Photon to Digital Converter and beyond

Fabrice Retière (TRIUMF)

For the PDC group

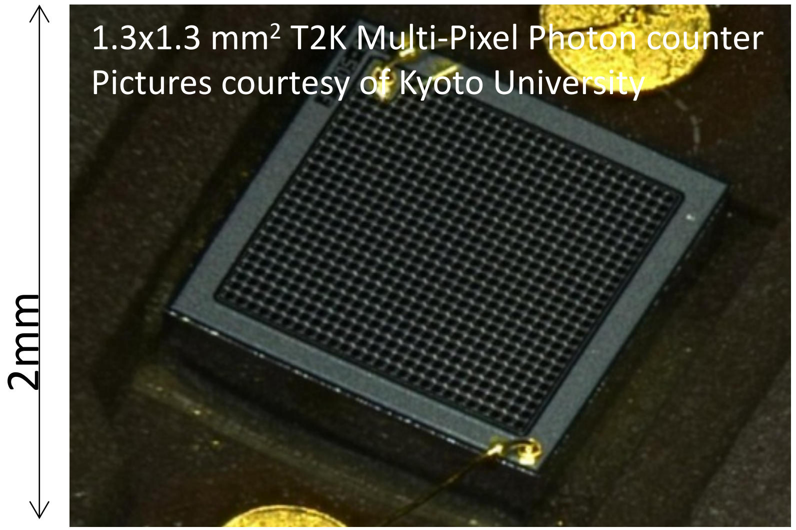
Discovery, accelerated

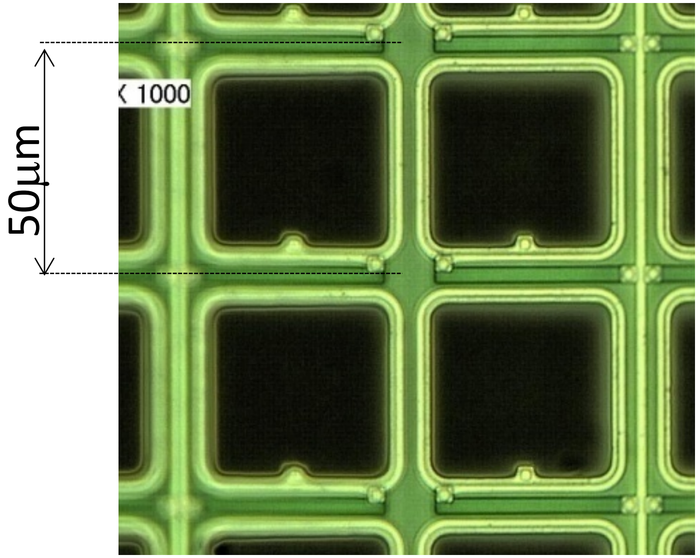
A technology enabling physics discovery

- nEXO – zero-neutrino double beta decay search
  - Single 175nm photon detection over ~5m^2 at -104C.
  - Maximizing efficiency and minimizing radioactivity and power dissipation are critical
- ARGO – dark matter search
  - Single 420nm (or 128nm) photon detection over ~200m^2 at 86K.
  - Minimizing cost while limiting radioactivity and power dissipation are critical
- Other single photon detection applications
  - Detection of scintillation from (small) plastic scintillator → uSR, EIC?, ..
  - Water Cerenkov or large scintillator but dark noise is an issue
- Beyond single photon detection

Silicon photo-multipliers

- Single photon avalanche diode (SPAD) array
- Single photon detection capability
  - High gain
- Large manufacturing capabilities
- High efficiency
- Radiopurity
- “Low” dark noise if cold

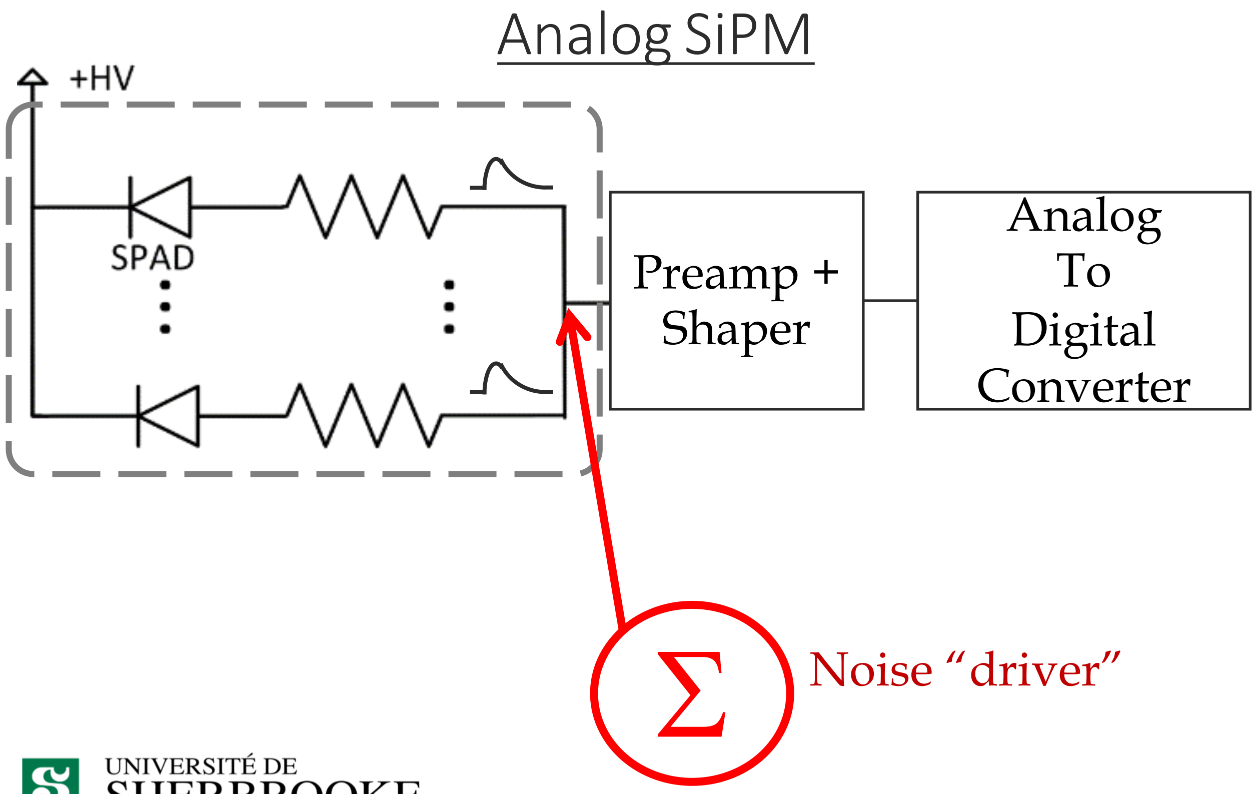


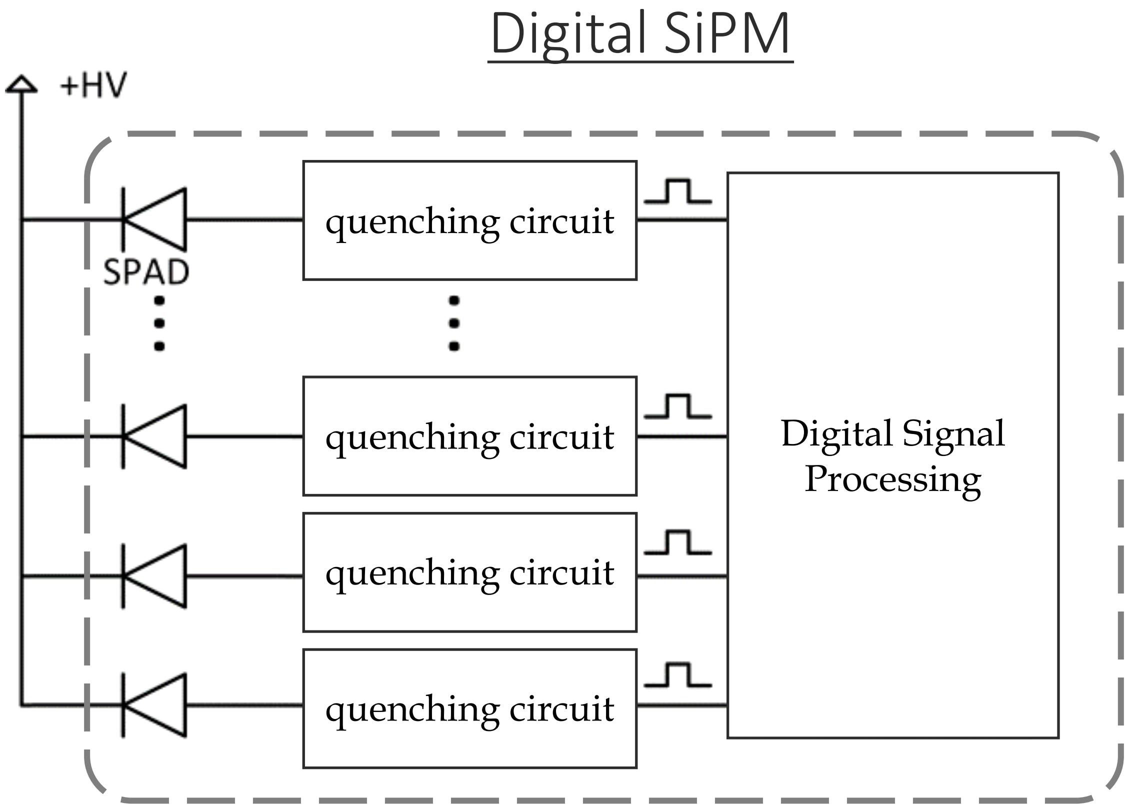


K. Yamamoto et al. PD07(04)

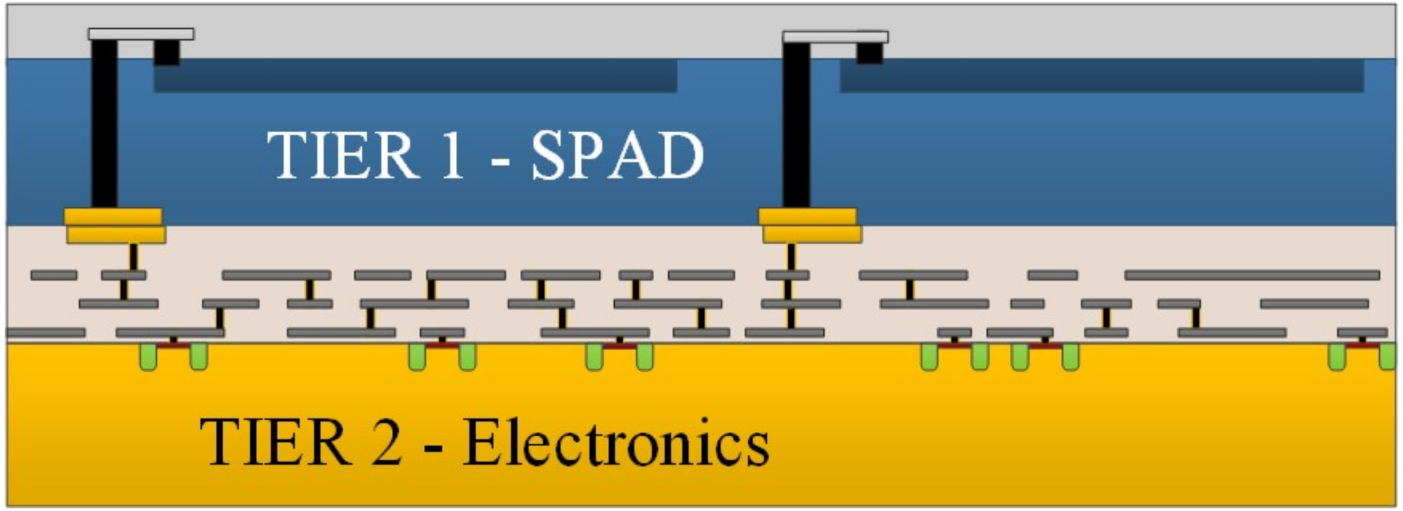
Going digital

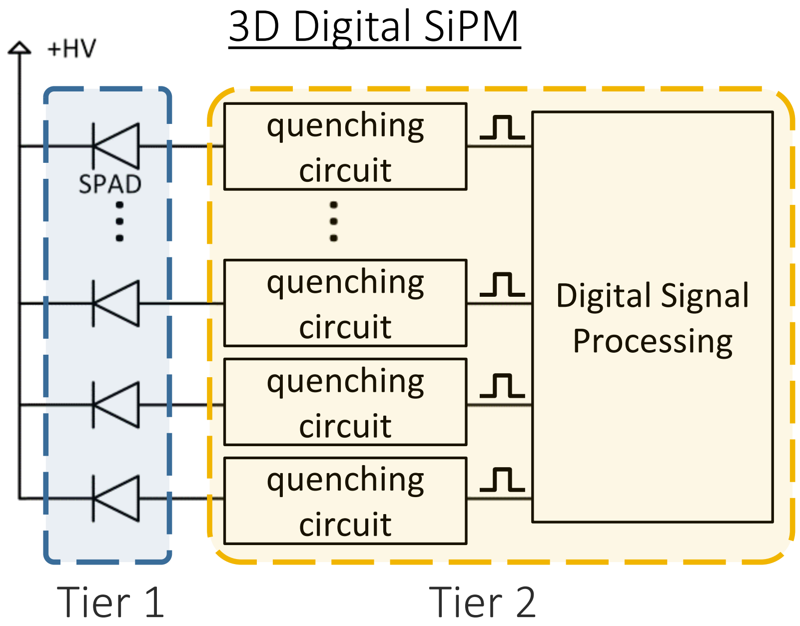
Single photon avalanche diode (SPAD) is the basic unit cell of **analog and digital SiPM**





3D Digital SiPM / Photon-to-Digital Converter Concept

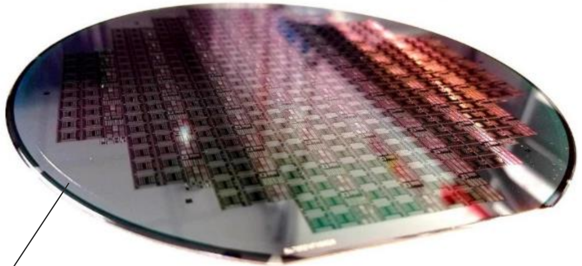




How to Build a Fully Industrial 3D Digital SiPM ?

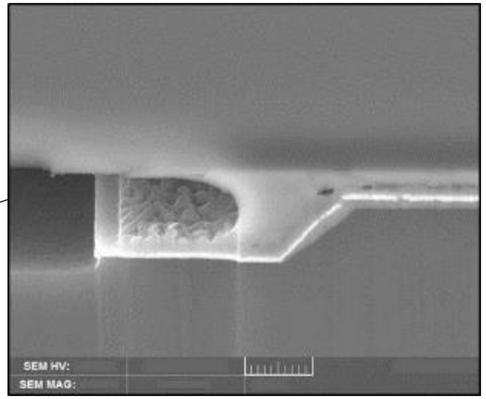
Partnership with Teledyne DALSA Semiconductor Inc.
(Bromont QC, Canada)

TELEDYNE DALSA
Everywhereyoulook™

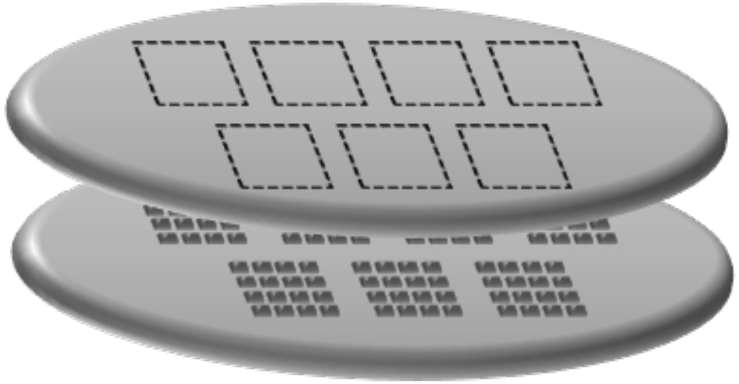


SPAD process

3D process



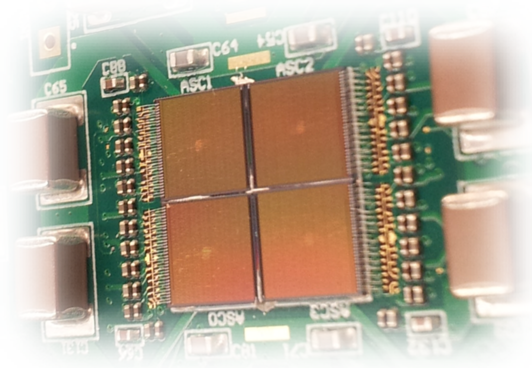
Wafer scale 3D digital SiPM technology



SPAD array layer

Wafer level process

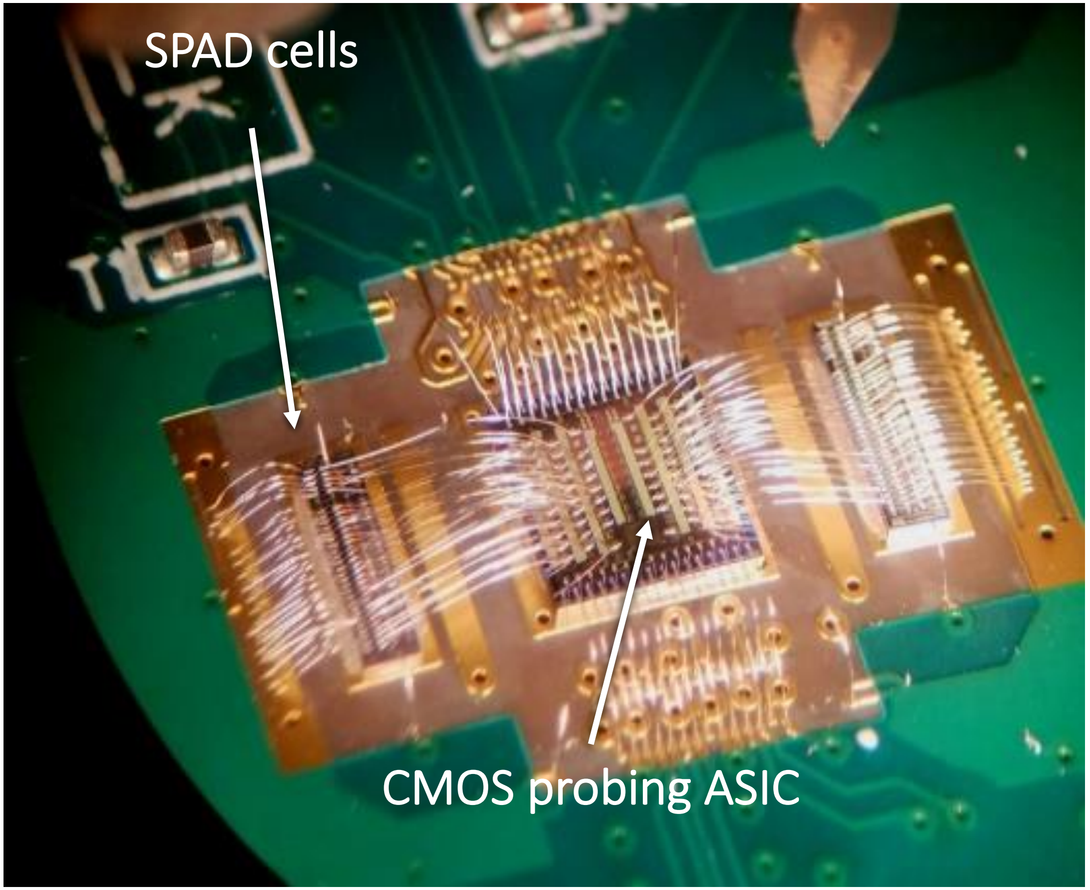
CMOS readout

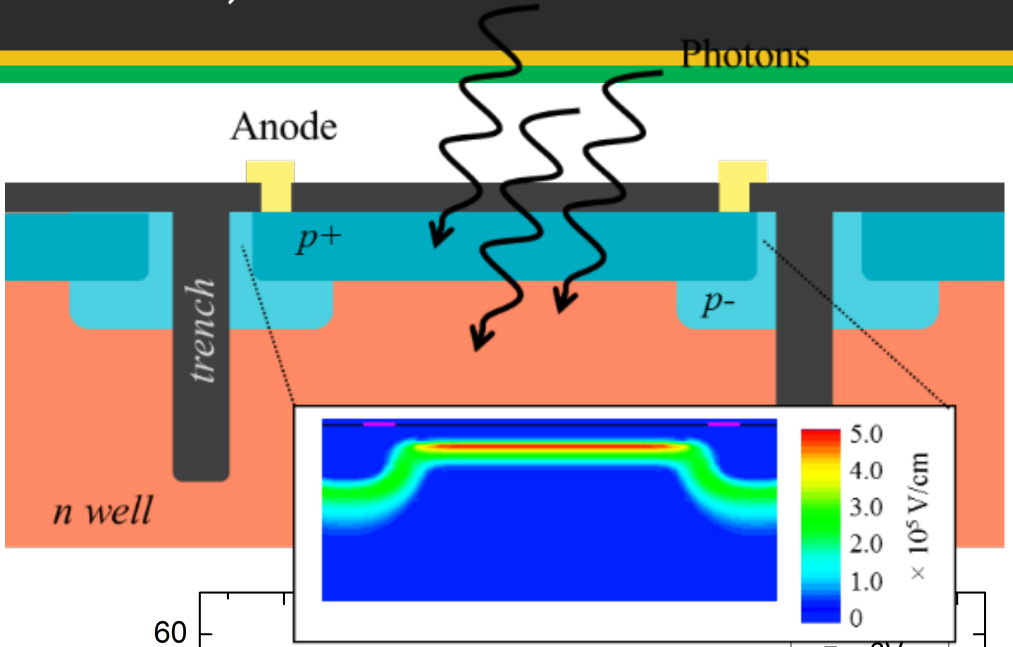


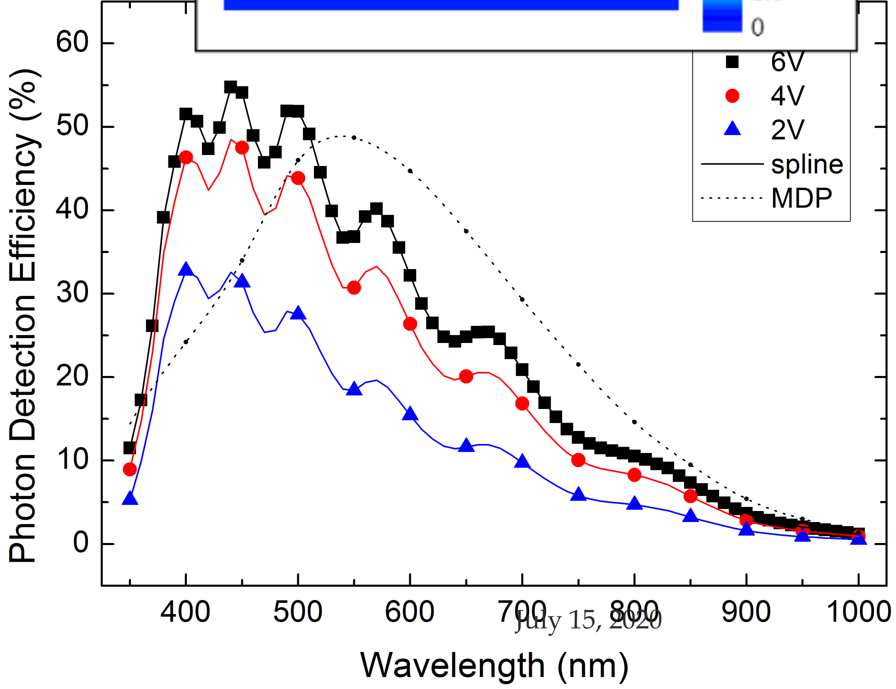
TSMC CMOS readout

2D SPAD made-in Canada (Bromont, QC)

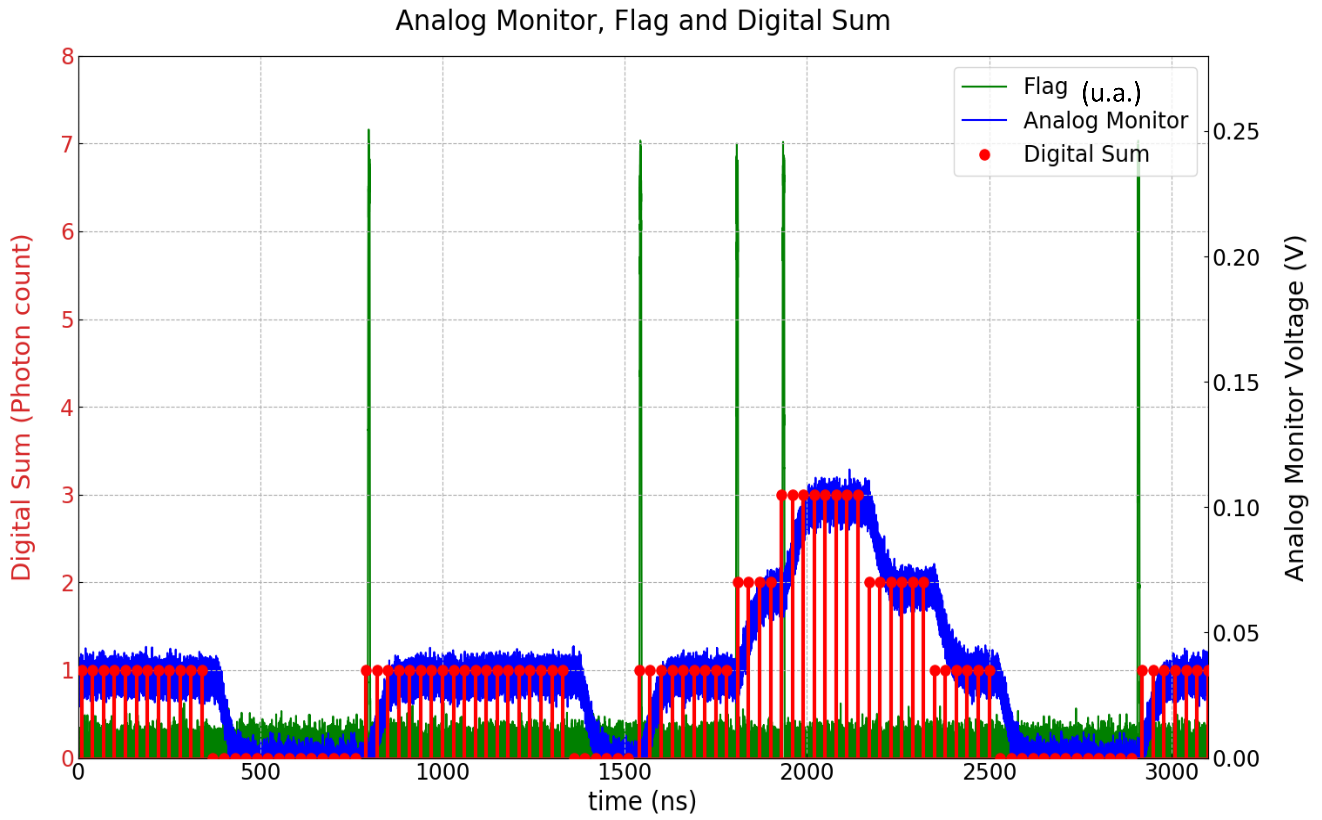
- 150 mm wafer (custom process using DALSA CCD production line)
- 1x1 to 5x5 mm^2 SPAD array

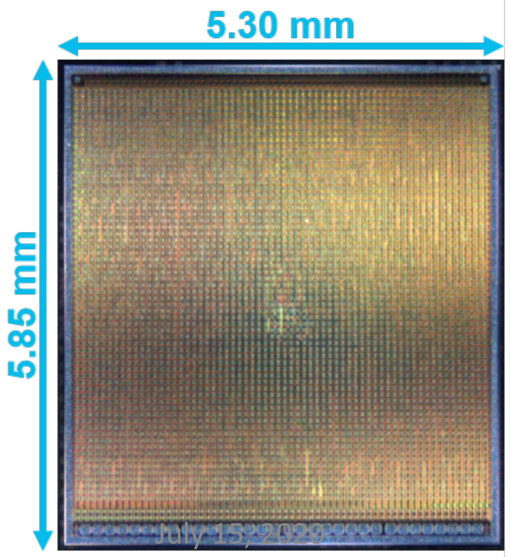


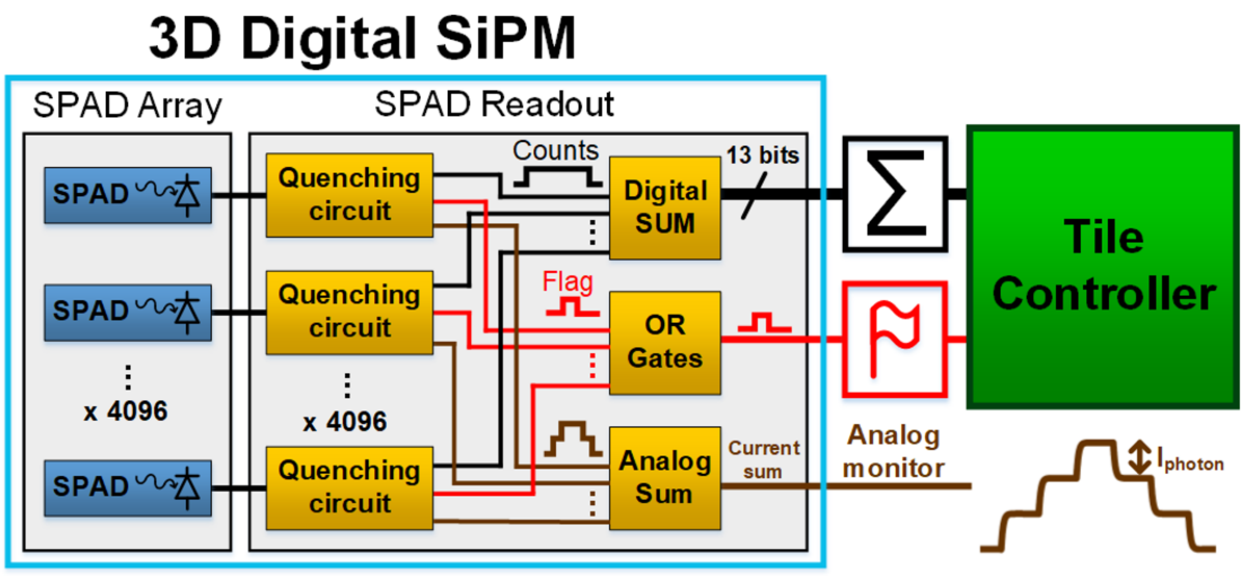




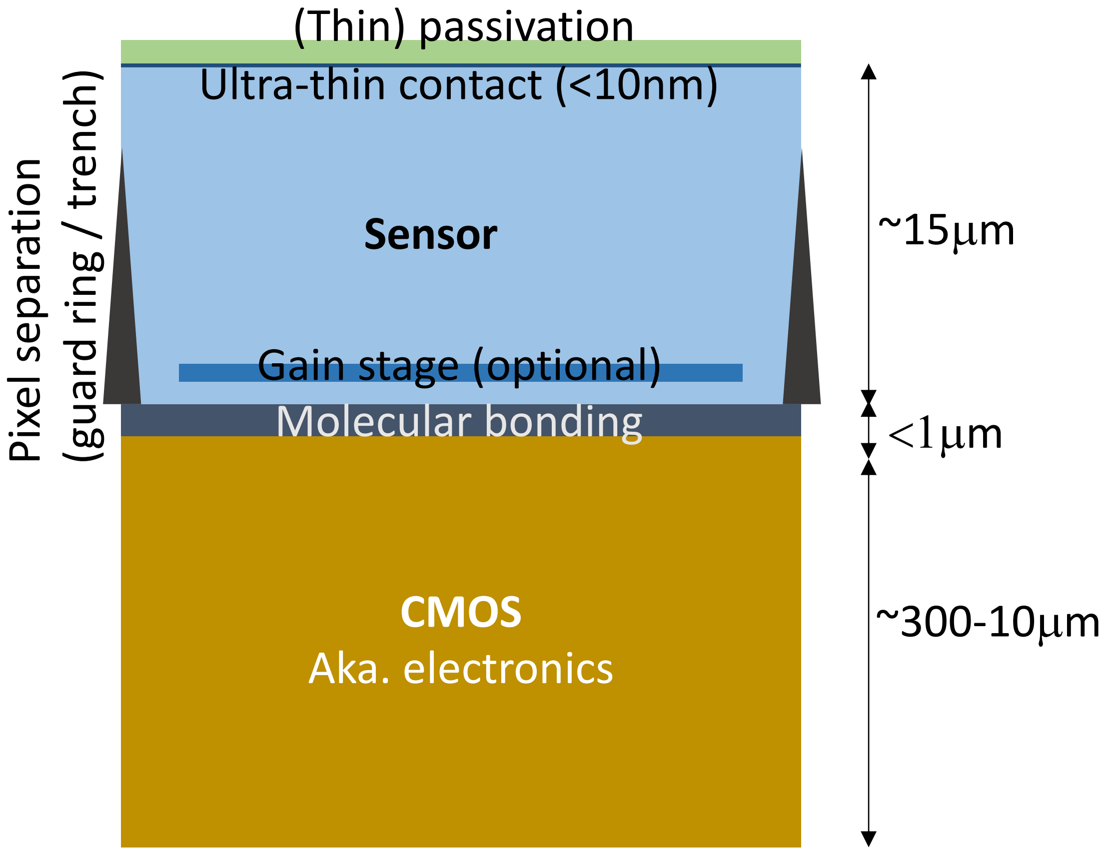
CMOS designed in Canada





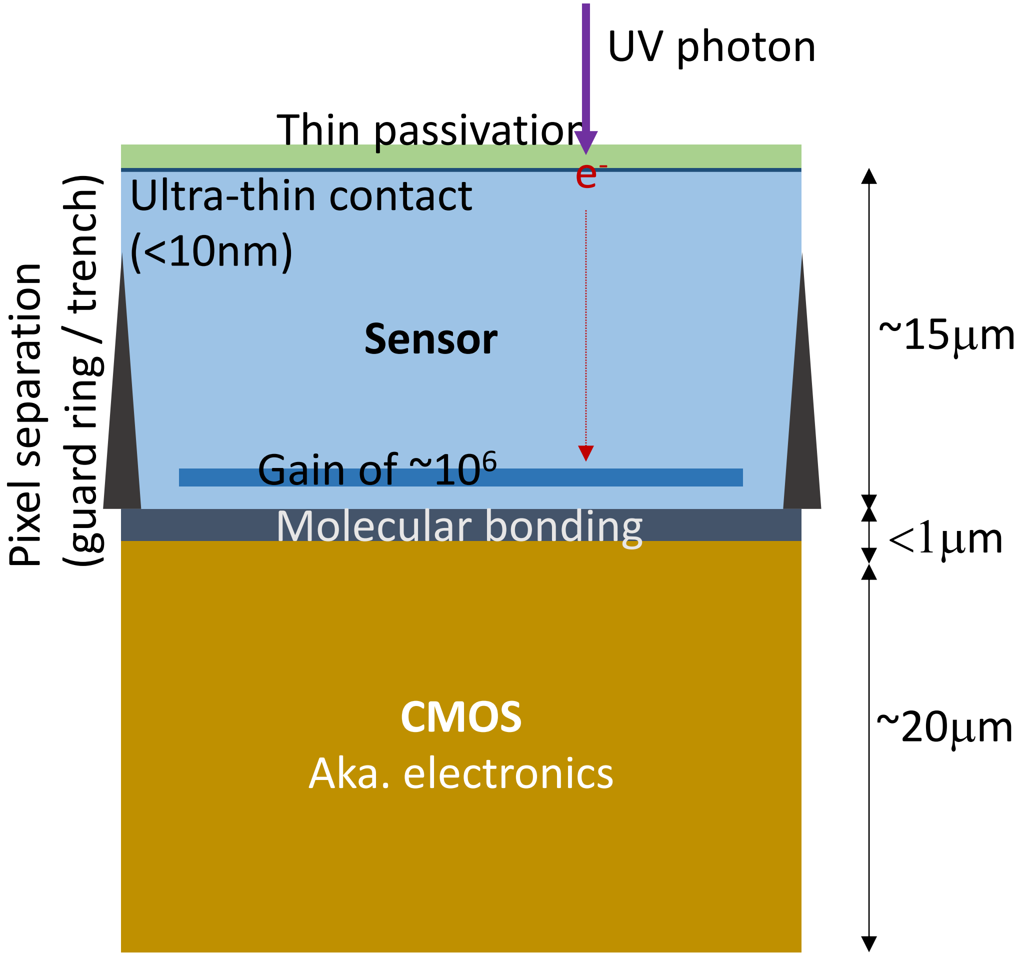


Moving towards a versatile solution
Hybrid (silicon) detector technology



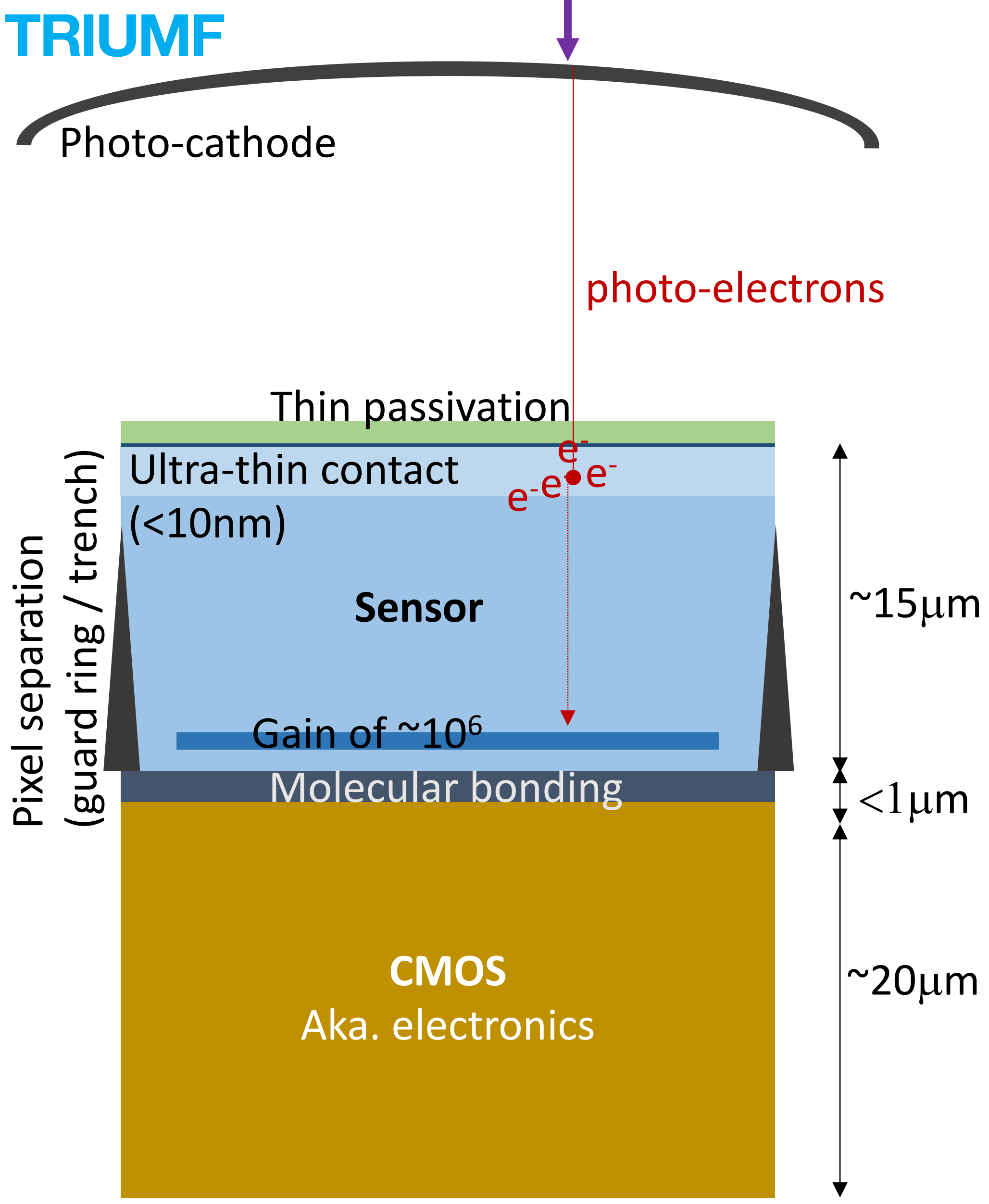
- Tight connection between electronics and sensor
- CMOS is Si but sensor does not have to be
- Major R&D effort in avalanche Si detector
- Molecular bonding is a very strong bond
- Key expertise in Canada at Teledyne-DALSA (Bromont, QC) and U. Sherbrooke (QC)

Hybrid solution for UV (120-400nm) photon



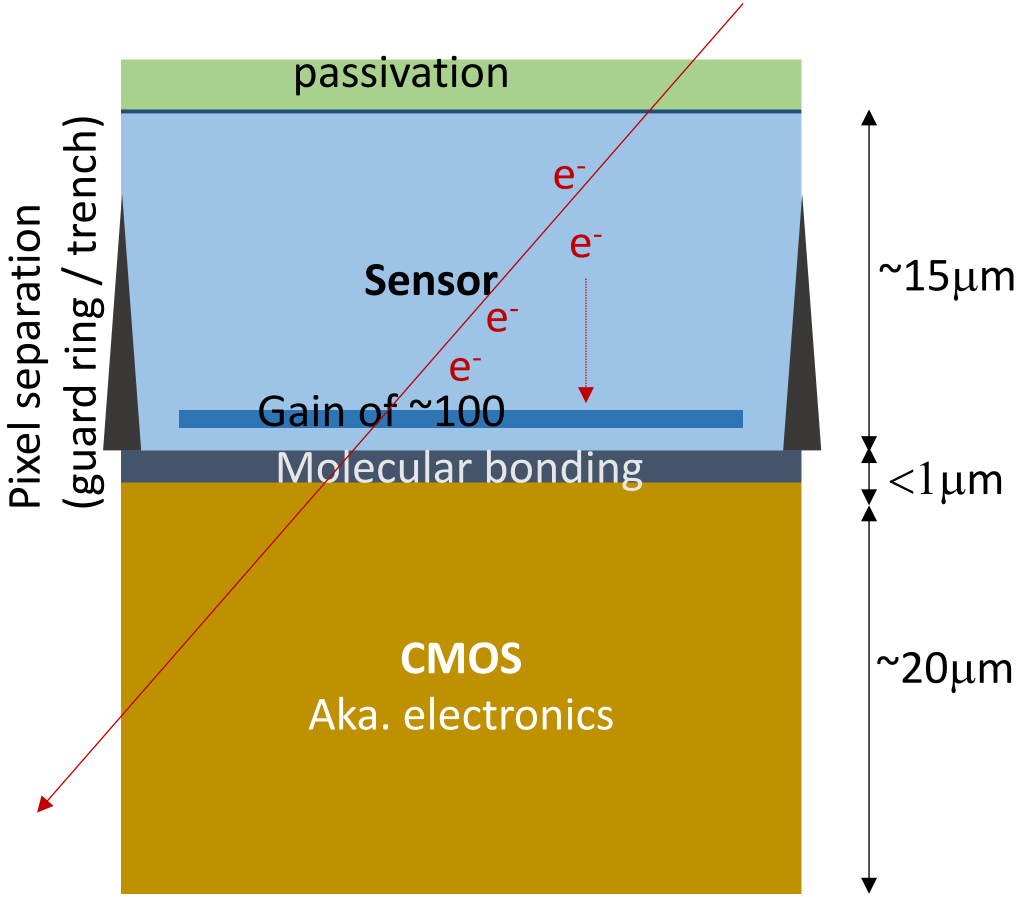
- Single photon avalanche diode
  - Gain > 10^5
- Advantages
  - Very high efficiency expected (>50%) in UV and visible
  - Single photon timing resolution <50ps
- Back-Side illuminated concept require significant R&D

Beating down dark noise



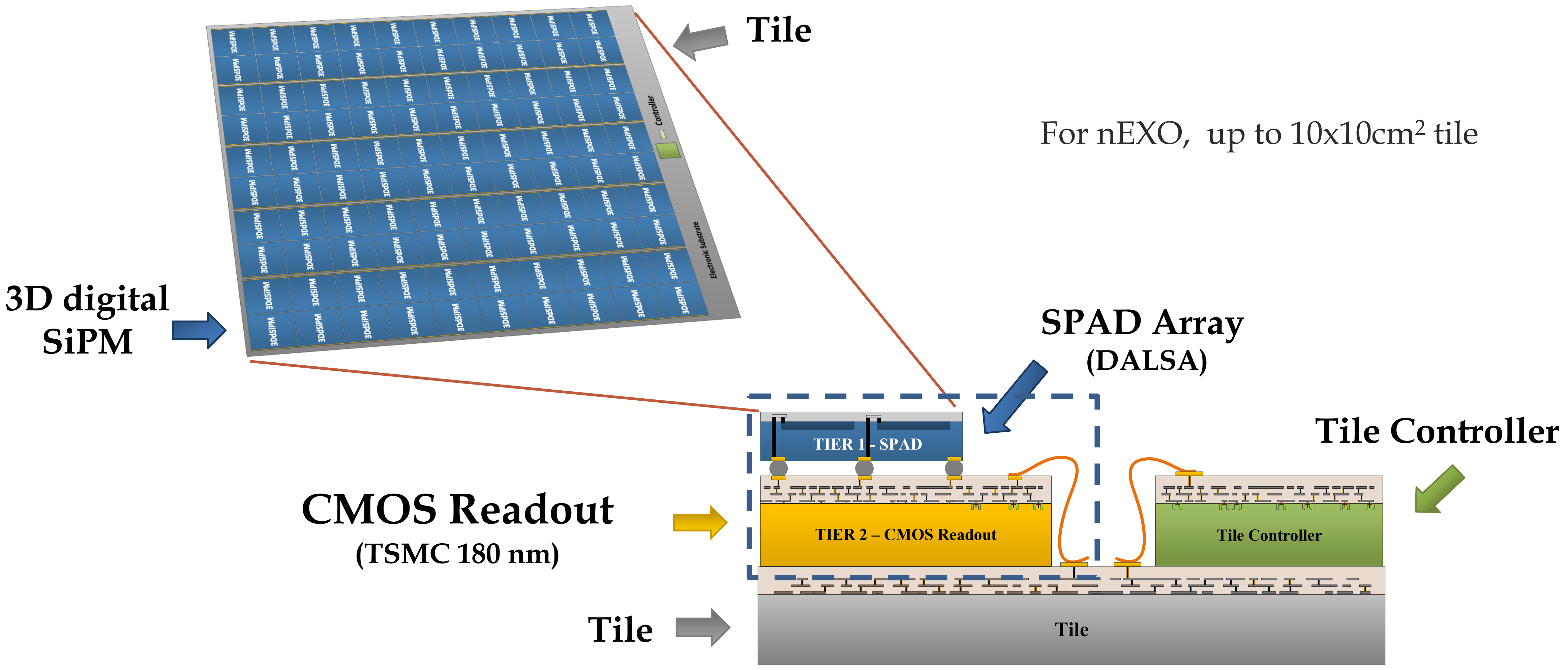
- Essentially identical constraints to VUV photon detections
  - Limit material in path of photo-electron
  - Charge collection very close to surface

Hybrid solution for tracking



- Low Gain Avalanche diode for future colliders
  - Expected to be radiation hard
- Advantages for nuclear physics
  - Very thin
  - Timing resolution < 100ps

From sensor to module

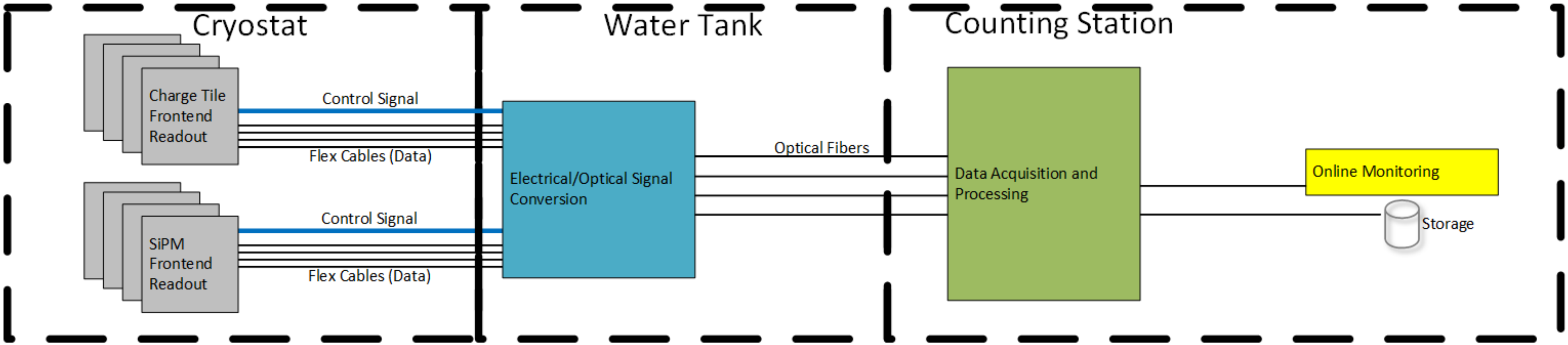


For nEXO, up to 10x10cm^2 tile

Scaling up to m^2

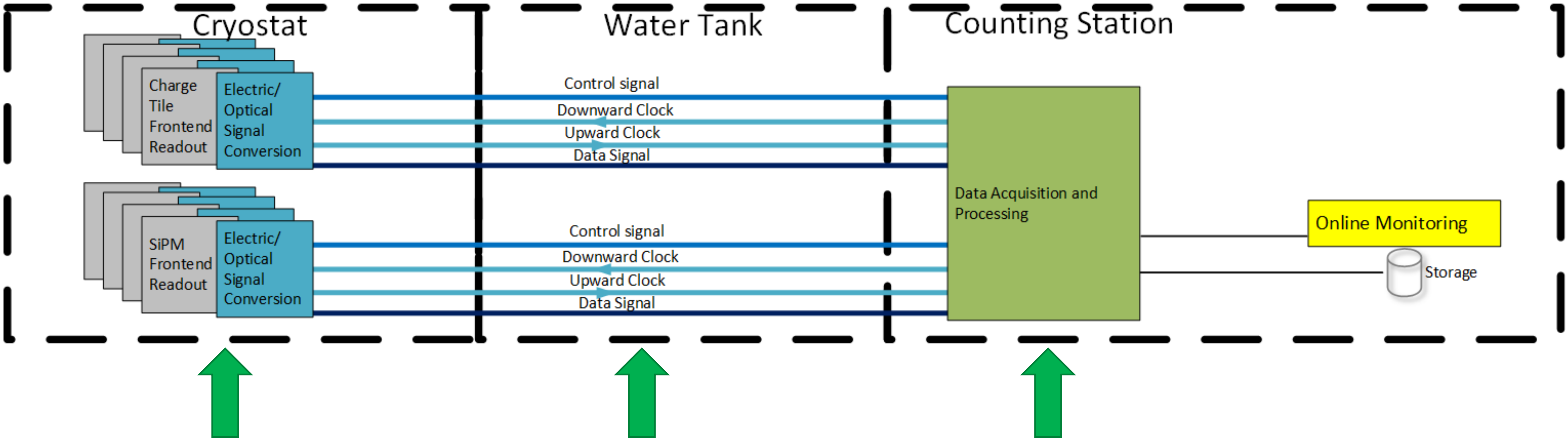
- Tiling constraints depend on application
  - Silicon interposer compelling for cryogenic, low radioactivity constraint
  - Minimizing radiation length and radiation damage at colliders would probably require a different solution
- Ultra-low power data transfer using photonics
- Building the capabilities for mass production with industry

nEXO Readout System - Baseline



Source: M. Chiu, L. Fabris, K. Kumar, F. Retière, S. Sangiorgio, L. Yan. “Trigger and Sparsification Committee Report”

nEXO Readout System example – Silicon Photonics for data transfer



No laser source at this stage.

Uses interferometry to modulate a clocked laser signal with data.

N.B. Staves of tiles could be muxed to minimize number of fibers (feedthroughs)

All data links are fibre optics all the way between the tiles and counting station.

Power cables are still copper.

Laser source.

Data acquisition module(e.g. FELIX borad)

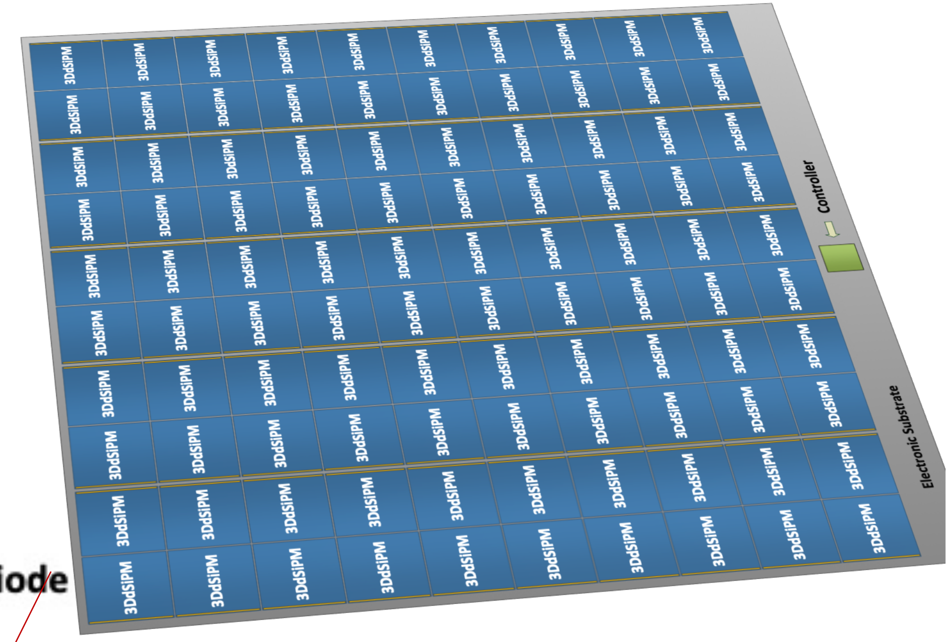
Scope of work

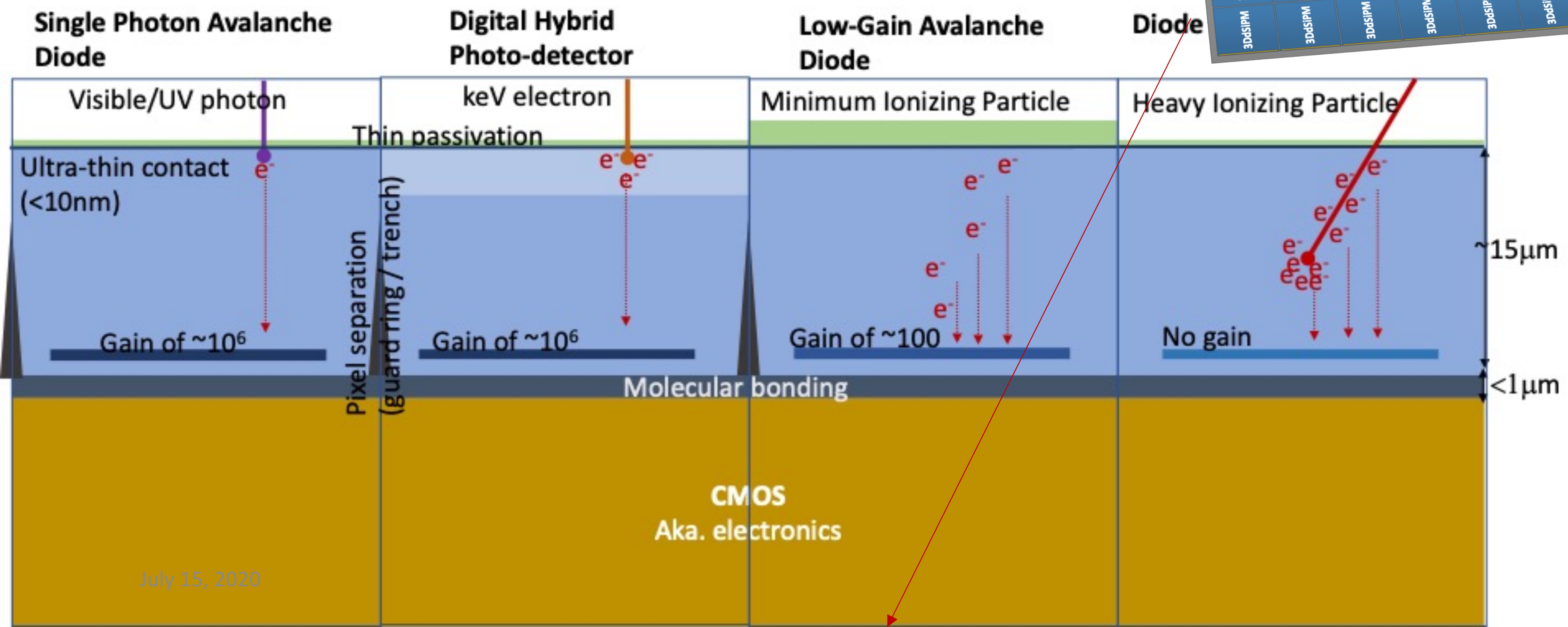
- 2022-2026
  - Establish collaboration for the development of Photon/Particle to Digital Converter in Canada
    - Include SPAD (photon), Hybrid photo-detector (photon), LGADs (tracker), and non-silicon solution
    - Consider joining RD50 collaboration
  - Develop set of prototype solutions
  - Start production within a big project if nEXO or ARGO move forward
  - Expand scope within and beyond subatomic physics
  - Develop photonic data transfer system prototype
- 2028+
  - Develop a complete set of module-size solution
  - Use solution in at least one major subatomic physics project
  - Foster commercial applications

Many technology transfer opportunities

- Time of Flight Positron Emission Tomography (led by Sherbrooke)
- Single Photon Air Analyser (led by TRIUMF)
  - Used for smoke (even early forest fire detection) and pollution detection
- Quantum communication and computing
  - Very promising with compelling physics experiment "spin-off"
- 3D imaging coupled to pulse light source
  - LiDAR – major market but probably too big to chew
- In general excellent topic "benefitting Canadians" in CFI jargon

Summary. A versatile Canadian technology





The end…
Q2Bit, a future Canadian story?

Photon to Digital Converter (PDC) →

Photon/particle to Digital Converter(PPDC) →
Quanta to bit (Q2Bit) converter

A mostly astro-particle driven technology