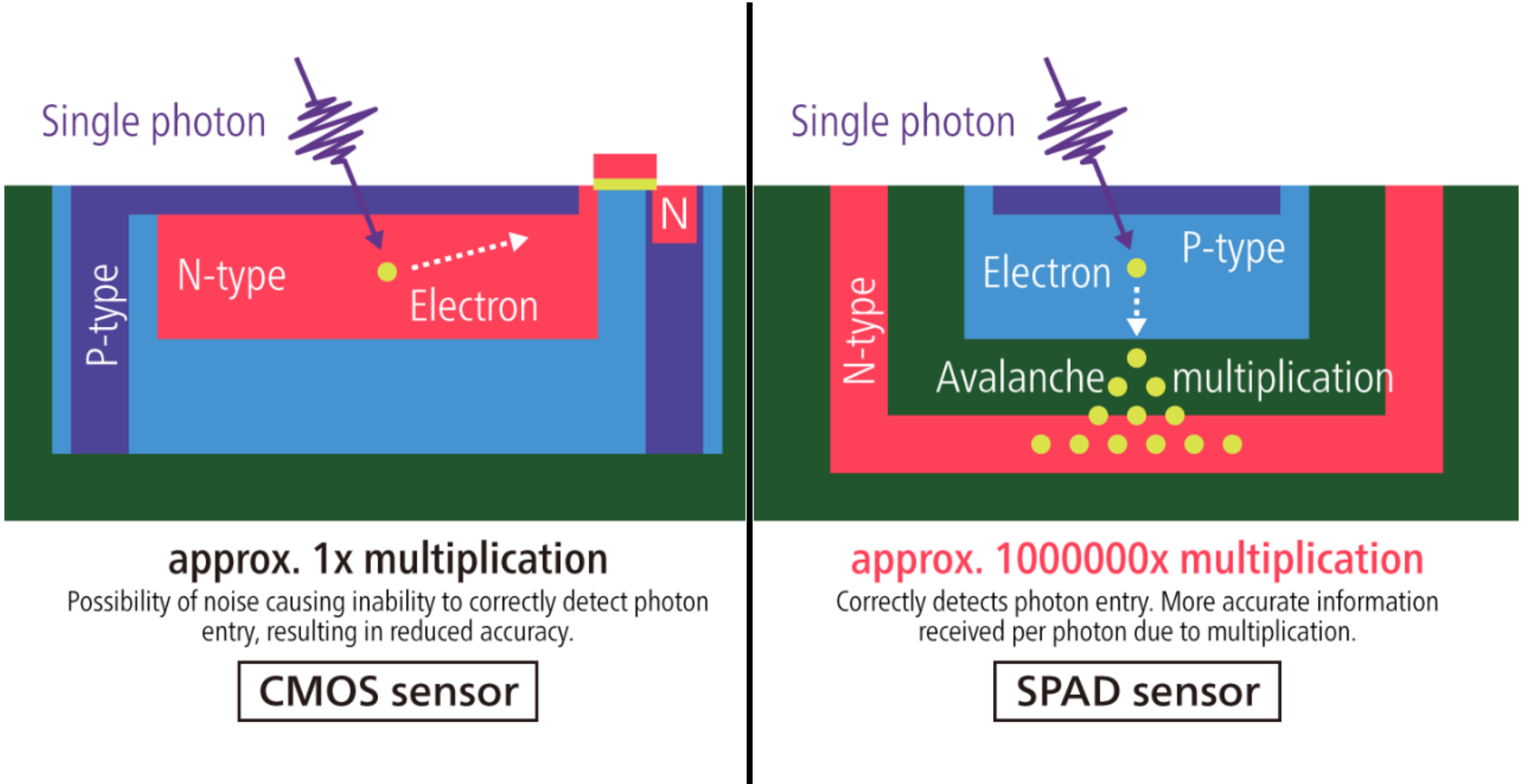
Digital SPAD array for many things

Fabrice Retiere (TRIUMF)

Discovery, accelerated

Single Photon Avalanche diode



https://www.canon.ca/en/Discover/Commercial-Imaging-Solutions/SPAD-Sensor-Long-Range-Night-Vision

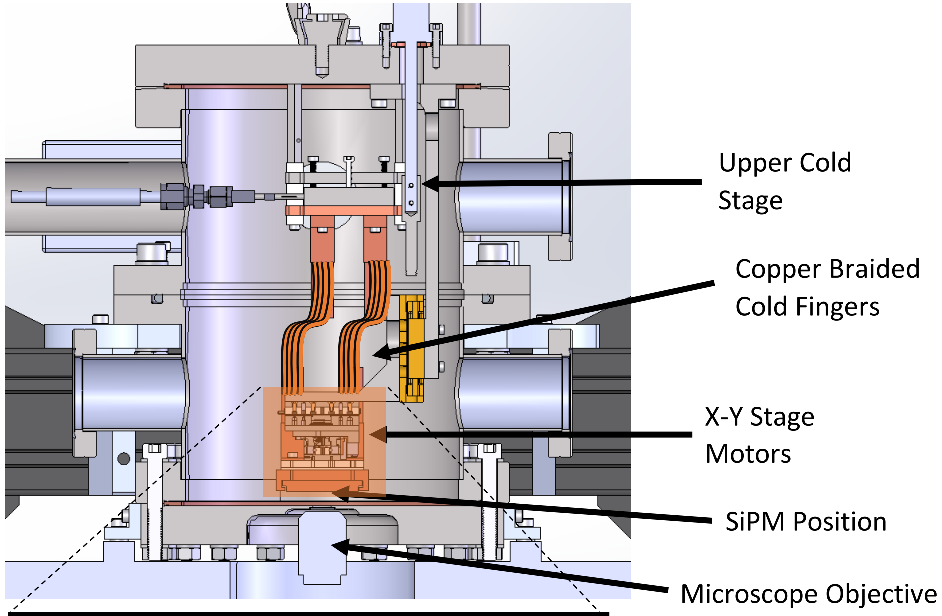
SPAD in astro-particle physics

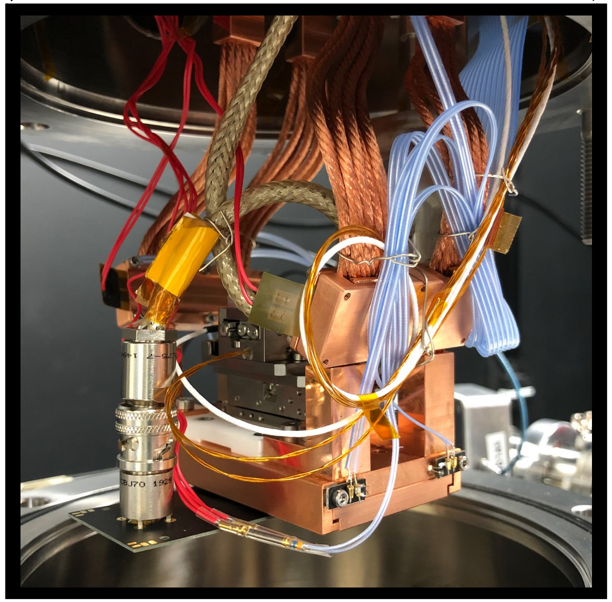
- Used/foreseen by several experiments
  - 4.5 m^2 for nEXO in liquid Xenon
  - 30 m^2 for DarkSide-20k for Dark matter search in liquid Argon
    - ARGO may need up to 200 m2
  - Considered for XLZD and DARWIN for dark matter search in liquid Xenon

- Pros
  - Ultra-low radioactivity (1/1000 compare to PMTs)
  - High efficiency
    - 25% at 175nm (vs 35% for PMT)
    - >50% at 420nm (vs 35% for PMT)
  - Fast timing (small size)
  - Few issues
    - Low dark noise (when cold)
    - Low after-pulse
    - **Emit light, which could prove problematic**
- **Cons: cumbersome to readout**

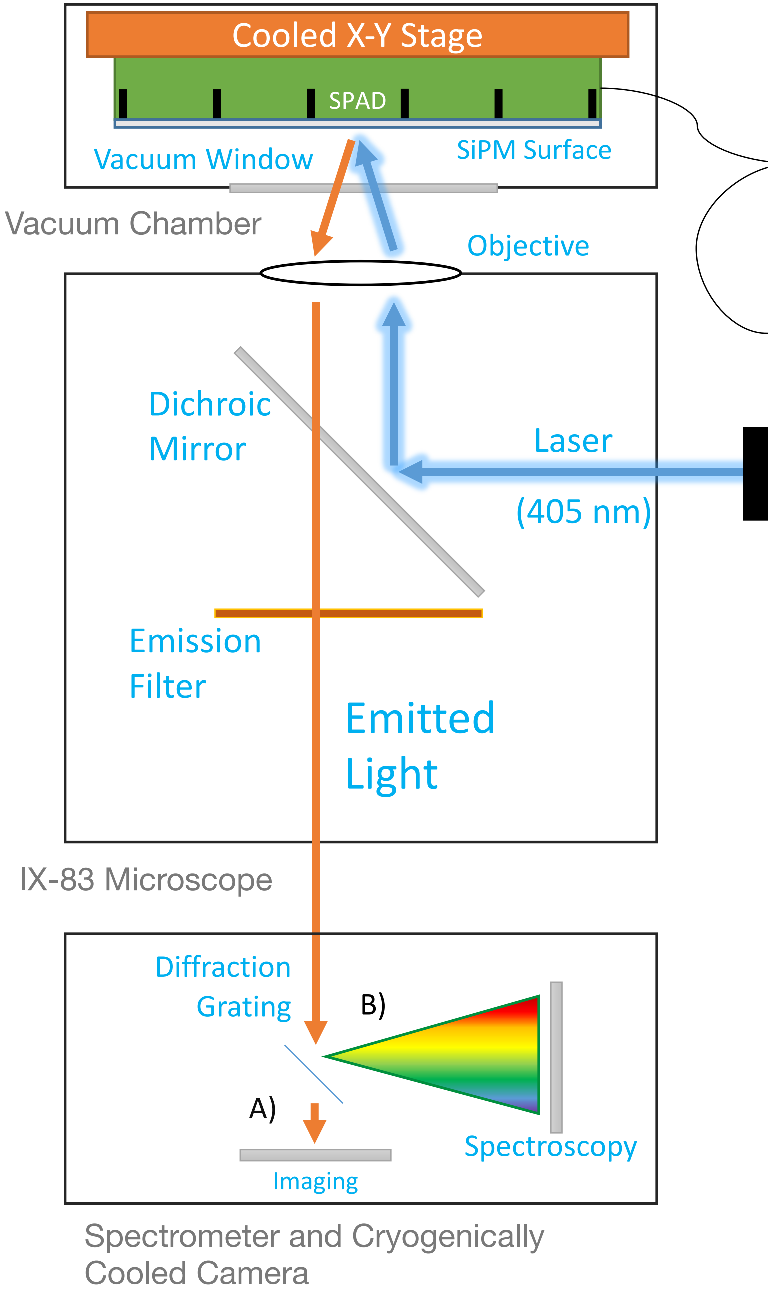
MIEL

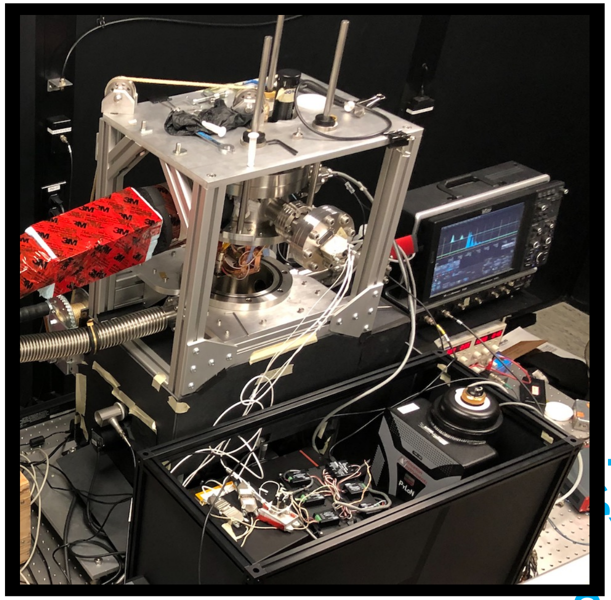
Microscope for the Injection and Emission of Light





Cryogenically Cooled X-Y Stage with SiPM Mounted





The MIEL Experiment

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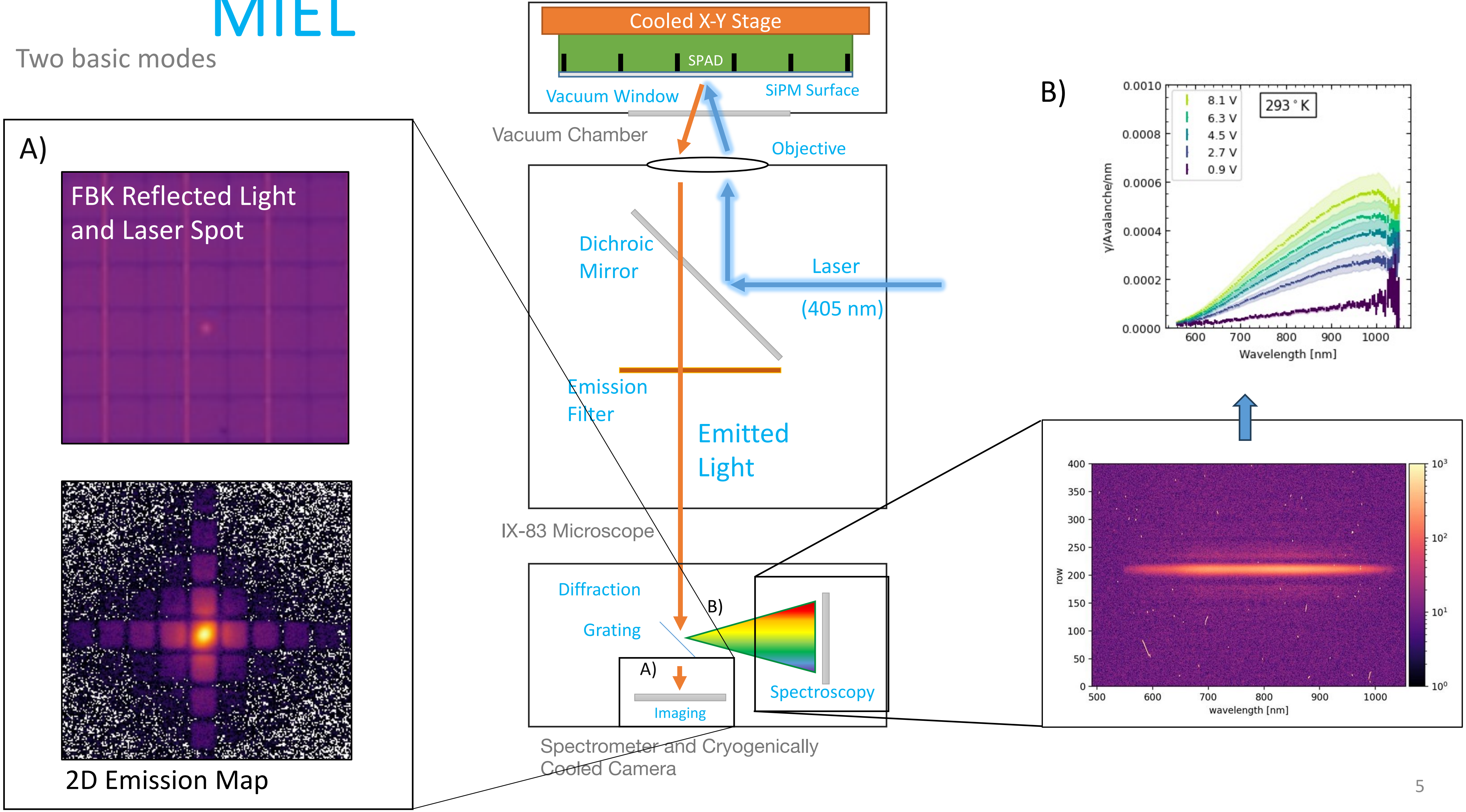
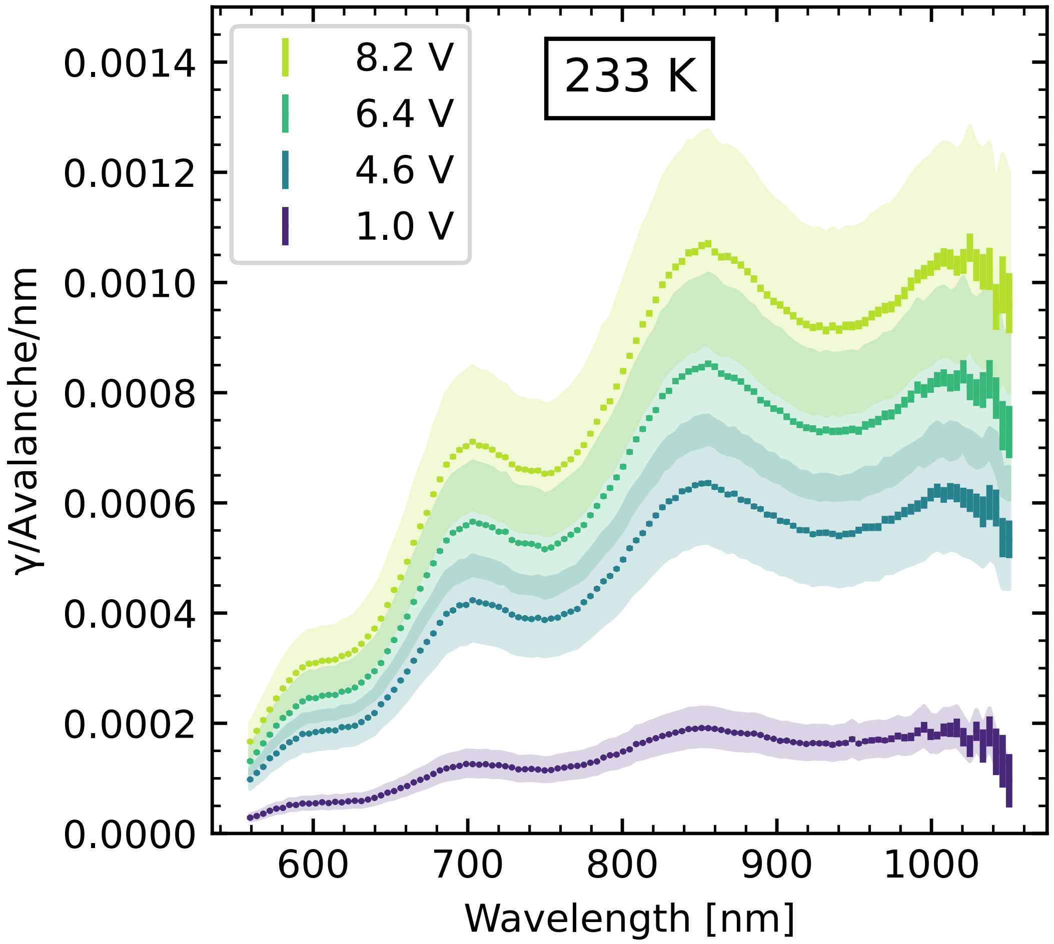
MIEL

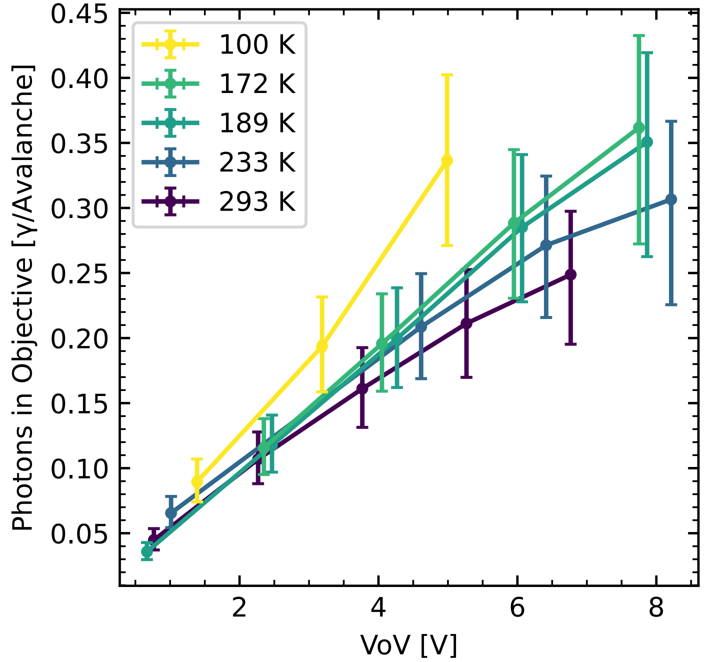
Two basic modes



Cross-talk. Light production and transport

FBK VUV-HD3 emitted photon within NA<0.45

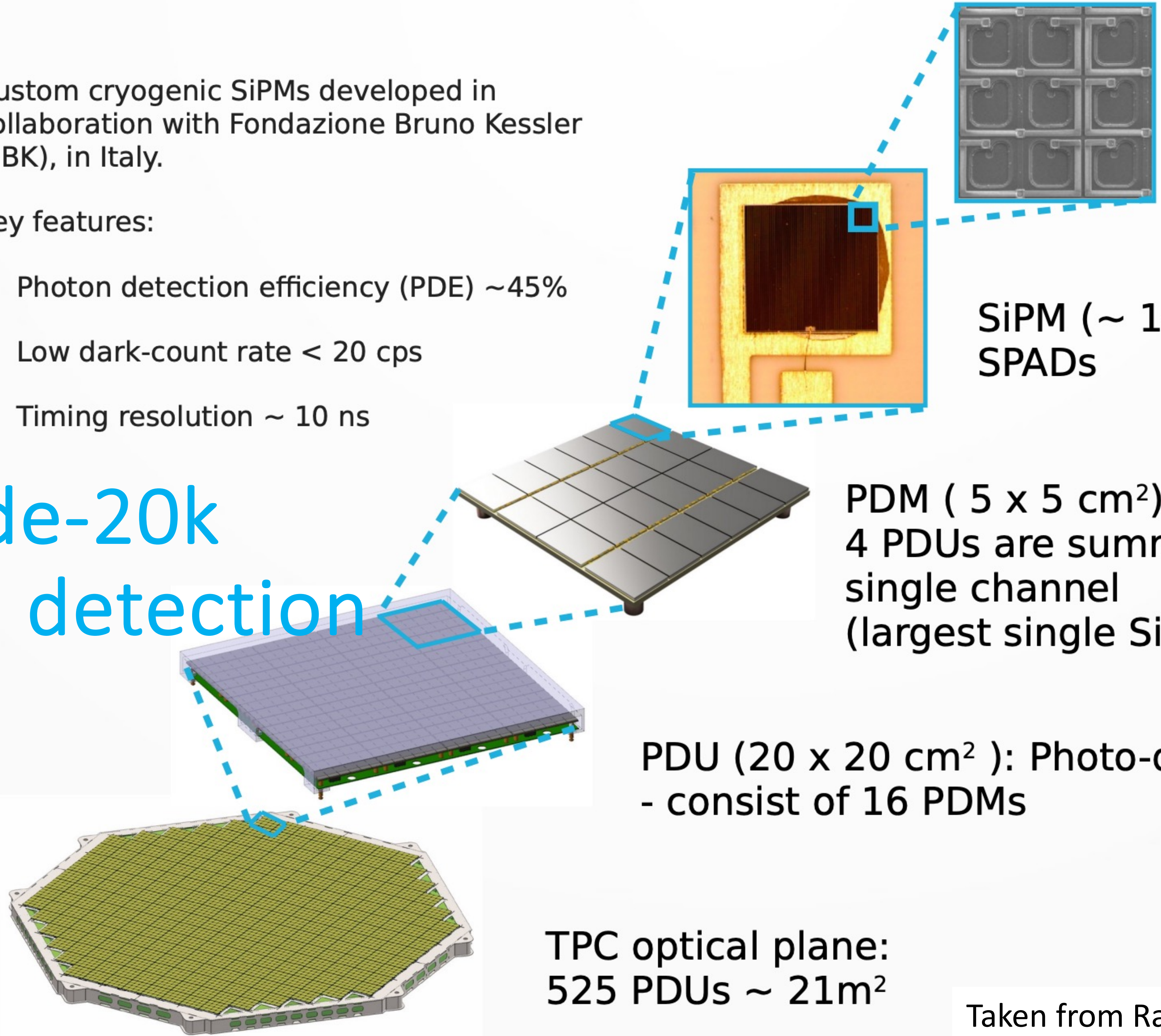




- Cross-talk is the dominant correlated nuisance
- We estimate that every avalanche emits 1-3 photons back in the liquid
- Fortunately the detection efficiency is low in IR (<10%)

DarkSide-20k photon detection

- Custom cryogenic SiPMs developed in collaboration with Fondazione Bruno Kessler (FBK), in Italy.
- Key features:
  - Photon detection efficiency (PDE) ~45%
  - Low dark-count rate < 20 cps
  - Timing resolution ~ 10 ns



SPAD: Single photon avalanche diode ~25-30 μm^2

SiPM (~ 1cm^2): 94 900 SPADs

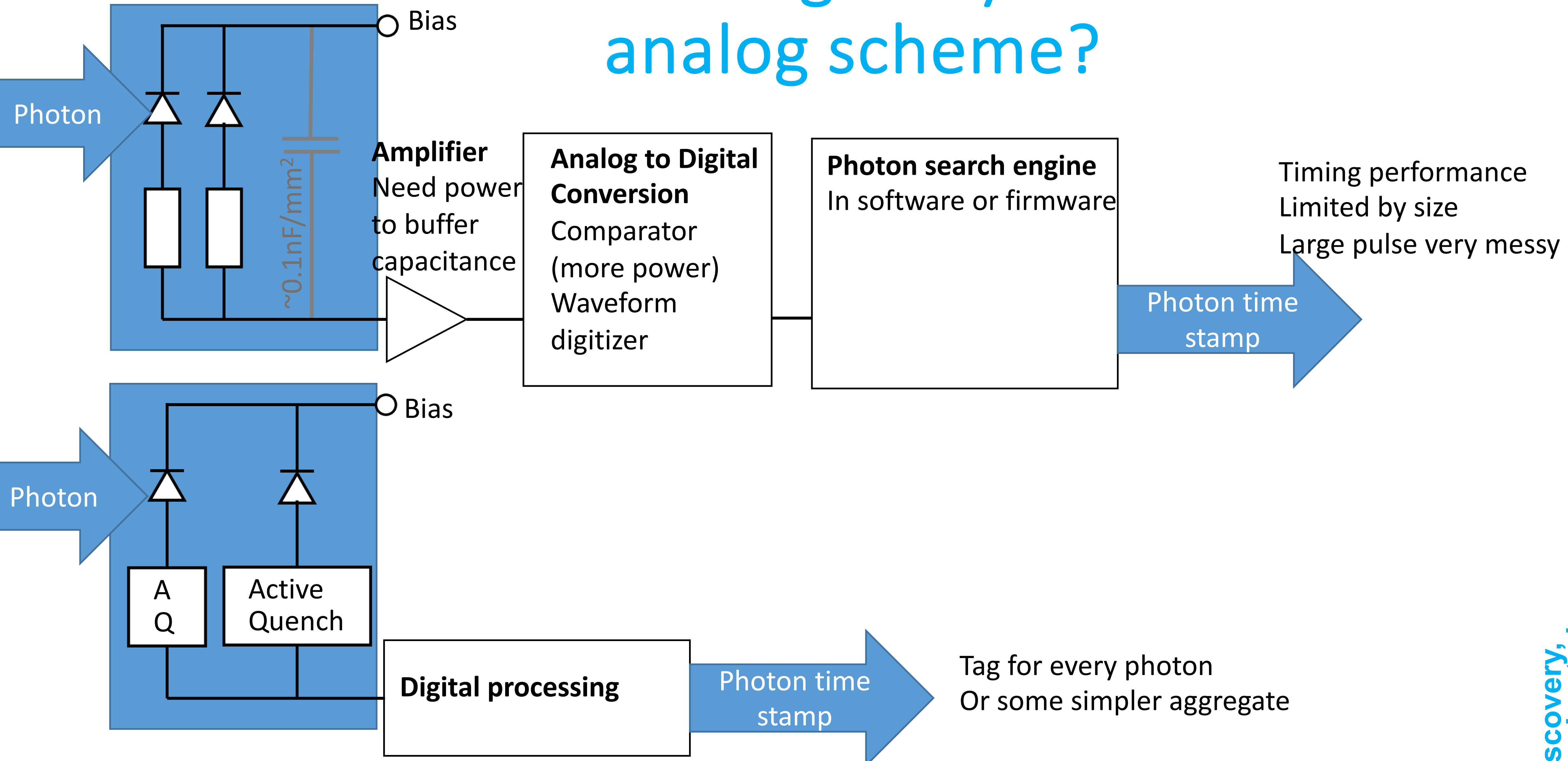
PDM (5 x 5 cm^2) : 24 SiPMs
4 PDUs are summed and read as a single channel
(largest single SiPM unit ever!)

PDU (20 x 20 cm^2): Photo-detection unit
- consist of 16 PDMs

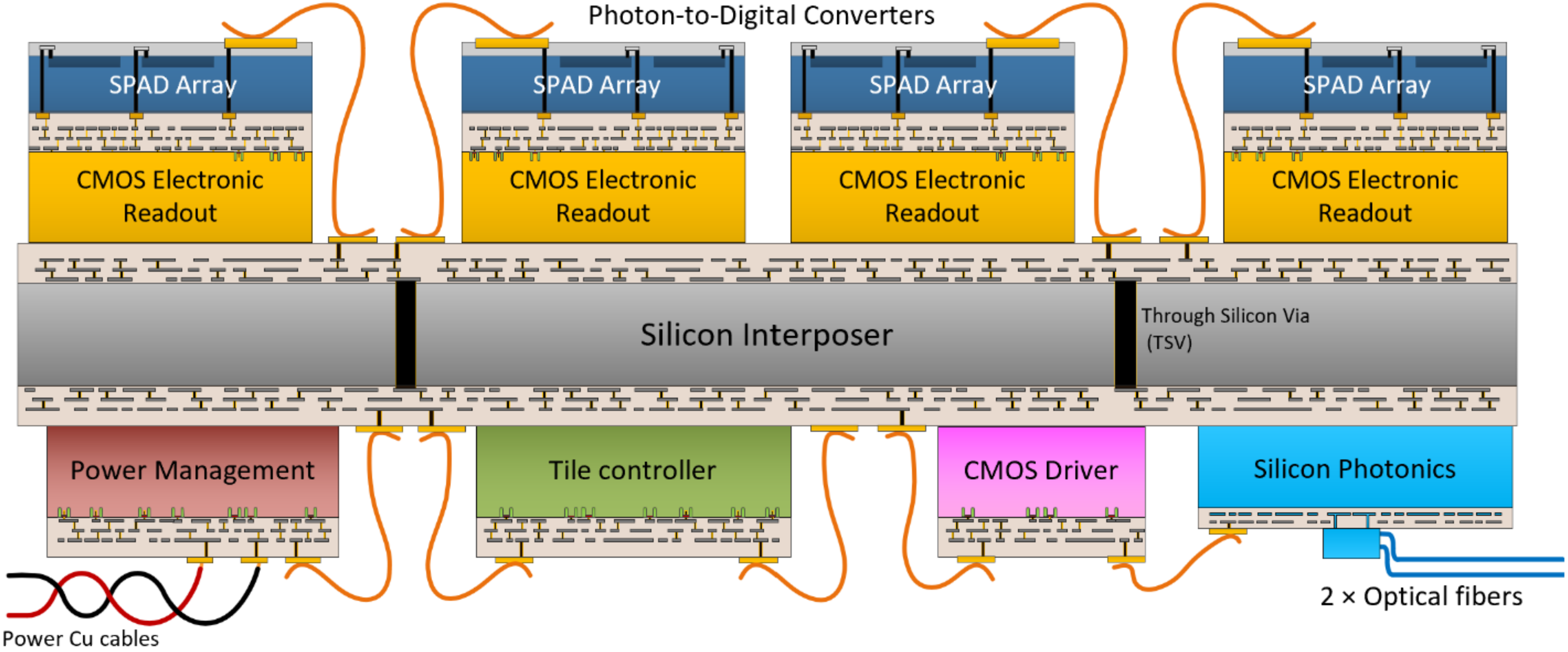
TPC optical plane:
525 PDUs ~ 21m^2

Taken from Rafał Wojaczyński (Astrocent)

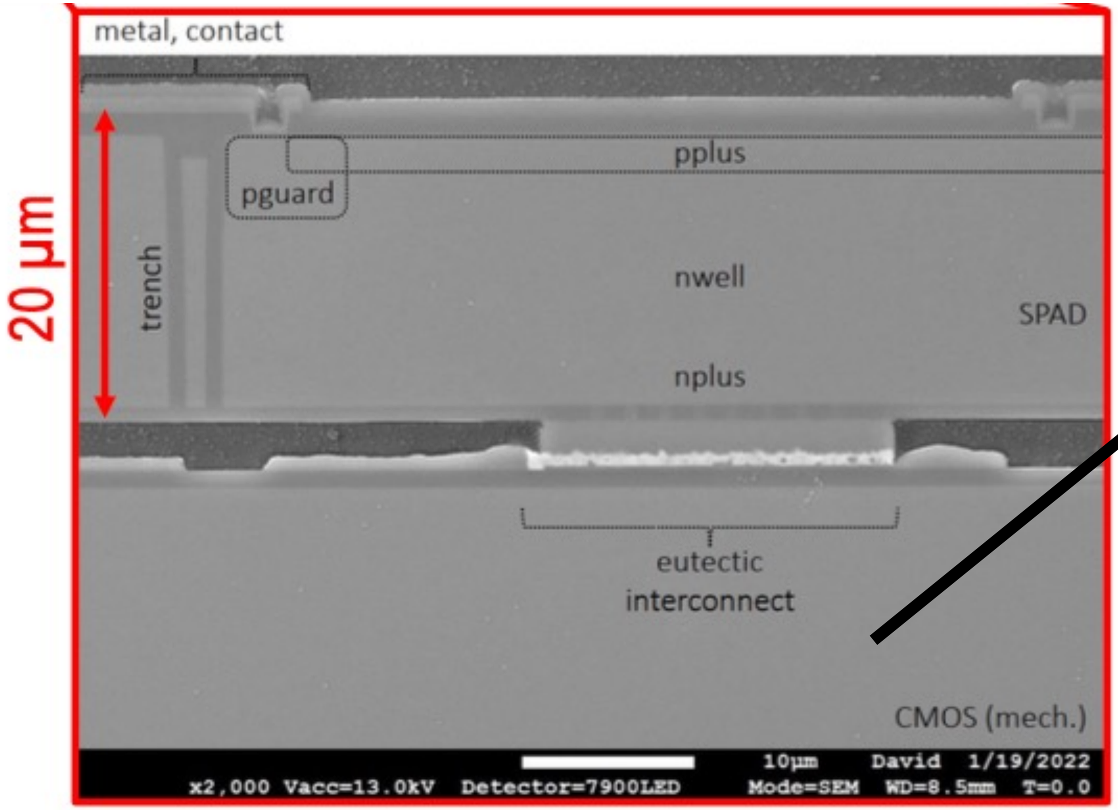
Moving away from DS analog scheme?

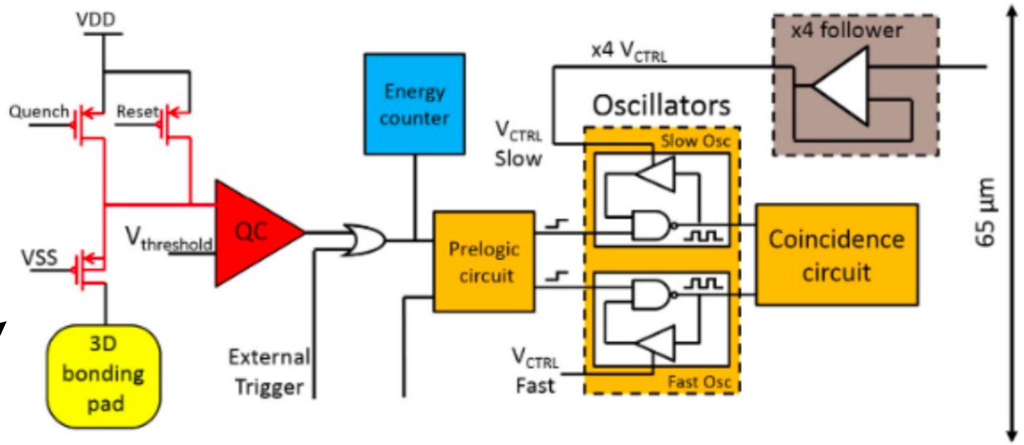


A *simpler* solution: Photon to Digital Converter



TDC integrated in each Single Photon Avalanche Diode (SPAD)





Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 949, 1 January 2020, 162891

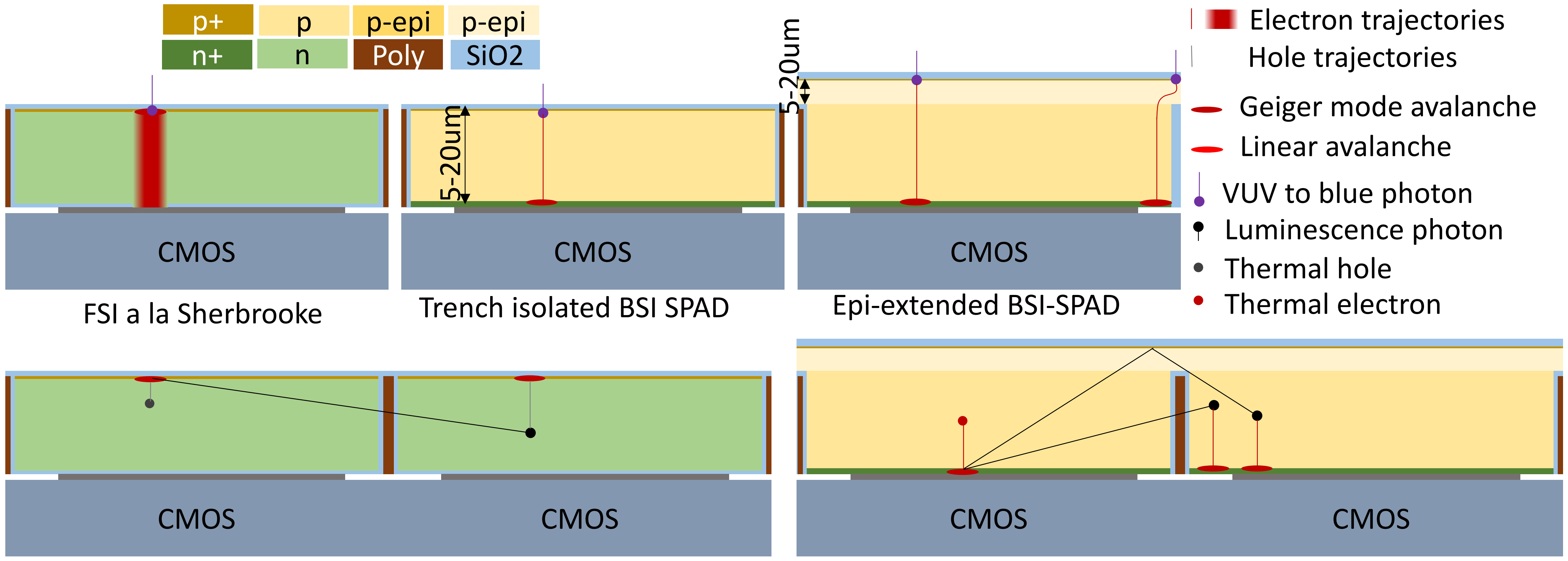
A 256 Pixelated SPAD readout ASIC with in-Pixel TDC and embedded digital signal processing for uniformity and skew correction ☆

Frédéric Nolet, William Lemaire, Frédérik Dubois, Nicolas Roy, Simon Carrier, Arnaud Samson, Serge A. Charlebois, Réjean Fontaine, Jean-Francois Pratte

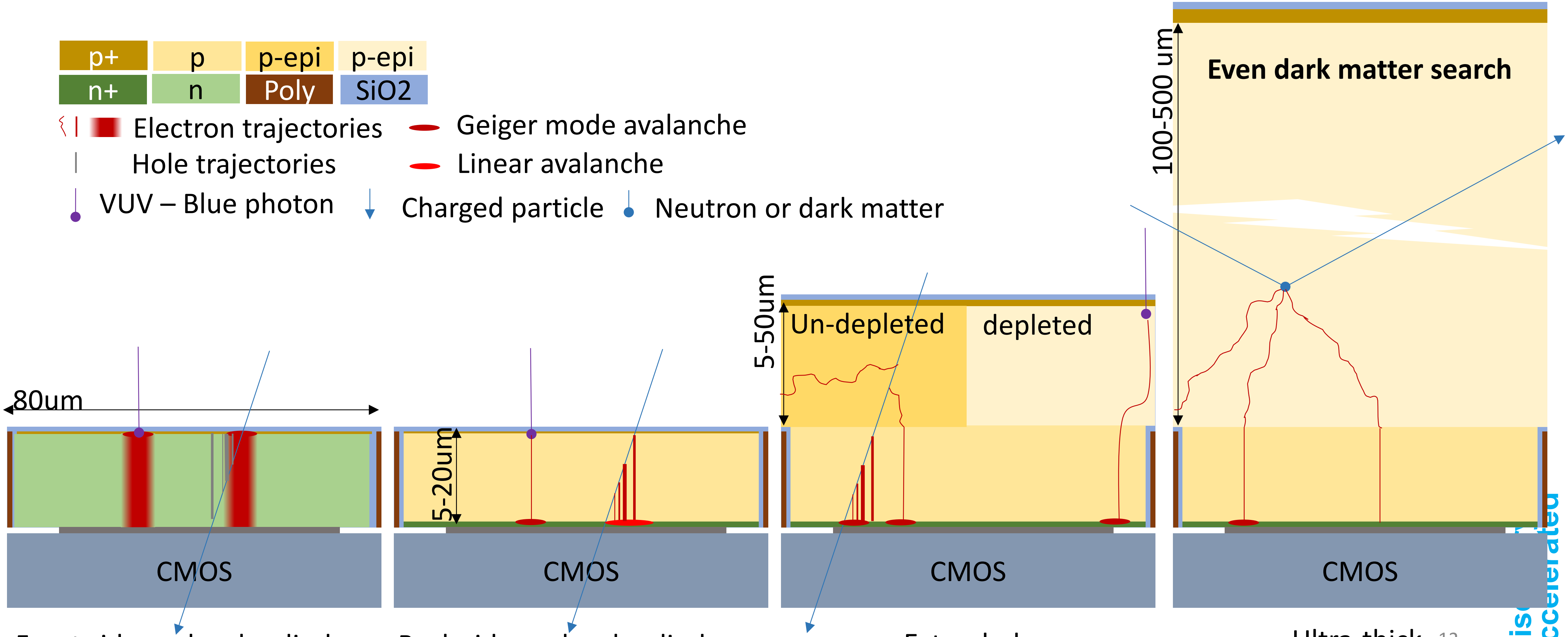
Interdisciplinary Institute for Technological Innovation and Department of Electrical and Computer Engineering, Université de Sherbrooke, Sherbrooke, QC, J1K 2R1, Canada

Received 28 June 2019, Revised 24 September 2019, Accepted 29 September 2019, Available online 1 October 2019, Version of Record 4 October 2019.

3D integration and FSI vs BSI configuration



BSI for other things than photon detection



Front side avalanche diode | Back side avalanche diode | Extended | Ultra-thick

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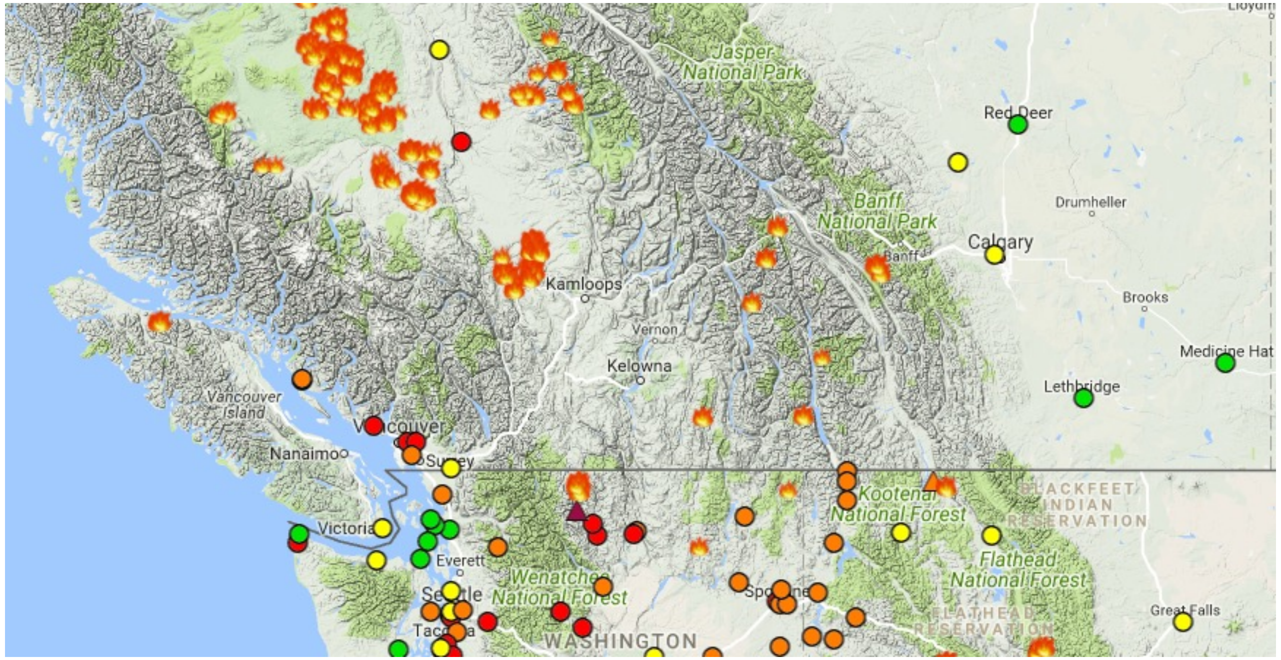
Beyond physics - Is it possible to prevent / control major fire with a sensor network?



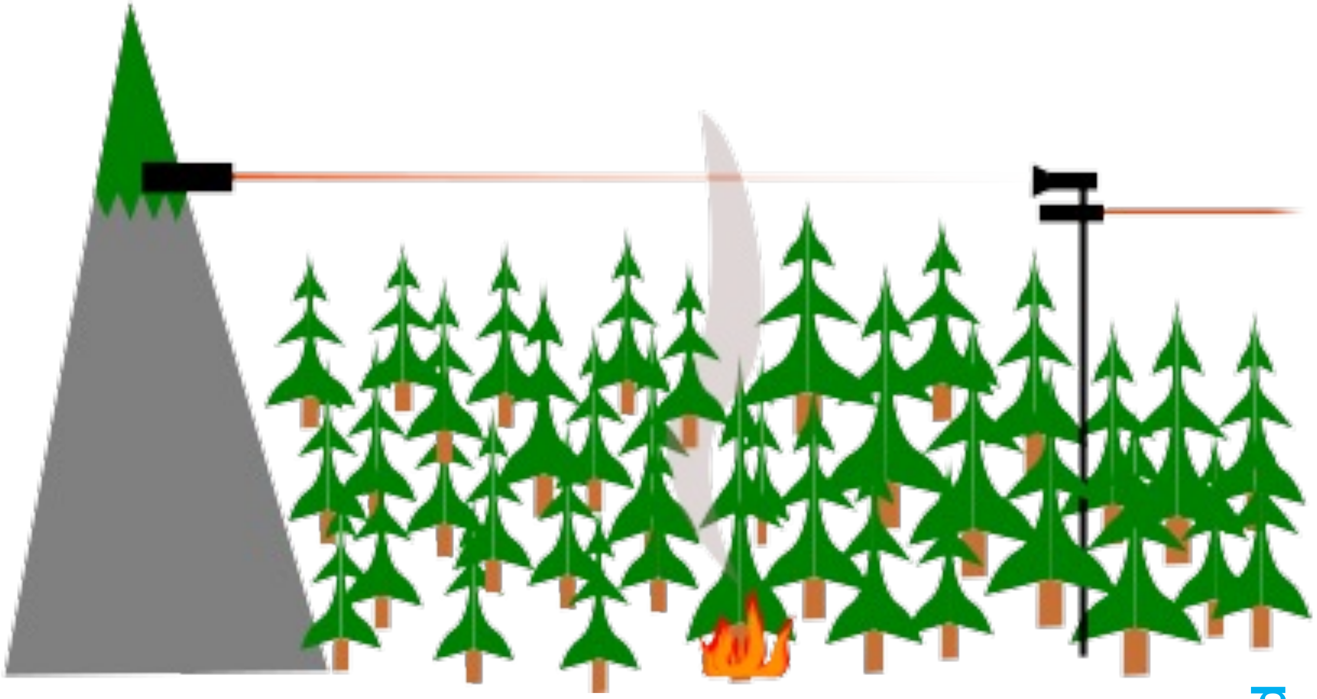
- It is certainly not obvious
- But there may not be any other alternative
  - Other solutions are not full-proof
  - We have to keep an open eye
  - Investigate all modalities
  - Work with commercial parties
  - And push the technology

SPAA + SENSENET

Discovery, accelerated

Single photon air analyser – open path

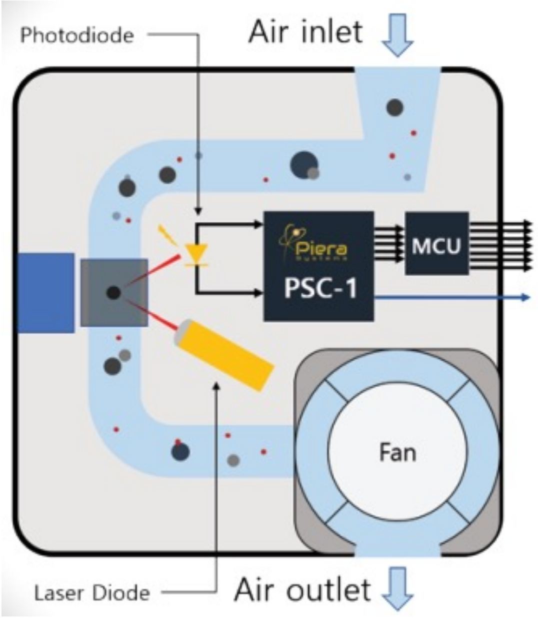
- Fire laser in open air
  - Backscattered light – smoke
    - LIDAR for distance
  - Fluorescence
    - "LIDAR" for distance
  - Attenuation
    - For conventional attenuation SPAD not so good because high flux required
    - Quantum scheme with entangled photons may reduce photon flux requirement



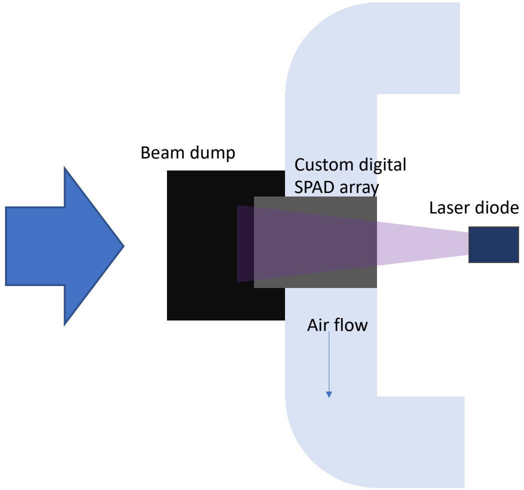
SPAA – enclosed sensor

- Replace photo-diode by array of digital SPADs
  - Measure scattering angle distribution – particulate size
  - Measure fluorescence with filters
  - Enhanced sensitivity requiring lower power
- SPAD promise high performance and low power
  - Cost should be competitive in large quantity

Existing Piera system

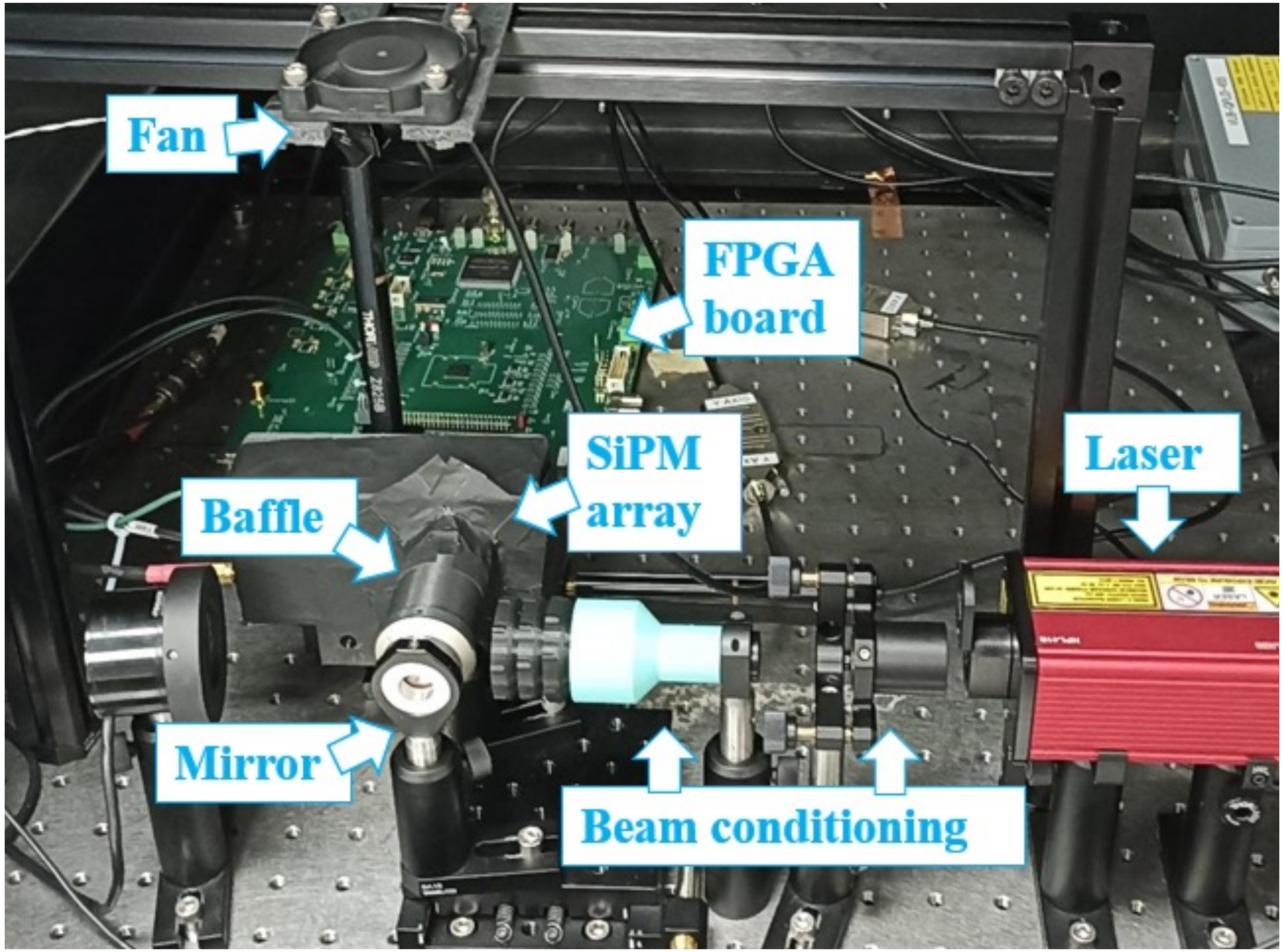


SPAA proposal

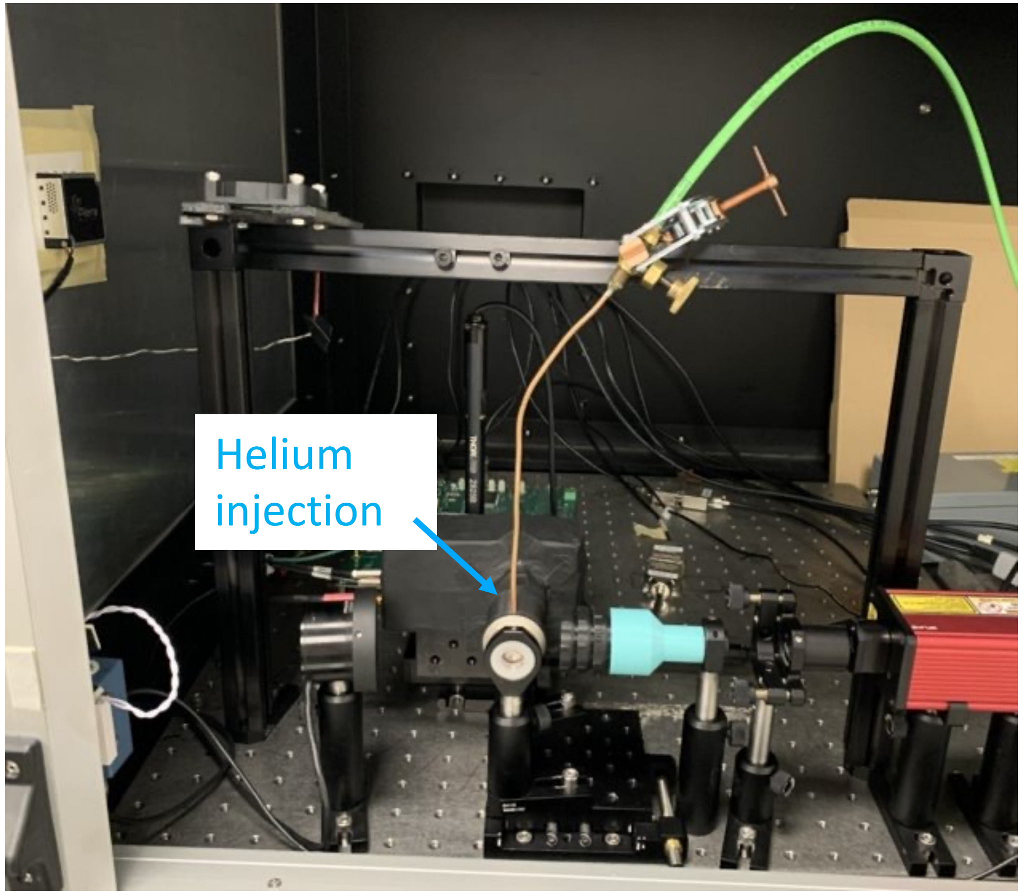


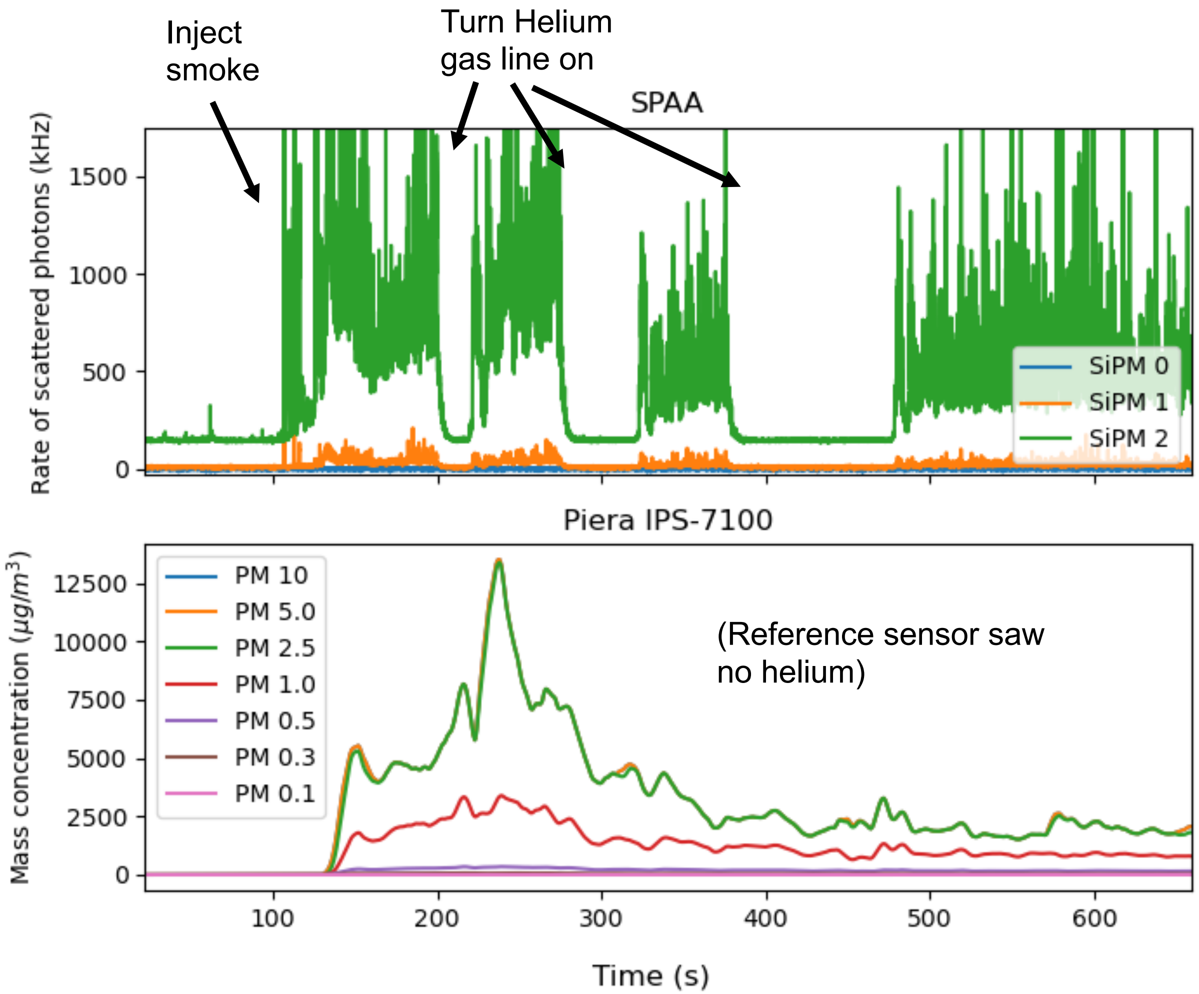
2^{nd} generation based on analog SiPM

(Early data)



On-of smoke measurements





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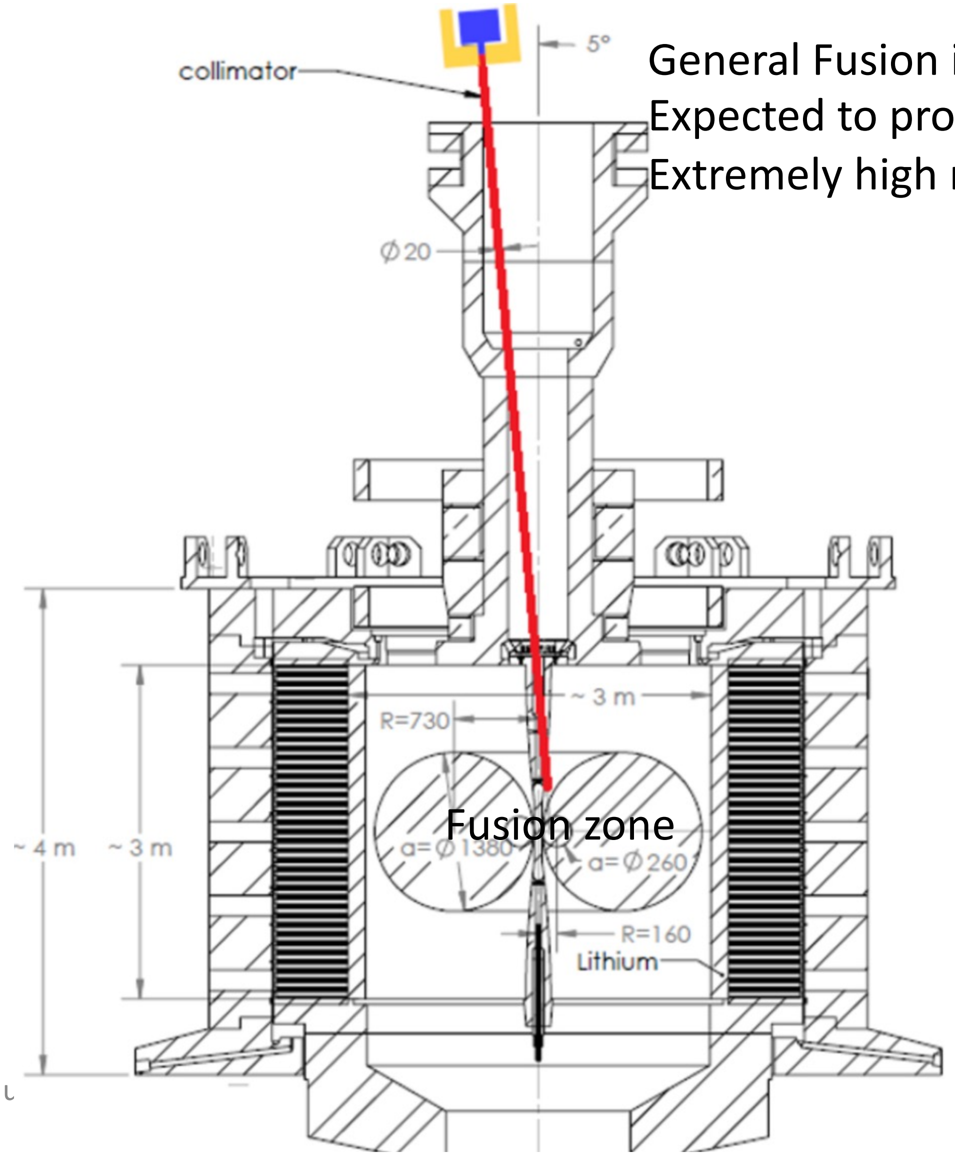
Summary and outlook – A bright future for digital SPADs

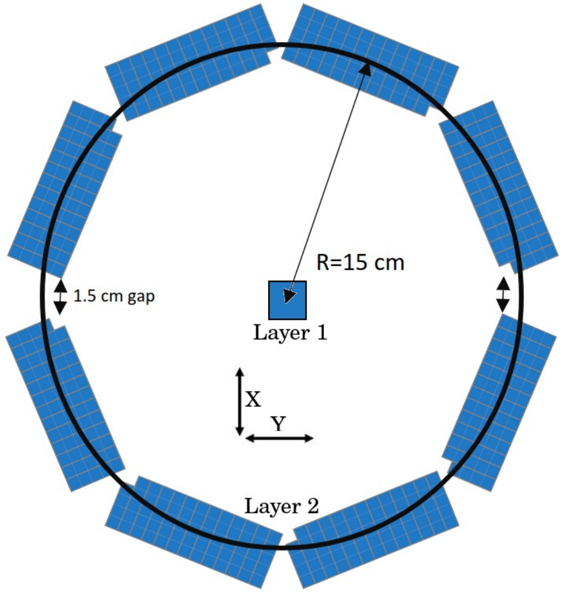
- Environment monitoring (forest fire, health care, water purity,…)
  - SPAD make sense when the detected photon flux is low: scattering, fluorescence, … entangled photon attenuation?
  - Low cost / low power photon counting – SPAD addressing, MHz counting
  - Possible LIDAR-like for open path monitoring – ns-scale timing resolution
- Radiation monitoring
  - High rate neutron counting for Fusion ”reactors”
- Physics research
  - Dark matter search and neutrino properties require scalable large area
  - Quantum entanglement studies with near unity efficiency. Need carefully tuned BSI with very effective AR coating for specific wavelength (green)
  - Collider – Now participating to CERN DRD4

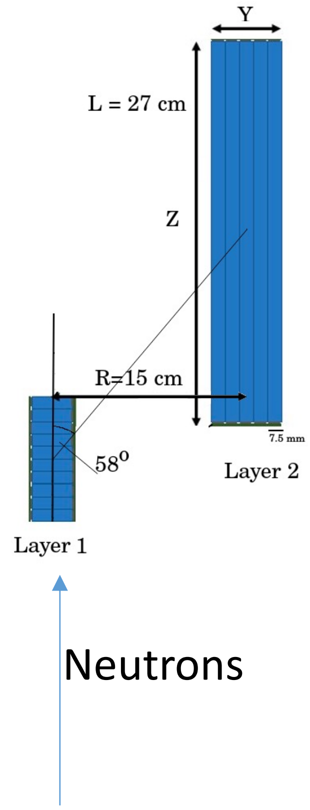
Discovery, accelerated

Supporting General Fusion

General Fusion is a company headquarter in Richmond BC (suburb of Vancouver)
Expected to produce 1GHz of neutrons (in pipe) during 10us
Extremely high rate that is very hard to deal with with analog SiPM







Discovery, accelerated

The end

6th International Workshop on New Photon-Detectors (PD24)

19–21 Nov 2024
Harbour Centre
US/Pacific timezone

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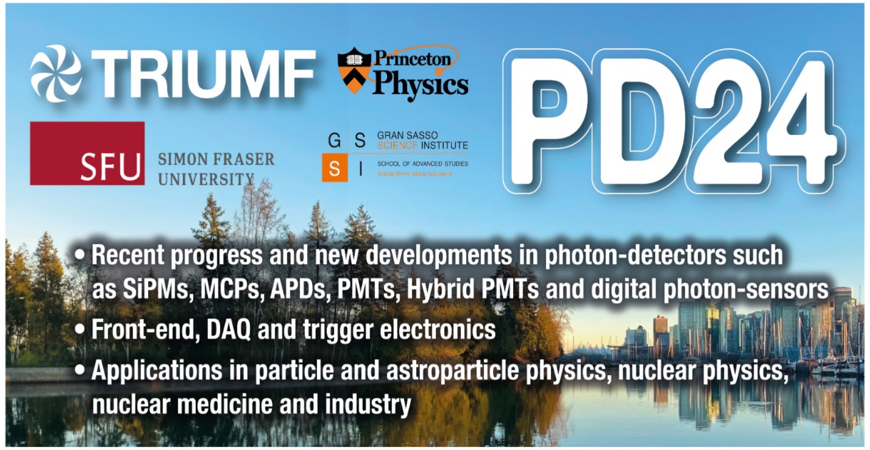
General Inquiries

infopd24@triumf.ca

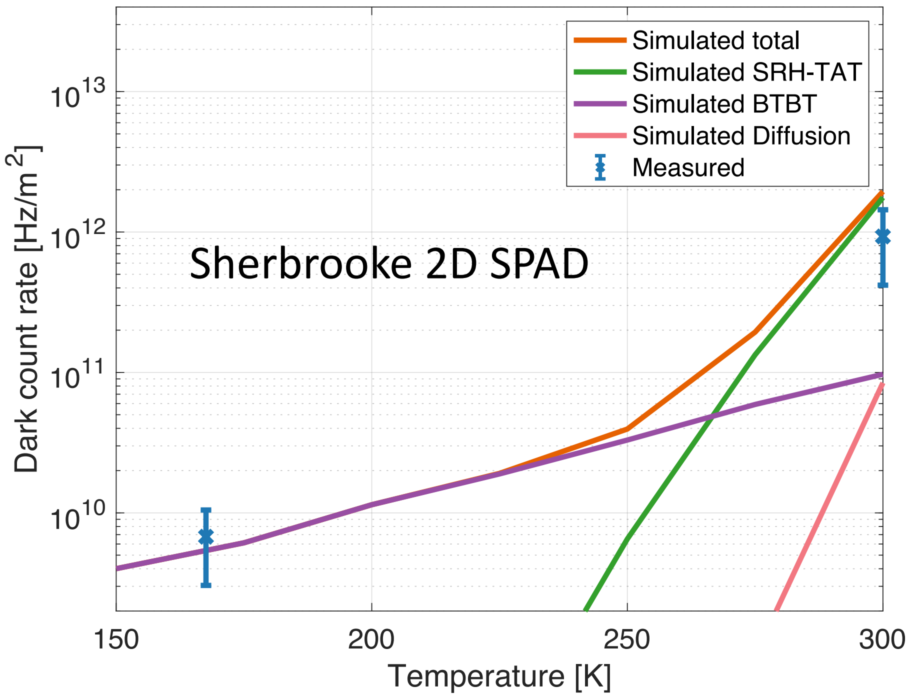
https://indico.cern.ch/event/1404192/

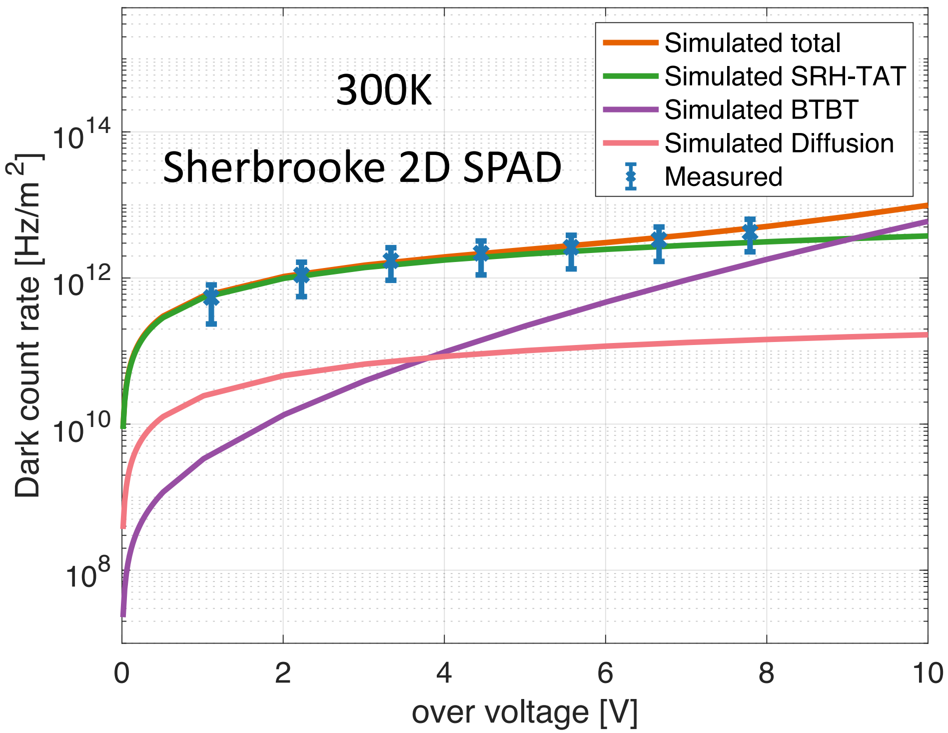


The 6th International Workshop on new Photon-Detectors (PD24) will be held November 19-21, 2024 at Simon Fraser University, Harbour Centre in Vancouver, BC, Canada.

Dark noise

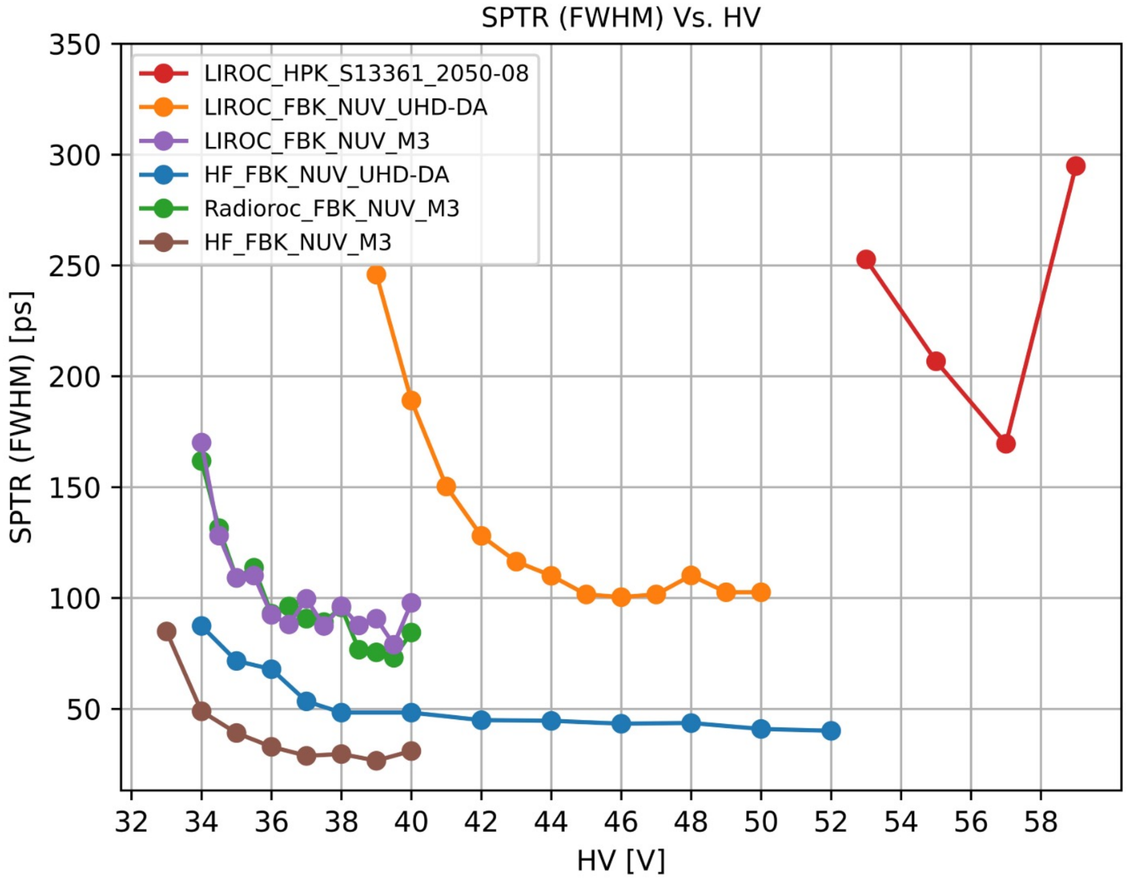
- Have we reached the minimum possible?
  - It may depend on temperature
- Field enhanced can dominate
  - Trade-off between probability of triggering avalanche and dark noise





Single Photon Timing Resolution

- The electronics matters a lot
- Does 3D integration provide best results
  - May be for the same power dissipation
- What about the SPAD avalanche evolution time?
  - Is it worth studying?
- What about tails?
  - Probe region of low field?
  - Mask such regions?
- In BSI the electron transit time may matter



Study experimental time resolution limits of recent ASICs at Weeroc with different SiPMs and scintillators

Tasneem Saleem,[a,1] Salleh Ahmad,[a] Jean-Baptiste Cizel,[a] Christophe De La Taille,[a,b] Maxime Morenas,[a,b] Vanessa Nadig,[c] Florent Perez,[a] Volkmar Schulz,[c] Stefan Gundacker,[c,2] and Julien Fleury[a,2]