TRIUMF

Industrialization
Realizing applied opportunities

Fabrice Retiere (TRIUMF) with major inputs from Serge Charlebois (Sherbrooke)

NSERC CRSNG

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

Arthur B. McDonald Canadian Astroparticle Physics Research Institute

INNOVATION.CA CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

Discovery, accelerated

Outline

- Motivation
- Jargon
- Examples of opportunities
- Roadblocks and breakthroughs
- You

Motivation – value/goal mapping – 20 years ago when I moved to Canada

Creativity

Achievement

Independence

Belonging

Develop experimental solutions for discovery physics

Integrate in Canadian SAP community

Ski

Motivation – value/goal mapping - now

Value

Creativity

Achievement

Concern for Environment

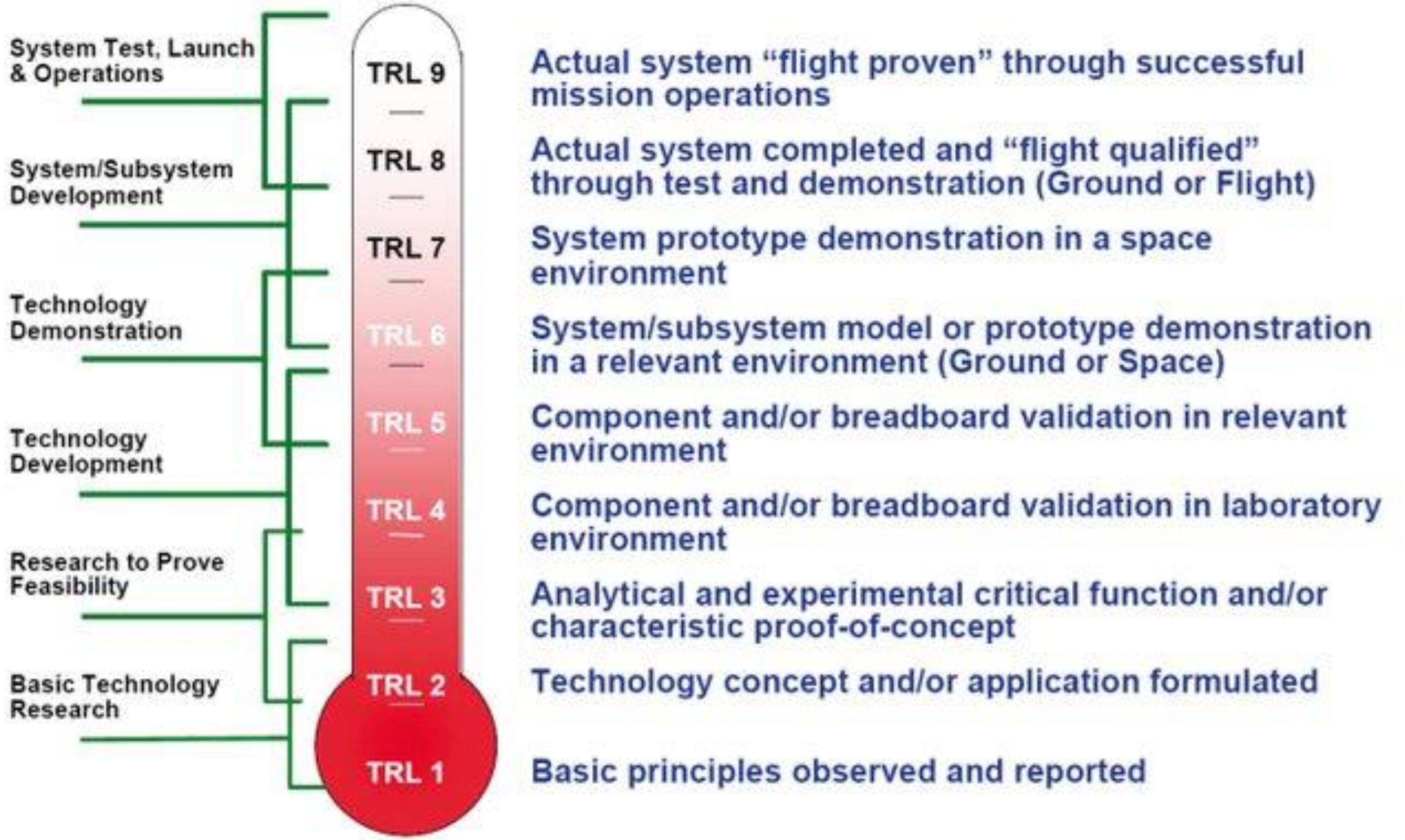
Responsibility

Goals

Develop experimental solutions for mitigating climate change and astro-particle physics

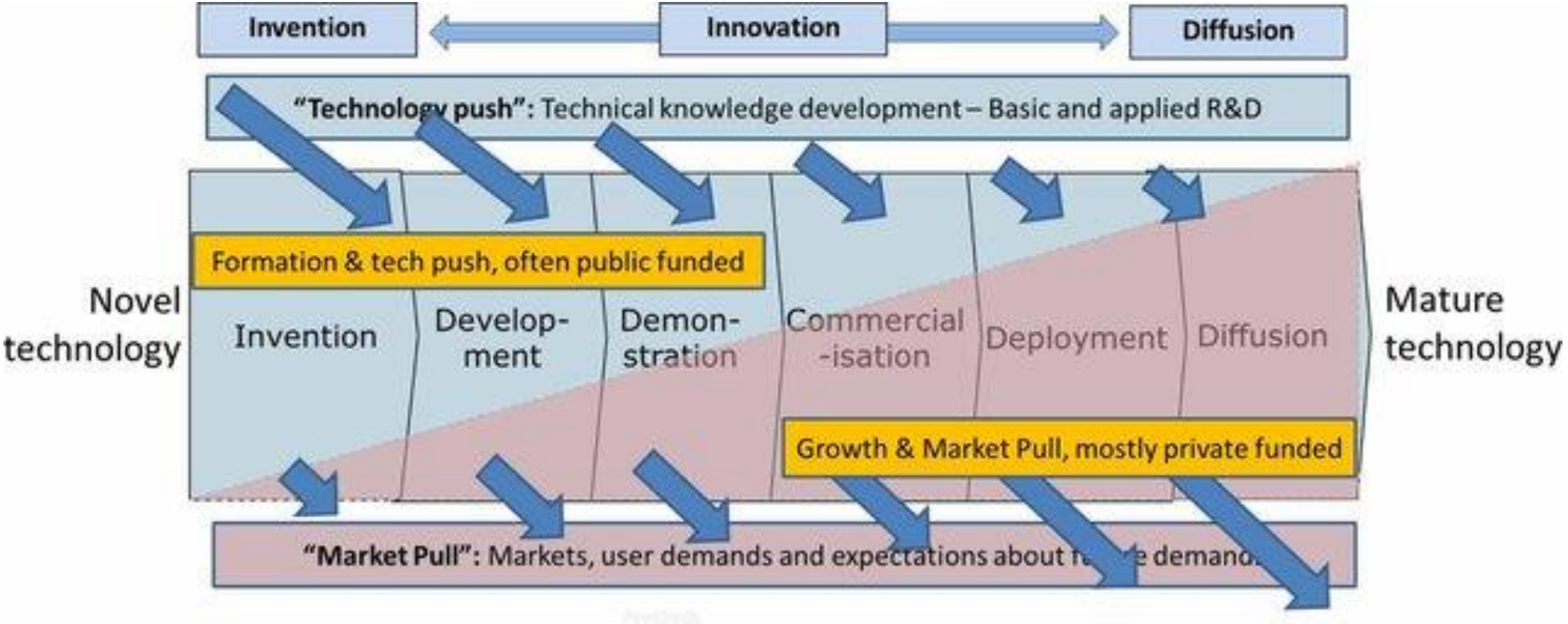
Develop effective technology resource management solutions

Technology Readiness Level



TRIUMF

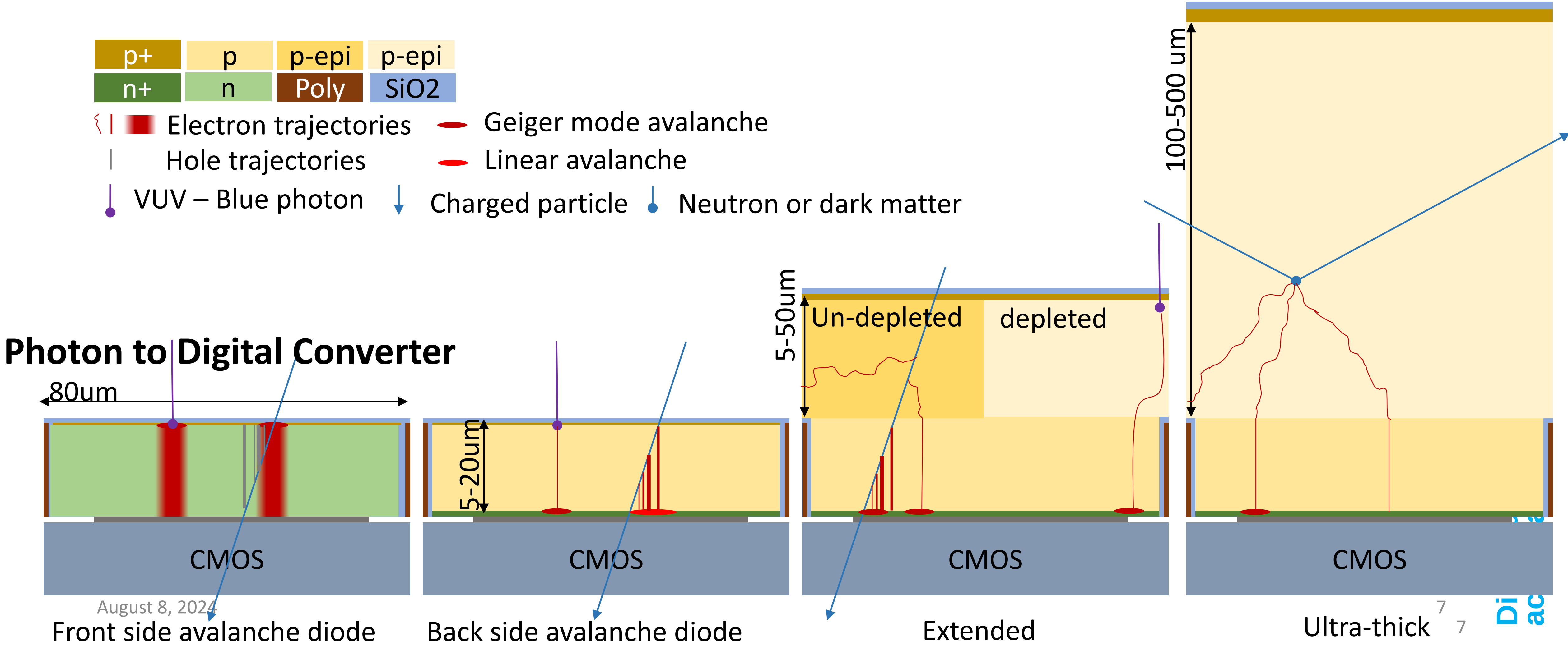
Push – Pull technology



Discovery, accelerated

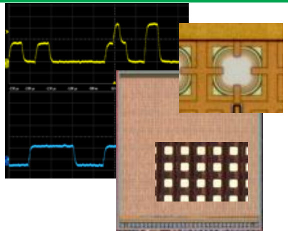
Push – TRL 1 to 8

Photon to Digital Converter ++

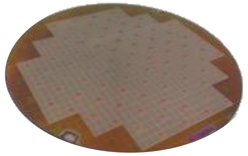


Development timeline and update – All critical gates passed (but the last…)

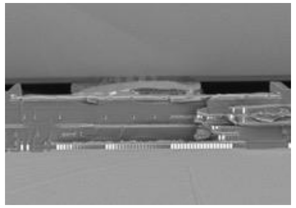
UdS



2D SPADs
and
Wafer level
bonding



1st 3D SPAD
wafer
(on fake CMOS)

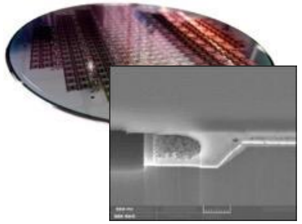


…

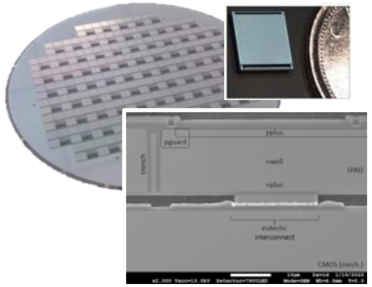
2018 | 2019 | 2020-21 | 2022 | 2023 | 2024

Start
at TDSI

1st CMOS
readout



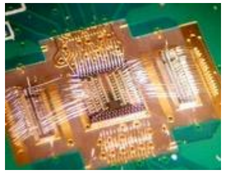
2nd CMOS
readout
wafer run



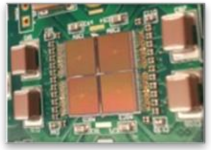
Bonding on
real CMOS
demonstrated

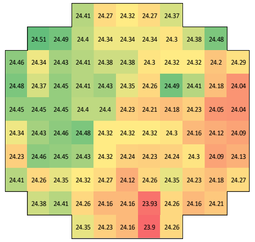
Complete
PDC

Photon detection layer (SPAD array) and 3D integration



Geiger mode
testing with
active probe





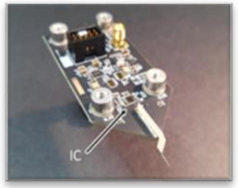
Large tile
8×8
dev.

System and
scaling up
challenges

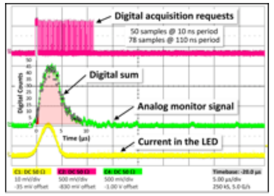
2019 | 2020 | 2021 | 2022 | 2023 | 2024

Electronics layer (CMOS)

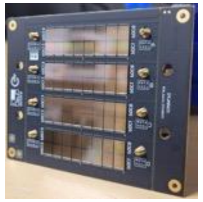
Geiger mode
testing during
SPAD dev.



First functional
2×2 tile



Wafer level
SPAD
testing



Made possible by the astroparticle physics community

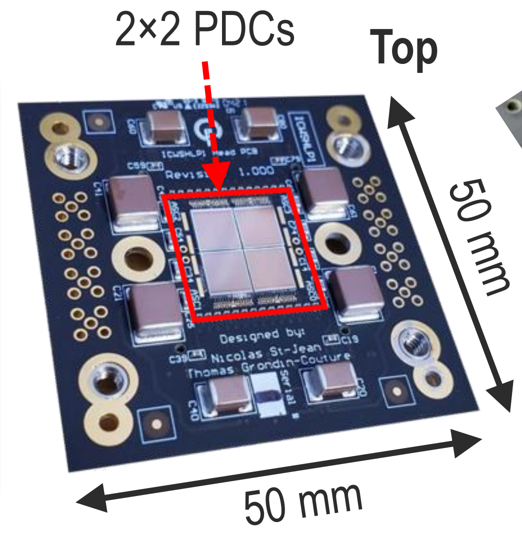
- Definite need for a new photon detection technology
  - High sensitivity and sensitive area, Low power consumption, Scalable to large area

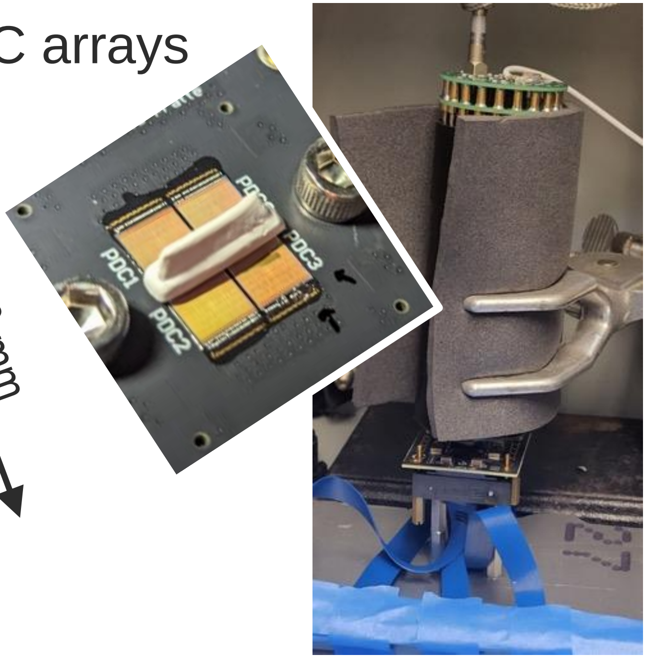
	Past	Current	Future	Leverage
• First CFI support through Carleton U. for ARGO and nEXO	1.2 M$			
• Completed PDC process development and completing first production run				
• Engineering support from MI	437 k$			
• nEXO CFI grand		1.2 M$		
• Maturing the PDC, producing silicon low radiation tile substrate (interposer)				
• Other partners: TRIUMF, UofA	~250 k$			
• Oak Ridge National Lab. project	902 k$		~1.6 M$	2.6 M$
• HEP direct support to Teledyne DALSA				350 k$
• ARGO's next CFI proposal			600 k$	
• Institut national d'optique / Defense R&D Canada				~1 M$
Total		**6.4 M$**		**~3 M$**

Dissimination of PDC: Creating a community of first users

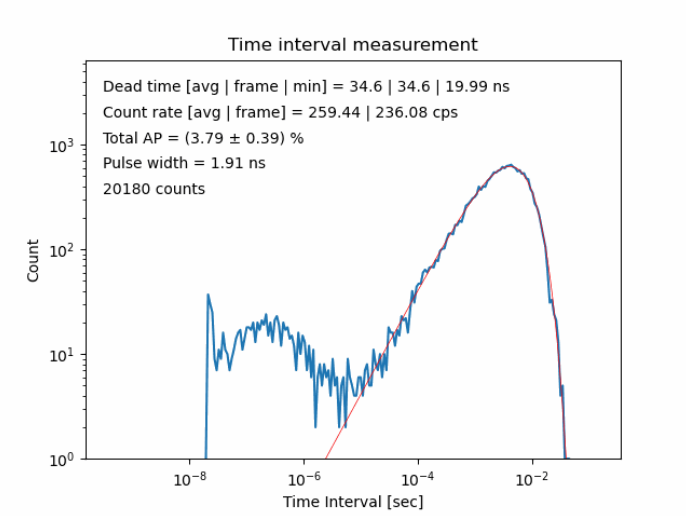
UdS

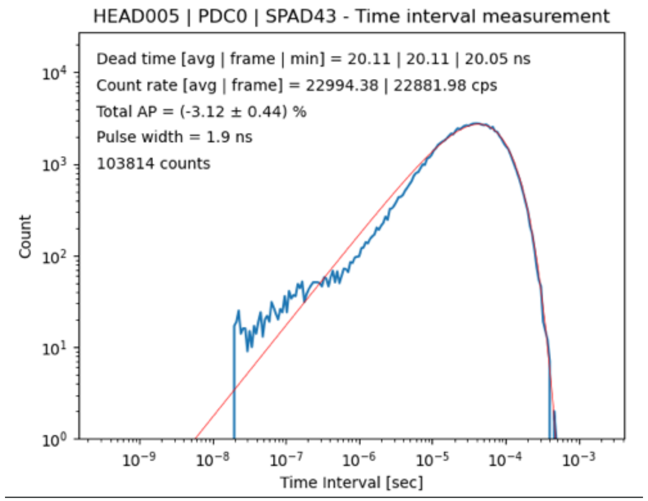
Single and small PDC arrays to larger PDC tiles

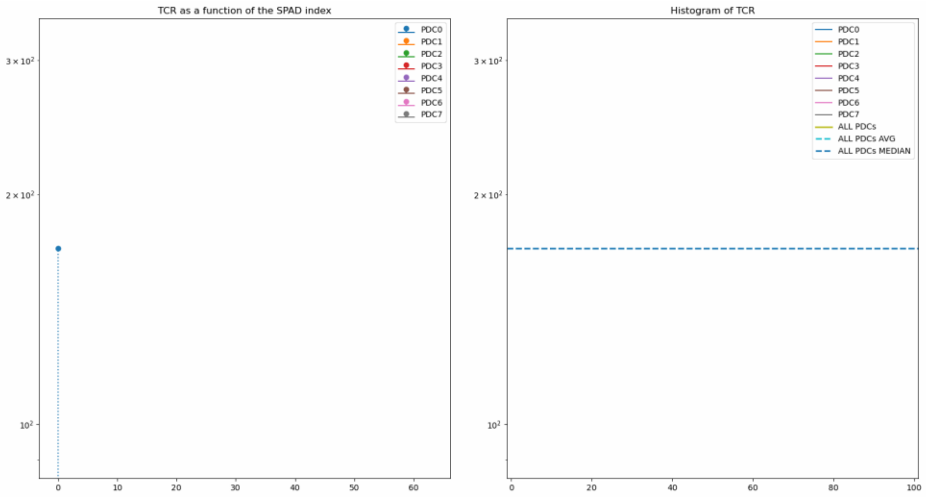




Exploring (strange) properties of some to performances from large ensemble of SPADs



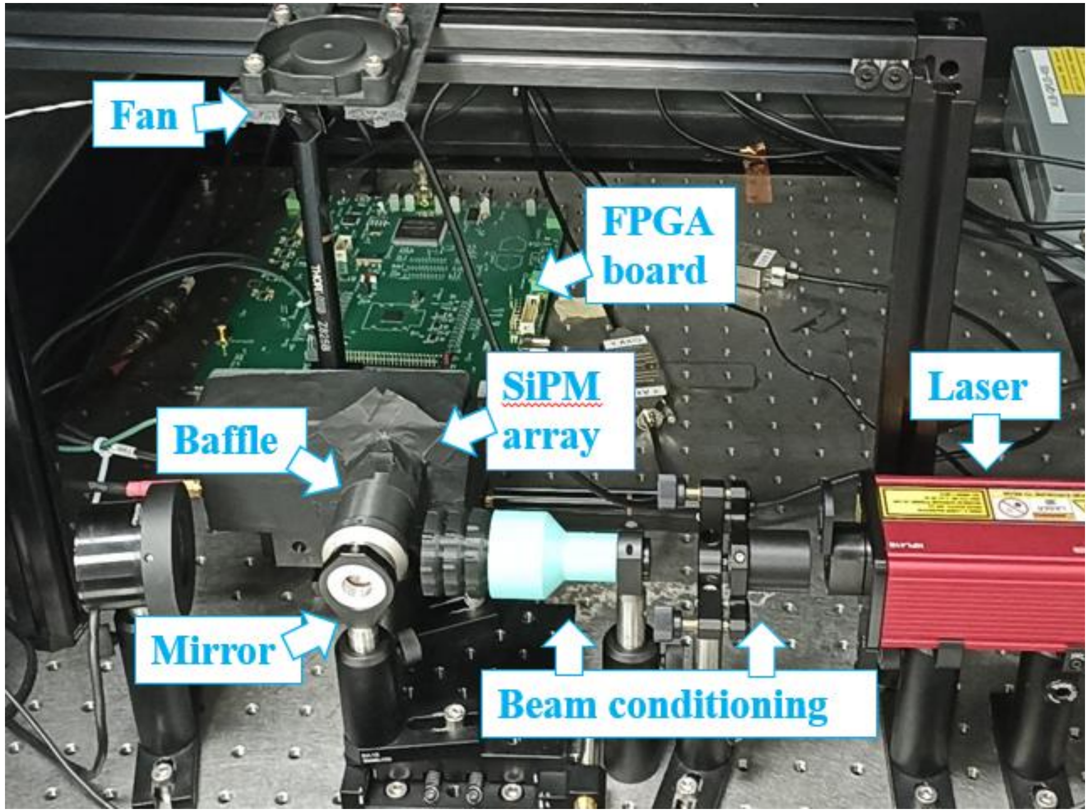


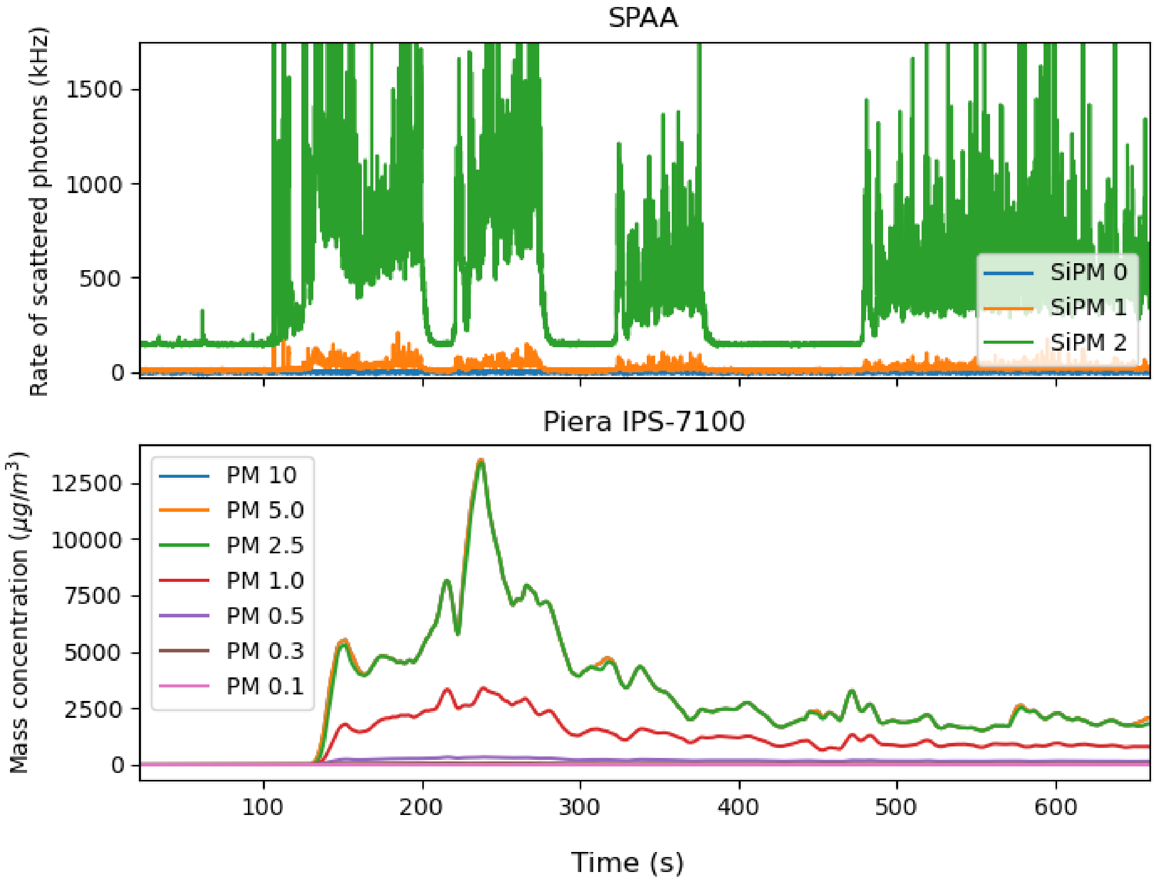


A wide range of (potential) applications

- Large cryogenic experiments
  - nEXO, ARGO, …
- Medical imaging
  - Time-of-flight positron emission tomography – ToF PET
  - Time-of-flight computed tomography – ToF CT
  - Photon counting X-ray imaging
  - Single gamma imaging
- Neutron imaging
  - Project with Oak Ridge NL
  - Project with General Fusion
- Muon imaging
- Quantum information sciences
  - Quantum key distribution – leverages embedded signal processing
  - Future entangled photons work
- LIDAR
  - Ranging is a crowded field (we don't do)
  - Free space air analysis - Time-of-flight with wavelength information
- Digital Single photon counting
  - Enclosed air analysis for Forest fire surveillance and beyond
  - Space telecommunication

Push – Single Photon Air Analyser





Dis acc

Forest fire

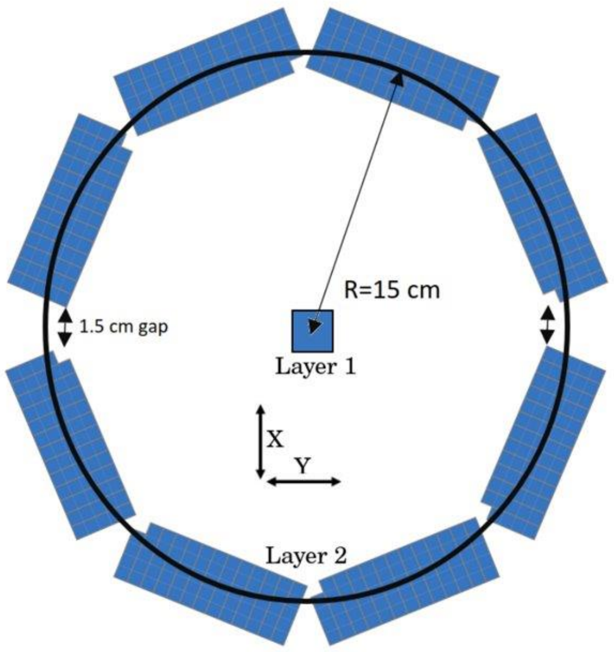
- It is a huge growing problem in Canada
- Why isn't there a consortium tackling this problem from all angles?
  - Forestry, detection, suppression (firefighting), AI,….
  - Nothing to do with astro-particle physics but has to be done!
- Applying to a variety of grants
  - NFRF exploration coming up

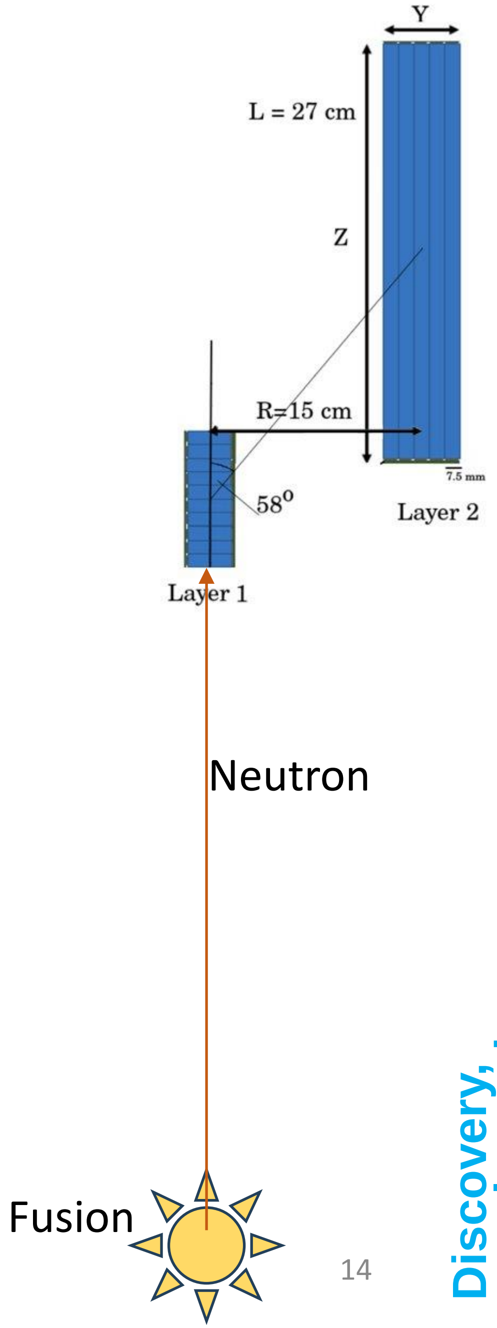
TRIUMF

Neutron time of flight spectrometry for General Fusion

Pull – TRL 3 to 8

- Challenge: GHz neutron flux for 10us or so – High rate, high efficiency needed - TRL
- Technology: Plastic scintillator + SiPM / PDC
- Funding: MITACS Elevate for R. Underwood (former SuperCDMS PhD) and NSERC ALLIANCE (1,200k$ for 4 years)



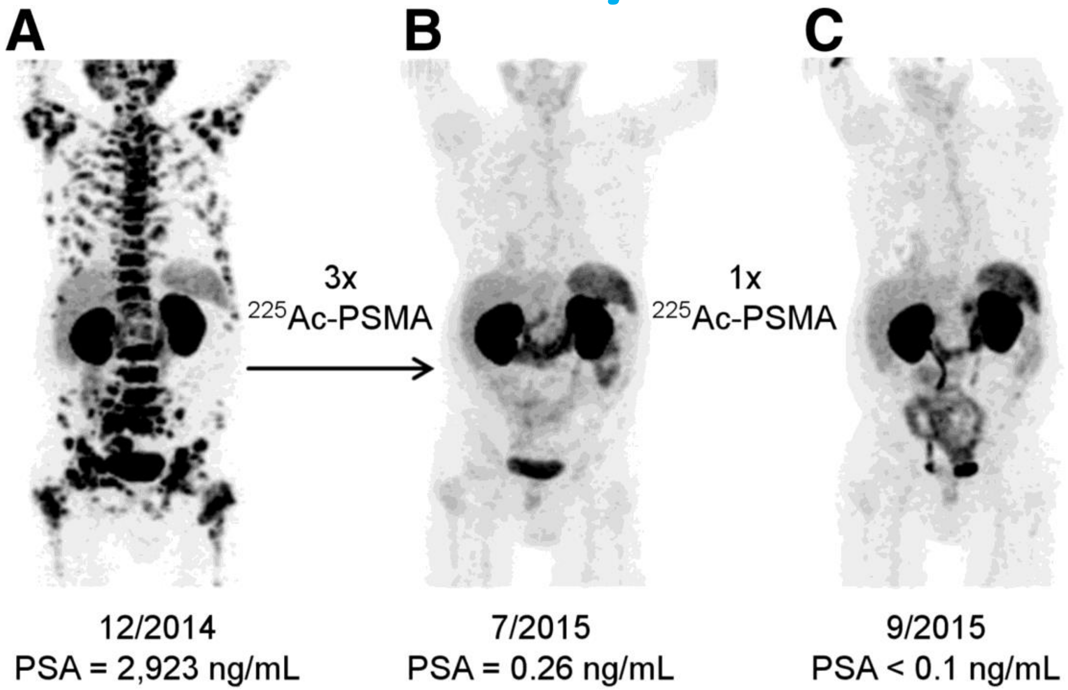


Discovery, accelerated

TRIUMF

Push – TRL 2 to 7

TIIGR, Therapeutic Isotope Imager with Gamma Rays



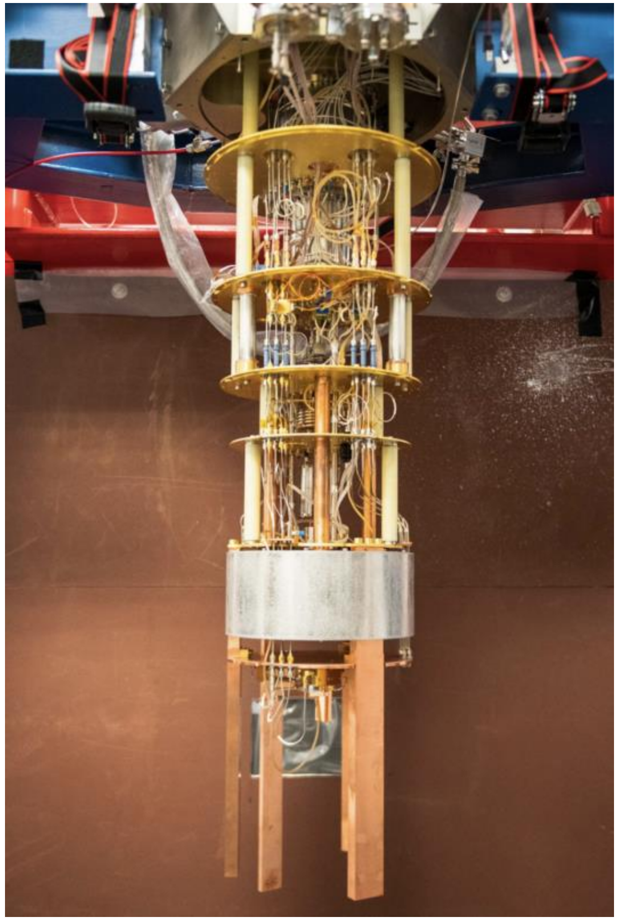
^{225}Ac decay into gamma rays

Isotope parent	Energy	Time scale	Intensity
^{221}Fr	**218 keV**	**4.9 min**	**11 %**
^{213}Bi	**440 keV**	**4.9 min + 46 min**	**25 %**
^{209}Tl	117 keV	4.9 min + 46 min + 2.2 min	1.6 %
^{209}Tl	465 keV	4.9 min + 46 min + 2.2 min	2 %
^{209}Tl	1,567 keV	4.9 min + 46 min + 2.2 min	2.1 %

- Challenge is the detection of single gamma at low rate - this is not SPECT
- Our (TRIUMF + Korea) aim is to identify a compelling detection scheme by the end of 2024
- If successful move towards a staged construction scheme with industrial partners

Pull – Qbit decoherence

- Key issue for (most) quantum computers
- Ionizing radiation (primarily from cosmic ray) affects the coherence of qubits and causes correlated errors.
- Work at SNOLAB in CUTE to characterize cosmic ray impact
- Emerging work on developing cosmic ray tag in cryostat
  - UK – Canada grant application led by Giampa (MI/TRIUMF) and Monroe (Oxford)



Roadblocks

- Technology transfer offices – Too far from basic research
  - We are not selling ice cream. The requirement of doing market assessments does not always make sense, though some grants require it (NSERC I2I, Korea)
  - Risk adverse – building trust is needed but should it?
- Academic administration – lack of strategic thinking
  - Intellectual property - Disconnect between potential IP and “money making” IP. Most IP don’t make money and IP protection requires strategic thinking
  - Research security – ad-hoc vetting for companies, more formalized for research institute but still piecemeal
  - Too many grants – what should we do?
- We need startup…

TRIUMF

Breakthrough

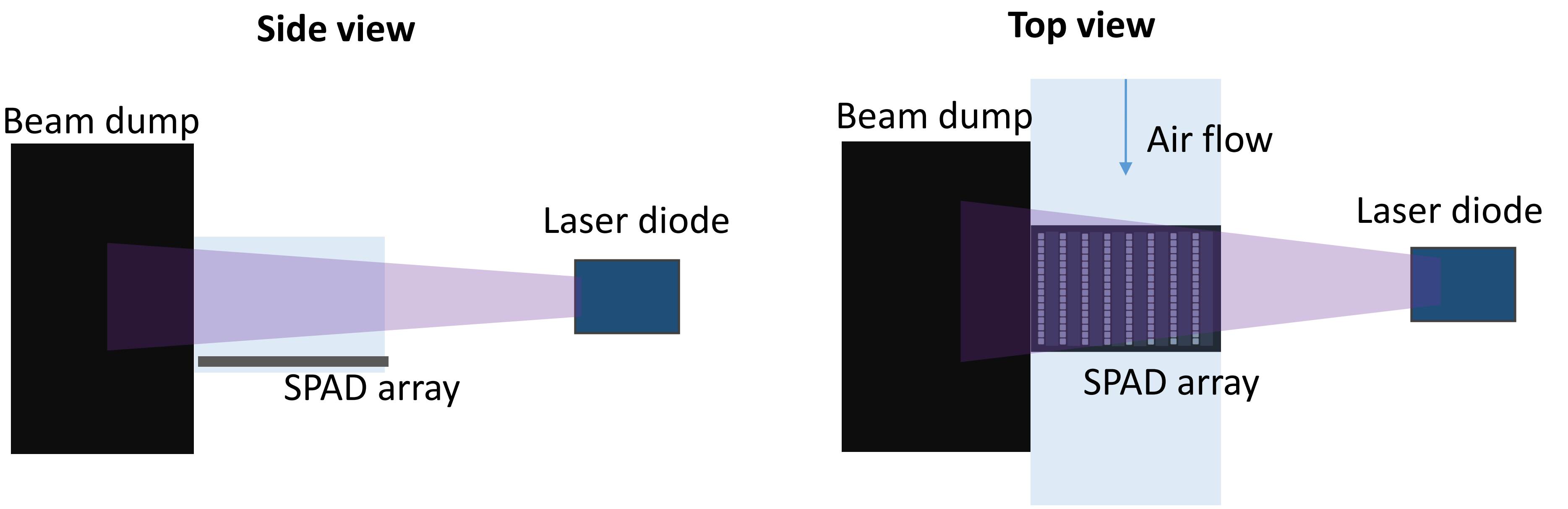
- Cutting-edge technology are often compelling solutions for applied problem
  - Moving technology through the TRL scale is absolutely worth doing
  - Be strategic - don’t push a solution without studying the competing solutions
  - Don’t worry about being “wrong”. Venture capitalist say that your drive and team is more important than your starting idea. Ability to pivot is key
- Advertising our expertise is key
  - Let companies come to us for solutions
  - Advertisement through Linkedin and websites but also networking – Tech transfer people do a great job at that.
- Many grants available though most require commercial partner matching
- Drive enables technical and scientific breakthrough … And startup

The end / Fin

Two related questions for all:

1) Should we do this, can we establish a vicious circle between basic research and applications without losing our soul?
2) At what TRL should we start working (not an industrialization question)?

Single Photon Air Analyzer – enclosed



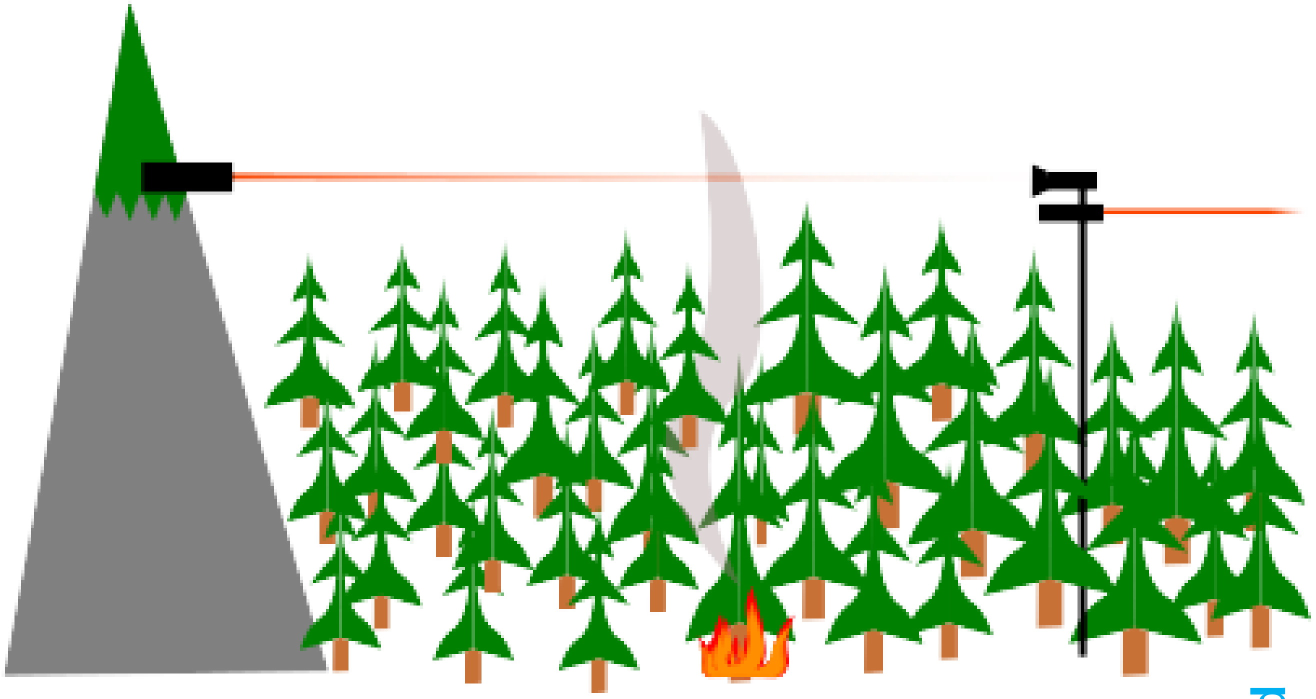
Three modalities in one unit:

- Scattering for smoke detection – Same wavelength as light source
- Fluorescence for many molecule detection – Select wavelength
- Fluorescence of specific film that react to the presence of specifc gases – select wavelength

TRIUMF

Single photon air analyser – open path

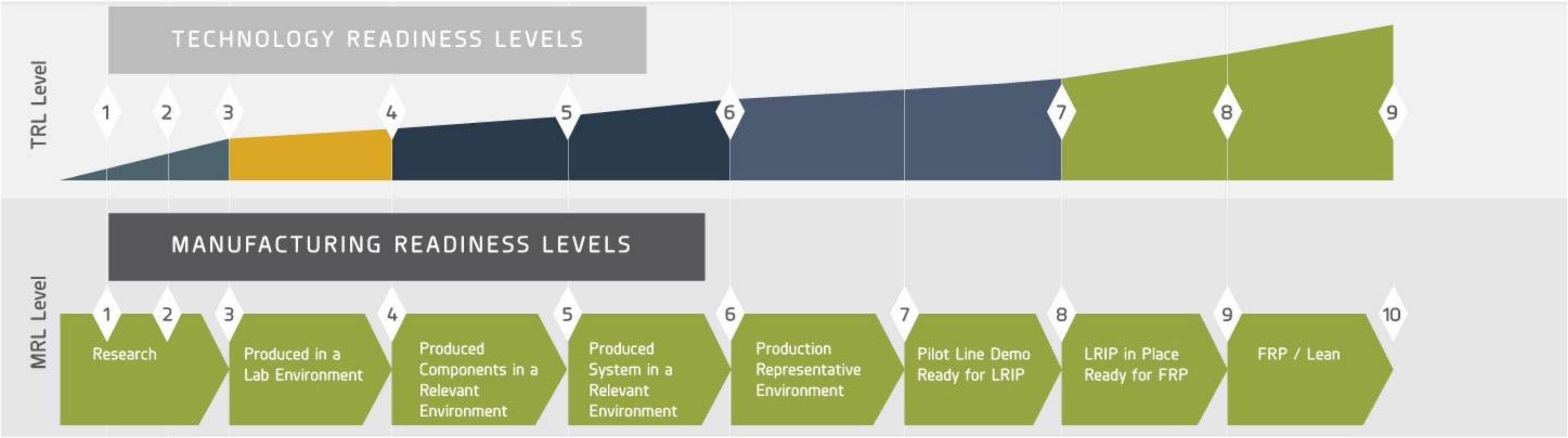
- Fire laser in open air
  - Backscattered light – smoke
    - LIDAR for distance
  - Fluorescence
    - "LIDAR" for distance
  - Attenuation
    - For conventional attenuation SPAD not so good because high flux required
    - Quantum scheme with entangled photons may reduce photon flux requirement

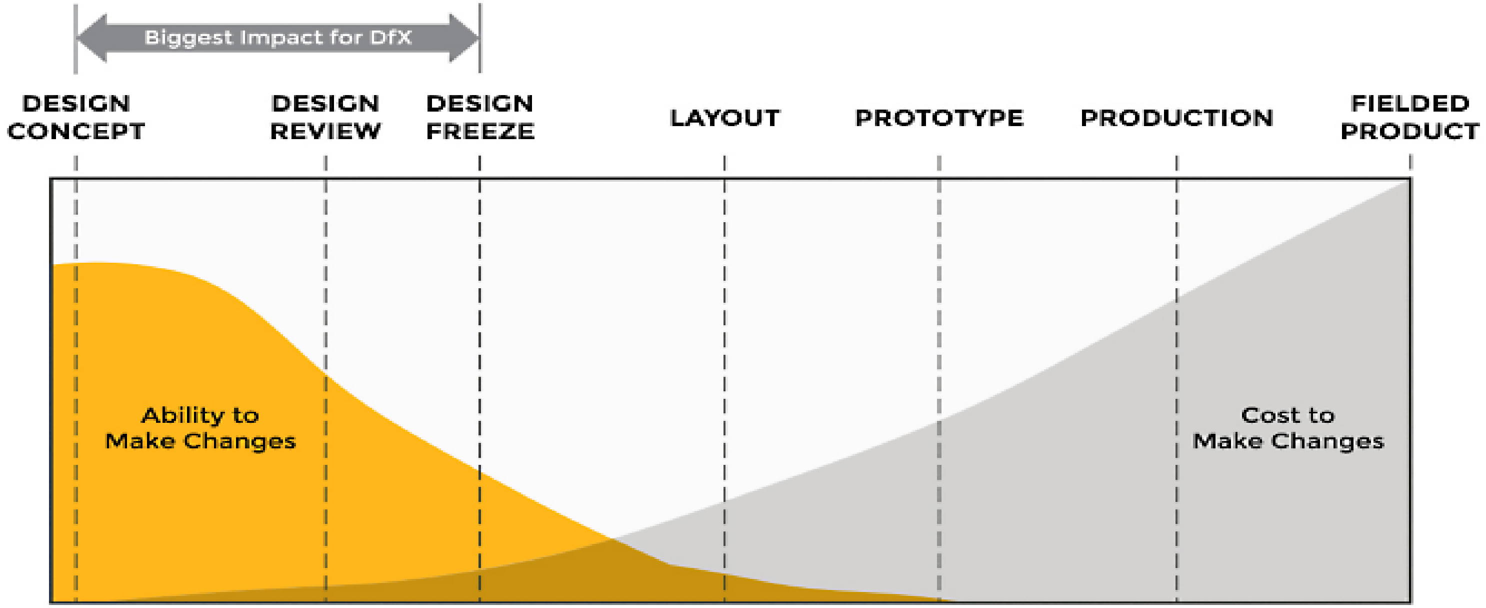


Discovery, accelerated

Comparison between TRL and MRL and relevance

UdS



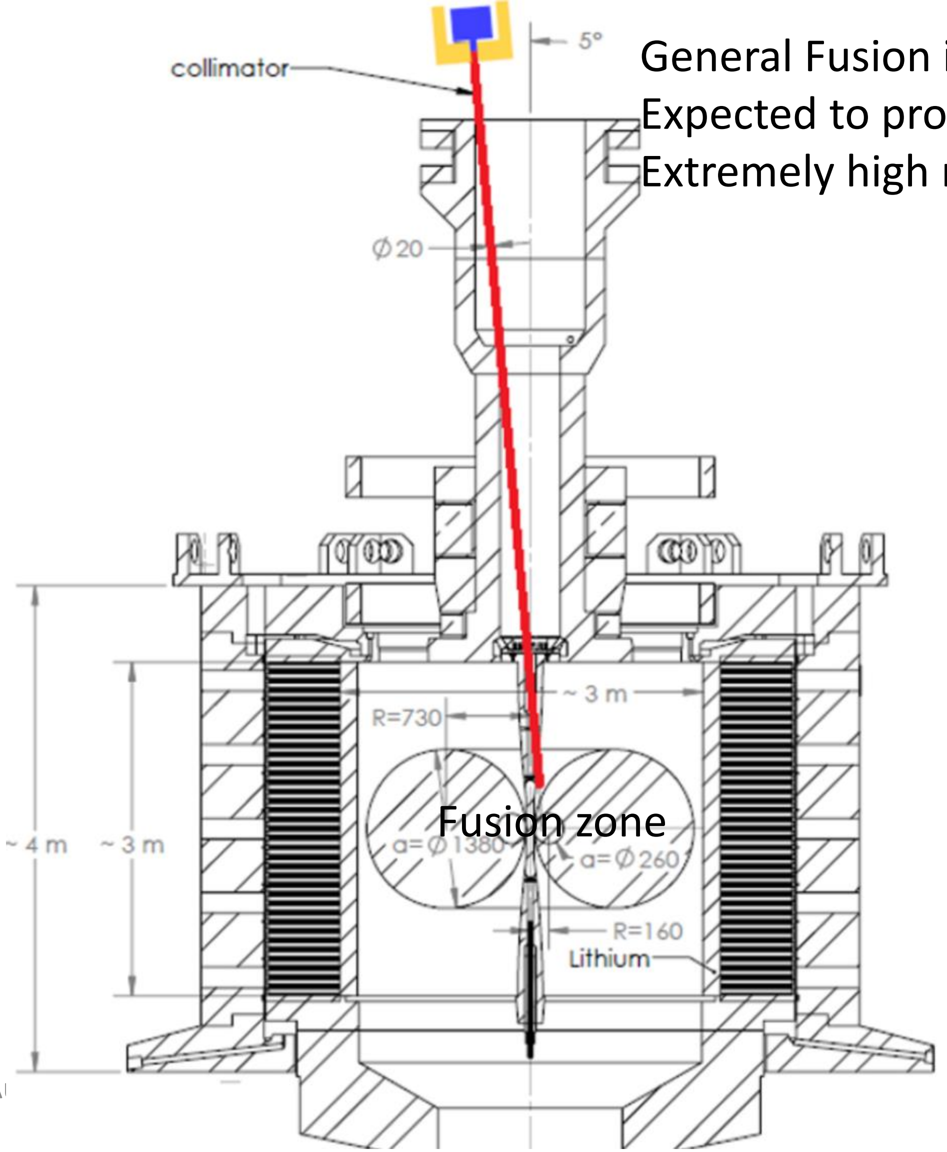


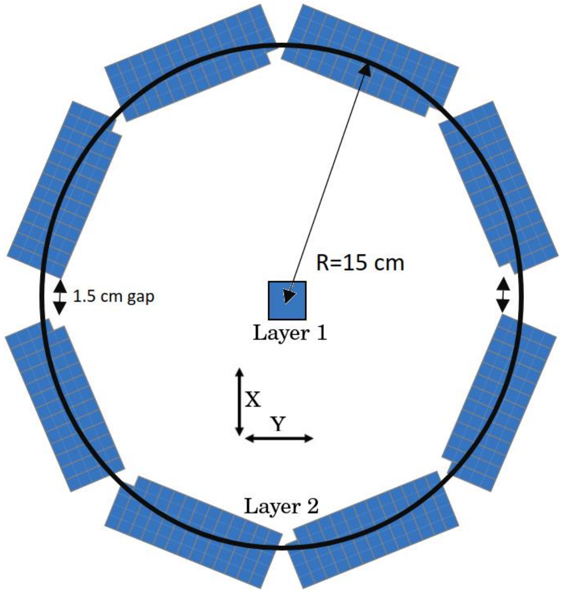
Plexus, https://www.plexus.com/en-us/current/articles/manufacturing-readiness-levels-aerospace-defense , 2024-08

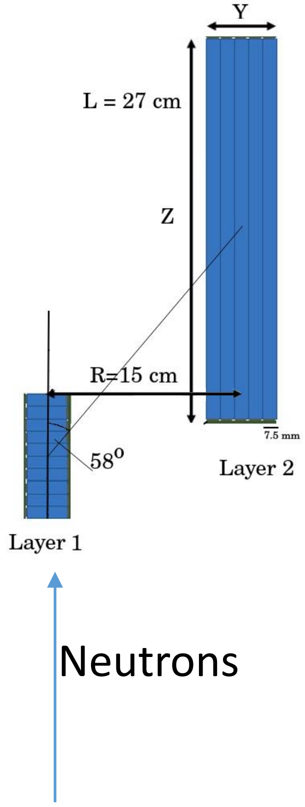
ANSYS, https://www.ansys.com/blog/what-is-dfx, 2024-08

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

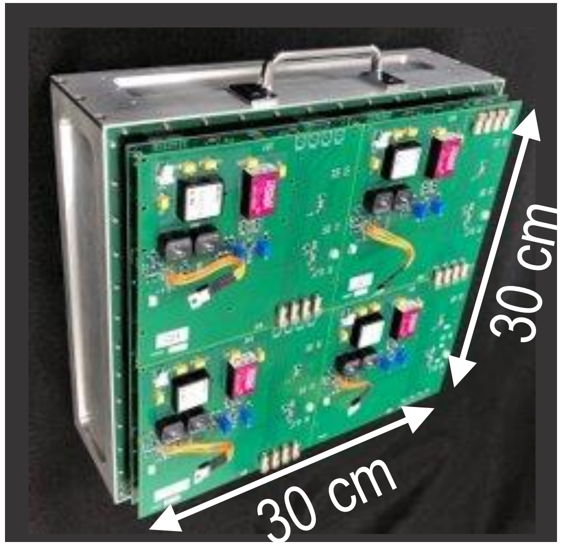


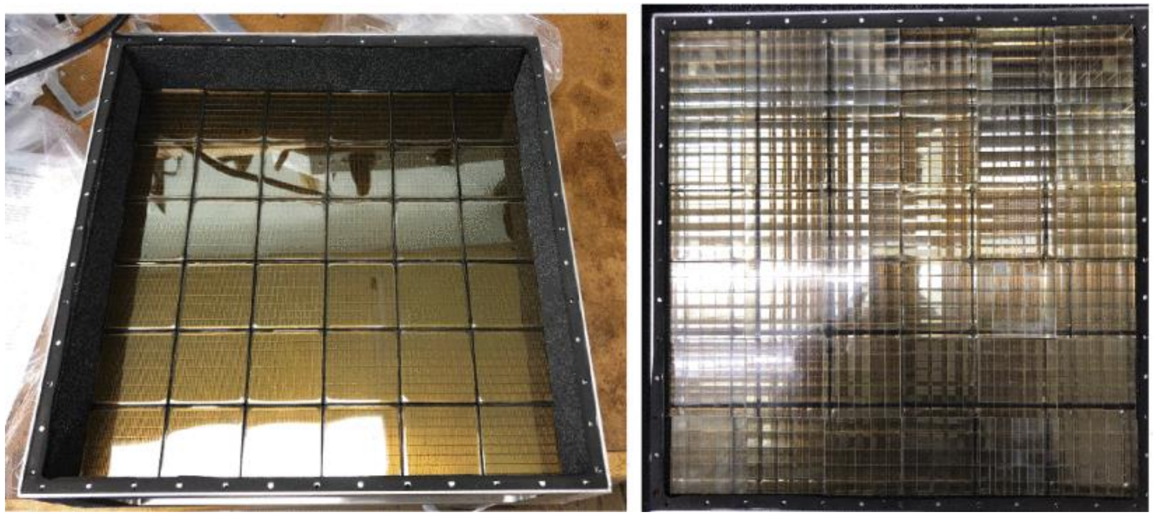




Existing solution developed by Oak Ridge National Lab.

- Multi-Anode PMT-based panel array.
- 2304 pixels over 30 x 30 cm^2.
- Eijen EJ-299 PSD pixelated plastic scintillators.
- 100s of Watts.

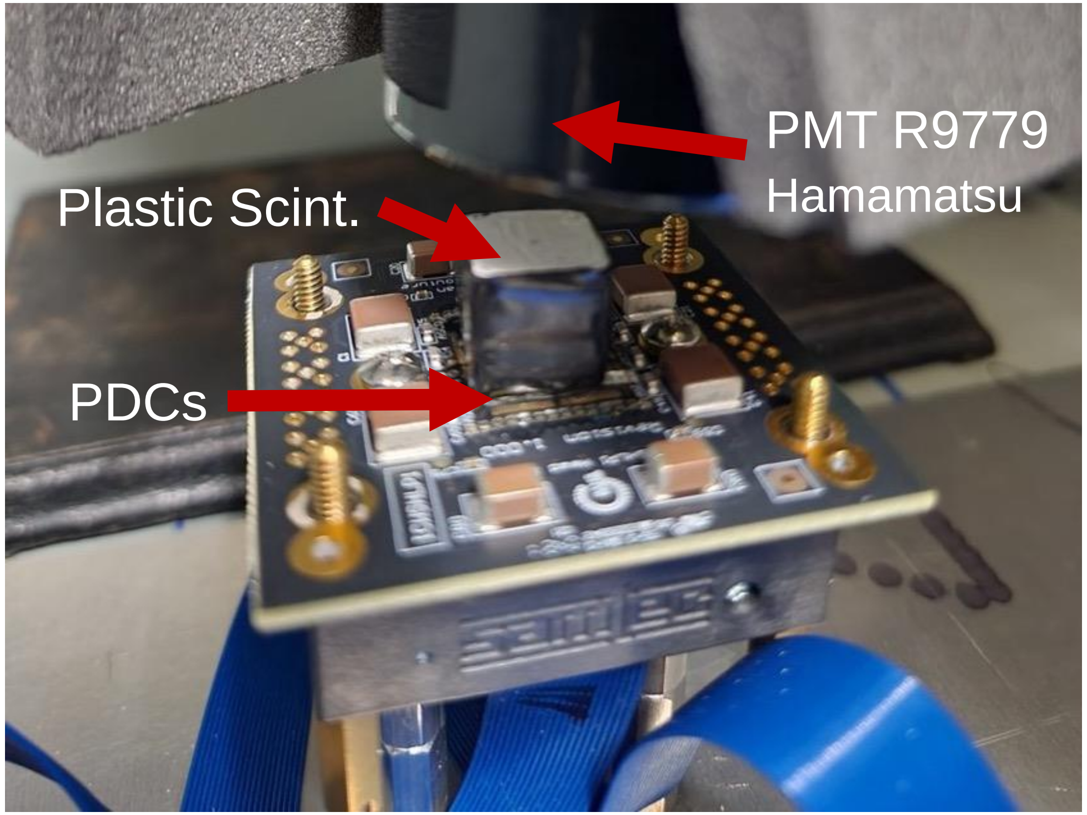




ORNL Portable Pixelated Fast-Neutron Imaging Panel [1]
Left: Multi-Anode PMT | Right: Pixelated scintillators

M. R. Heath *et al.*, "Development of a Portable Pixelated Fast-Neutron Imaging Panel", DOI:10.1109/TNS.2021.3136344.

Gamma detection demonstration
2×2 tile with scintillator and PMT



Eu-152 (10 µCi), EJ-200 Plastic Scintillator

Development of a 8×8 tile

FPGA-based controller to setup and gather data

Outside radiation instrumentation

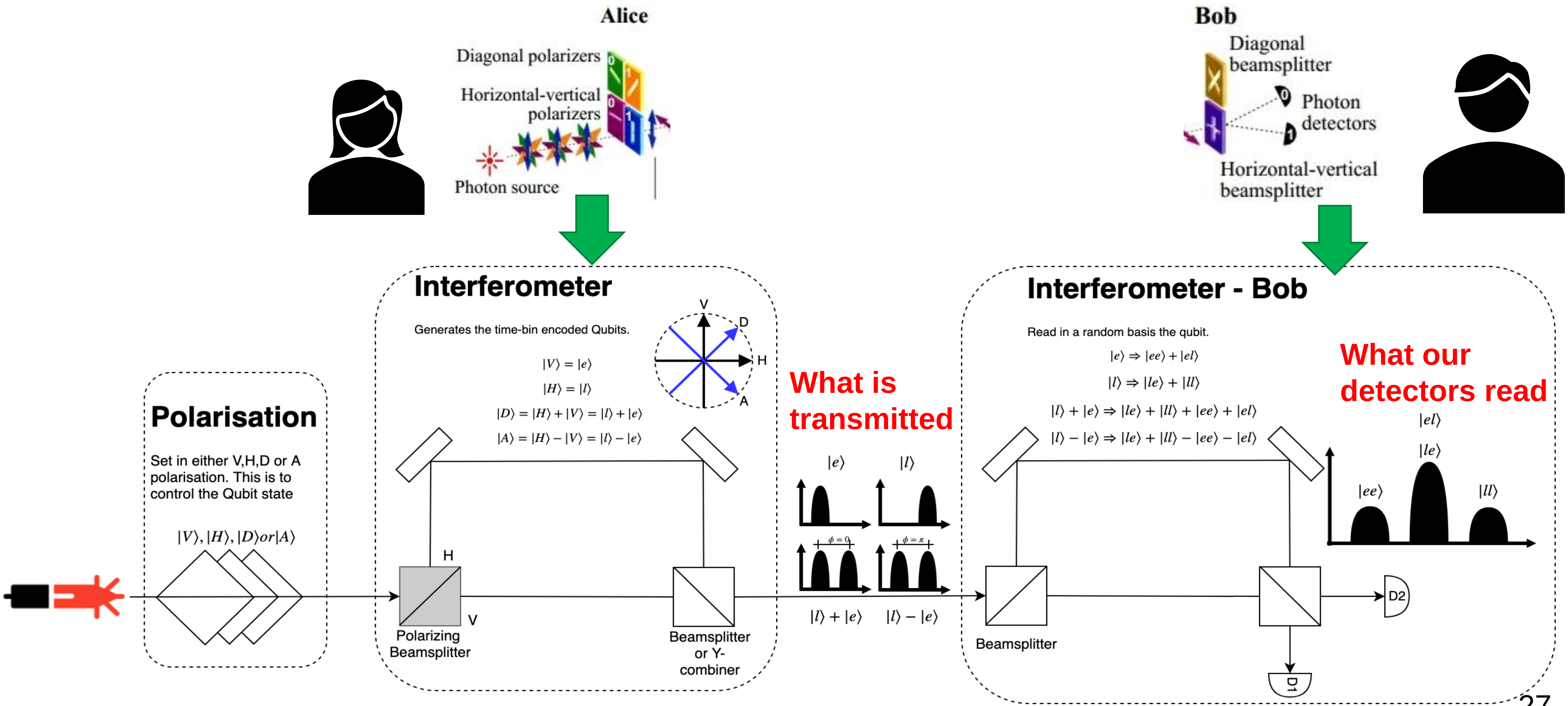
UDS

- Quantum information sciences
  - Quantum key distribution – leverages embedded signal processing
- Spectral LIDAR
  - Time-of-flight with wavelength information
    - Remote sensing of pollutants
    - Remote sensing of threats
- Single photon counting and high sensitivity
  - Forest fire surveillance
  - Space telecommunication

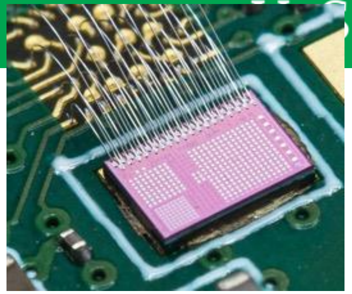
Few words on conventional LIDAR:

- Use short infrared wavelength for eye savety
- Can use low sensitivity detectors (<15%) because repeated high intensity laser source
- Major industrials in this race with highly dedicated sensor design

Interferometer convert polarisation states into **time-of-arrival** quantum states



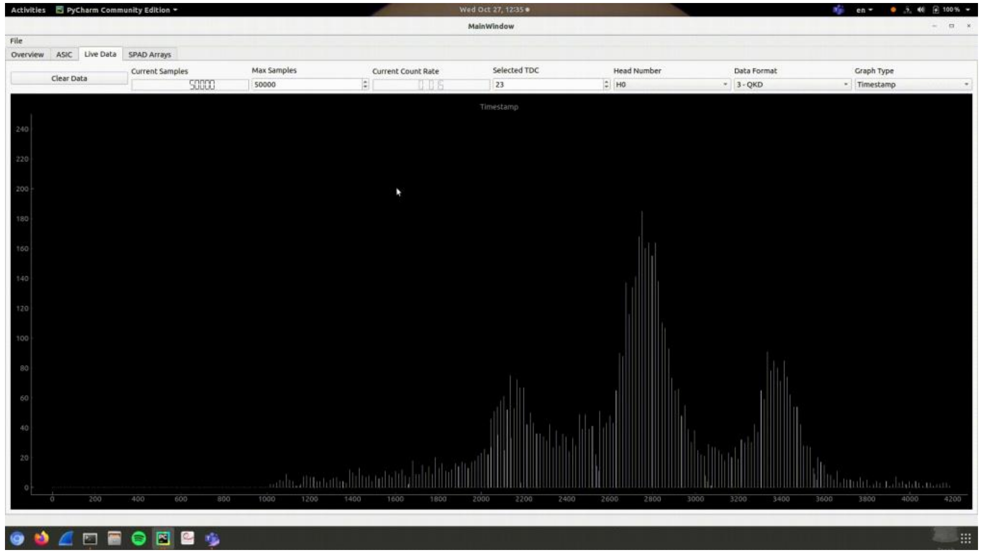
Time stamp classification: the power of embedded processing



Raw time stamp data

Each photon is timestamped in the chip
- ~20ps resolution and precision
- Timestamps are transmitted to the computer

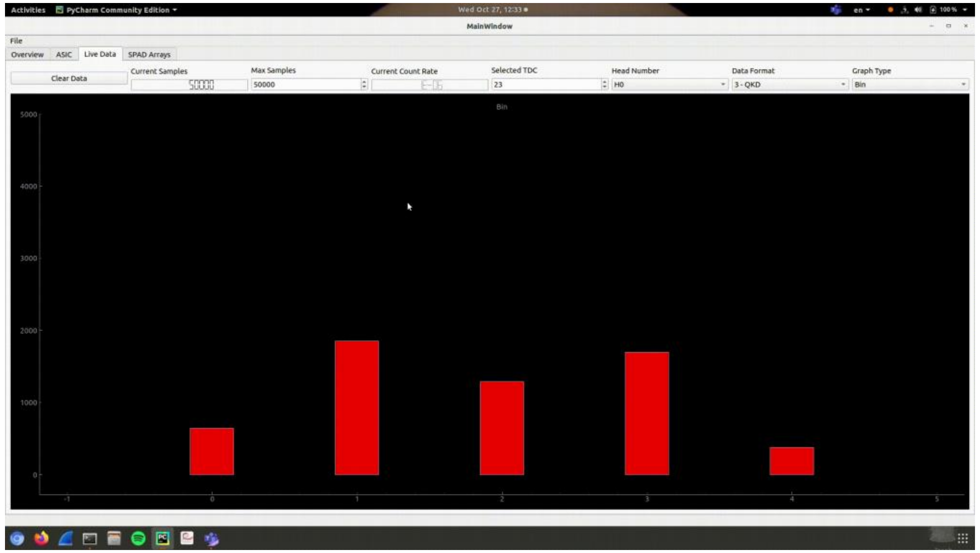
The histogram shows 3 modes to the distribution corresponding to the projection of the 4 states of the qubit onto the time base (center bin holds 2 states)



Classified time-bins

Timestamps are classified inside the chip into 5 bins
- Two bins for out-of-range values
- Programmable bins

The provides effective data compression limiting to a 2-3 bits only the relevant information about each qubit



The two graphs show different measurements.
Time variations are due to slow tuning of an interferometer for the purpose of this demonstration.