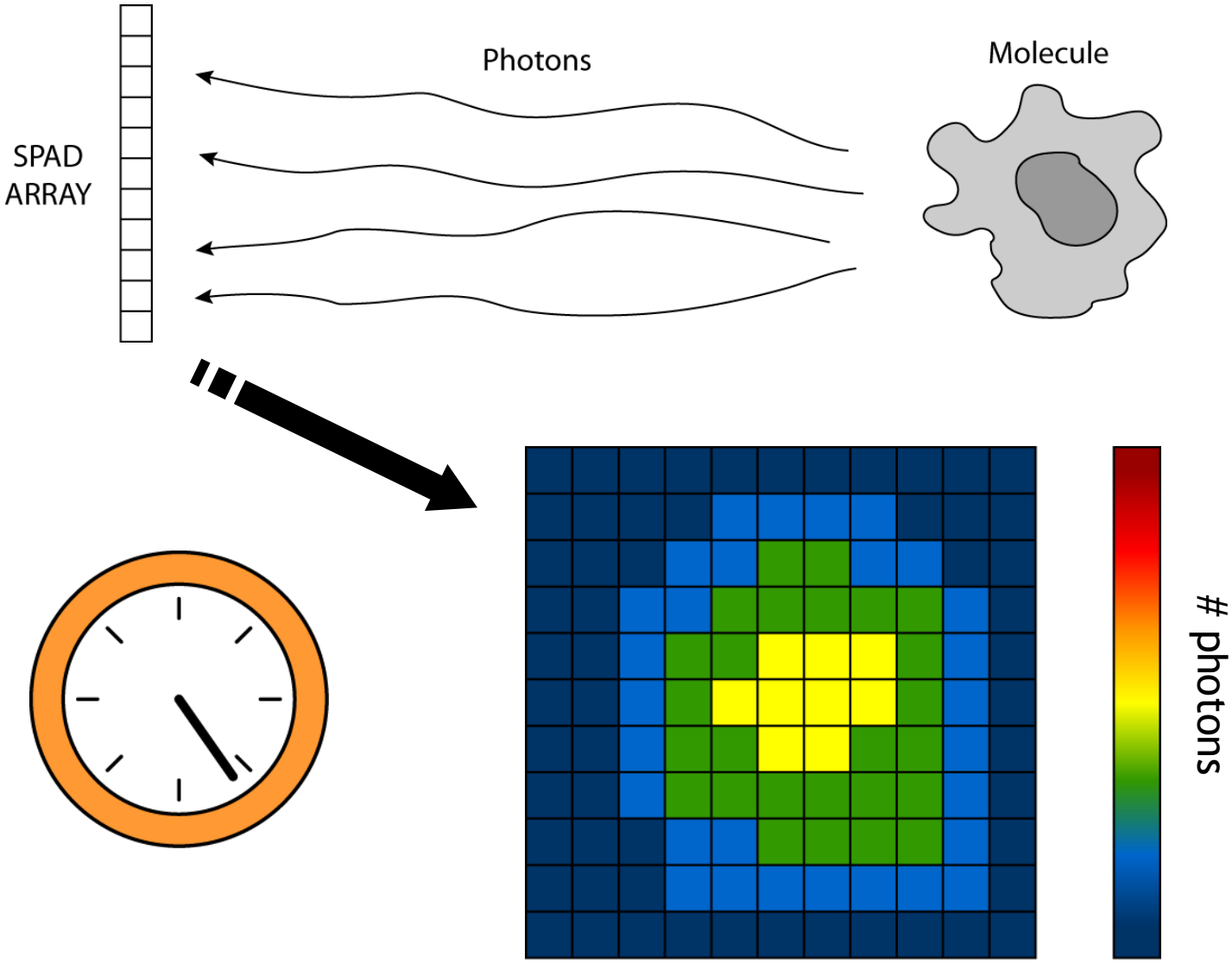
IN OUR ARRAYS EVERY PIXEL CONTAINS
EVERYTHING TO DO PHOTON-COUNTING




SPAD
ARRAY
Photons
Molecule
photons


SPAD
ARRAY
Photons
Molecule
photons
FRAME
START


SPAD
ARRAY
Photons
Molecule
photons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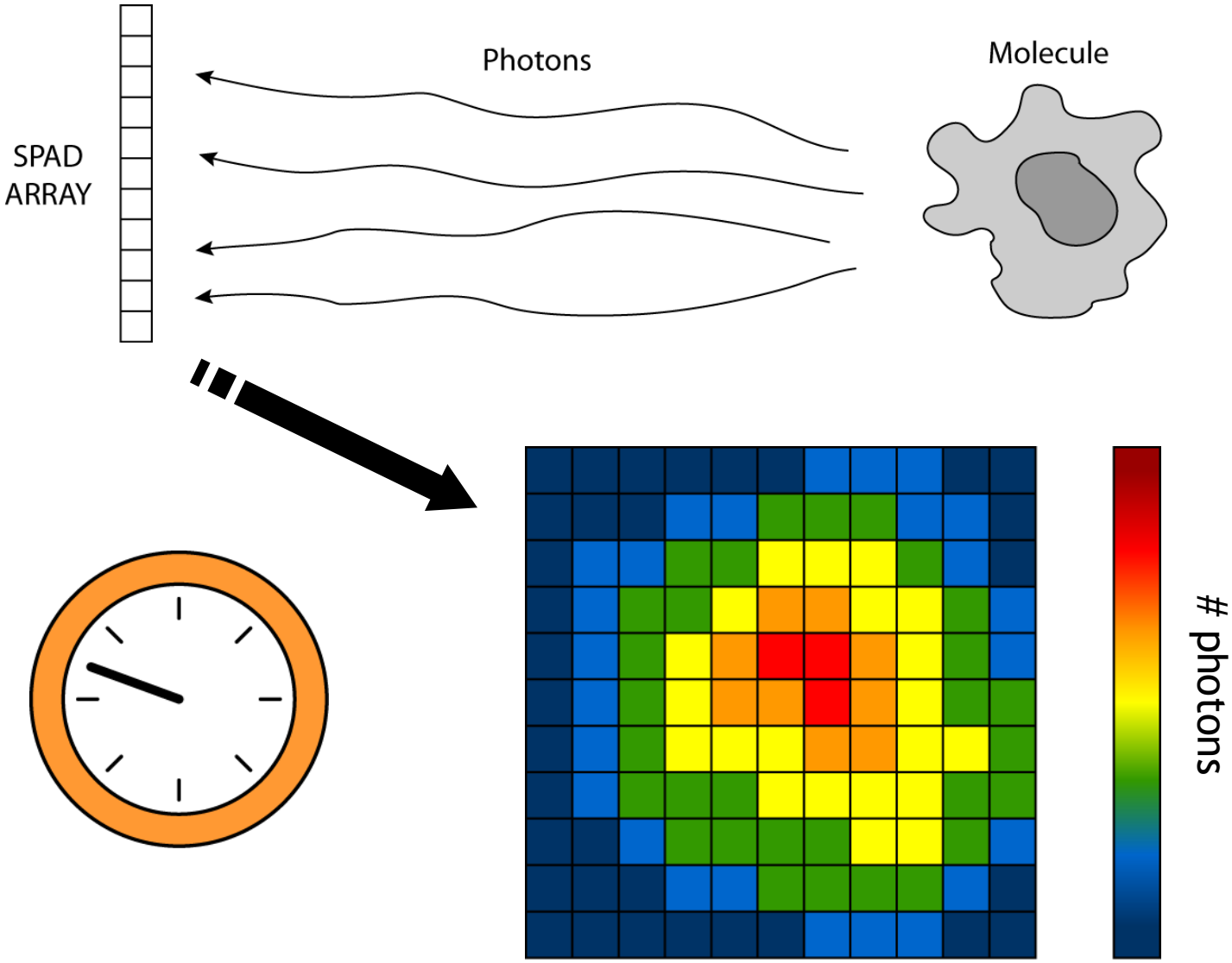
SPAD
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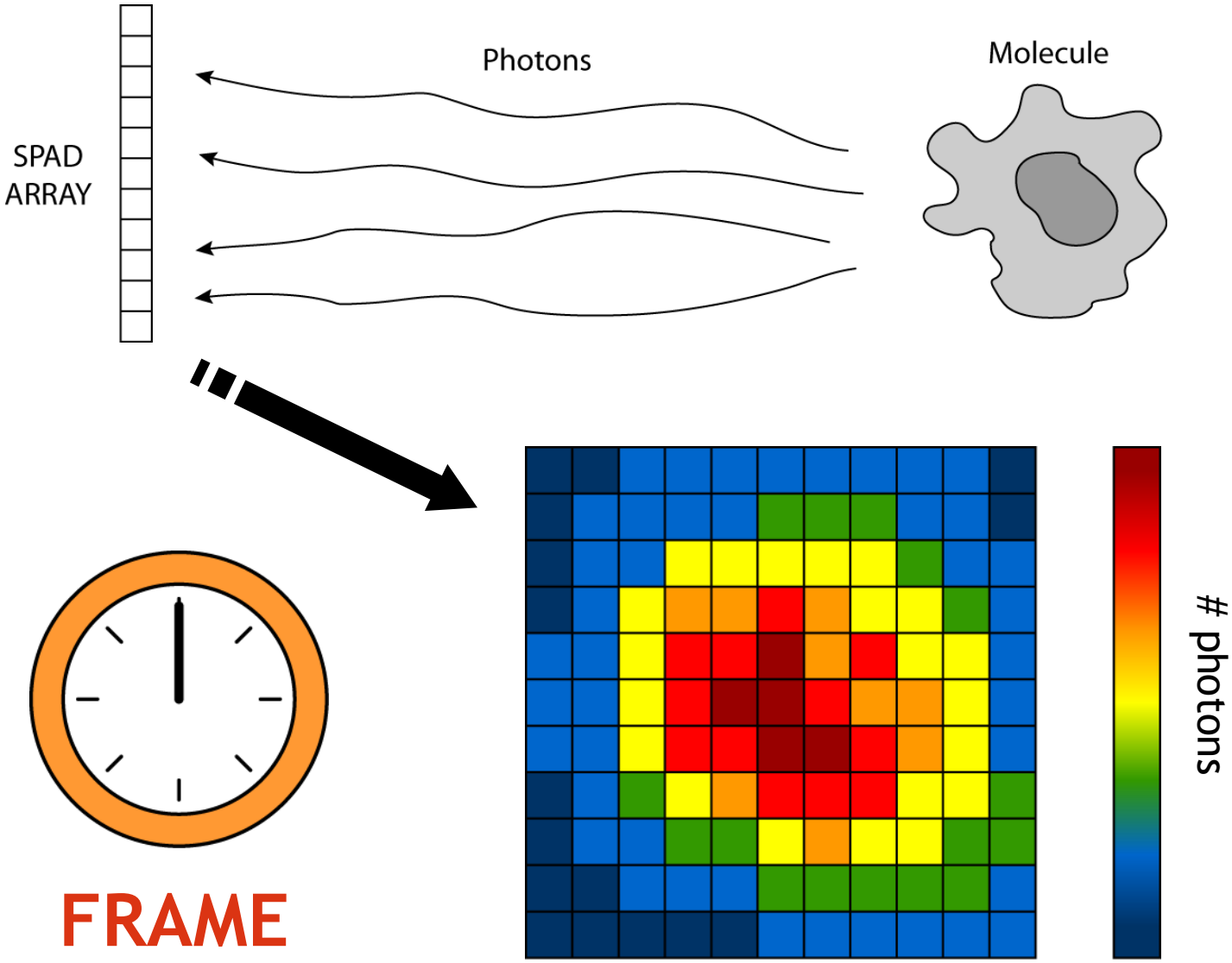
SPAD
ARRAY
Photons
Molecule
photons
FRAME
STOP