

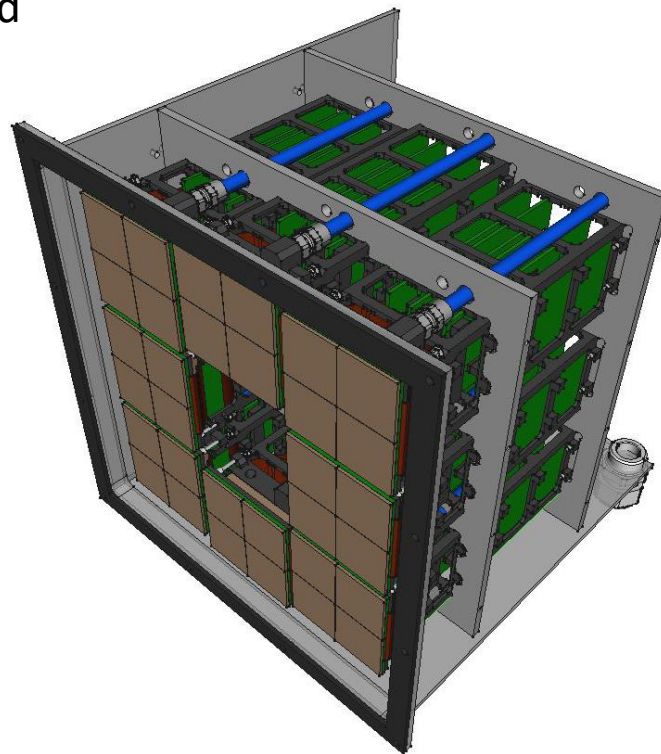
Photo-detector R&D in the FCC era

Fabrice Retiere (TRIUMF) on behalf of the DRD4 collaboration

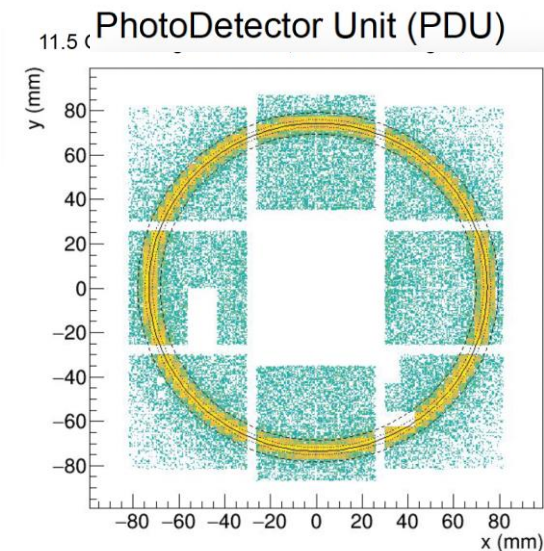
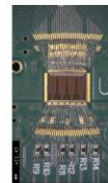
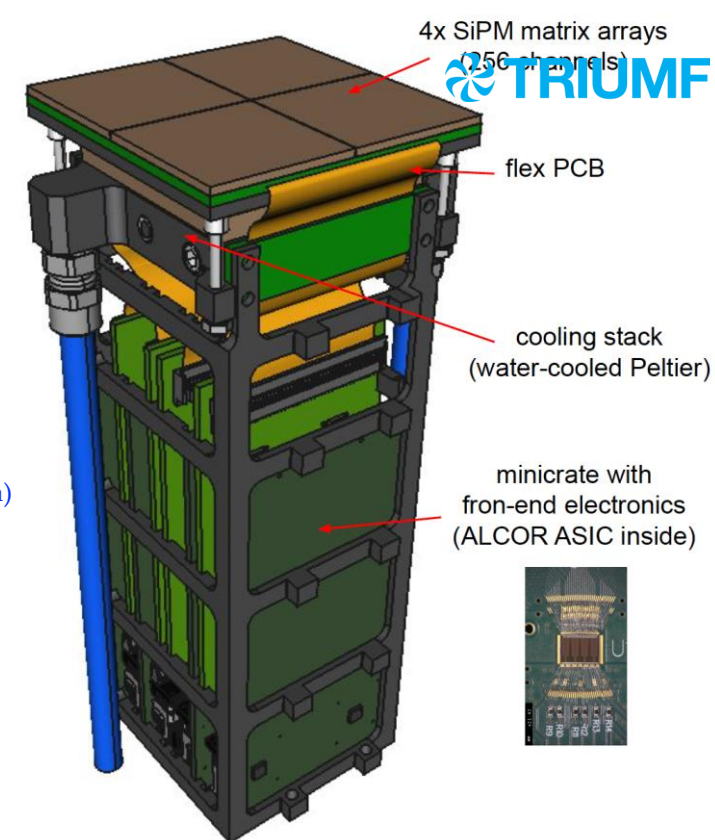
Although very much a personal selection

State of the art Ring Imaging Cerenkov

- Dual RICH (dRICH) detector with SiPM for ePIC (EIC)
 - 2 radiators: aerogel ($n \sim 1.02$) and C2F6 ($n \sim 1.0008$)
 - 4x matrix Hamamatsu (8x8 S13361)
 - Read-out board with front-end chip (ASIC), FPGA, and cooling
 - Single-photon detection inside high B field (~ 1 T)
 - Advanced design and prototype tests



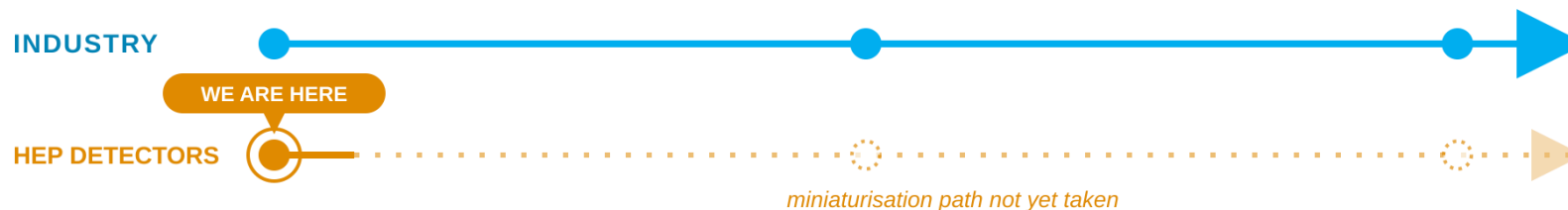
R. Preghenella (INFN Bologna)



State of the art?

The miniaturisation path our field hasn't taken

Consumer imaging went from hand-held cameras to monolithic single-photon imagers. HEP single-photon detection is still at the first stage.



Industry reached monolithic single-photon imagers; HEP single-photon detection is still discrete. The integration path — DRD4 WP1: BSI, CMOS-SPAD, 3D — lies ahead.

Working Groups and Work Packages

Six WGs are open R&D forums; five WPs are funded, milestone-driven projects mapped to the ECFA roadmap — the same roadmap that defines detector needs for the FCC.

Spokesperson: M. Fiorini (INFN Ferrara), deputy spokesperson: F. Retiere (TRIUMF)

WORKING GROUPS

open forums · no committed resources

WG1 Photon Detectors *Retière, TRIUMF*

Writing a 400 pages compendium about single photon detectors

WG2 Particle ID *Easo, RAL*

WG3 Technological activities *Tessarotto, Trieste*

WG4 Software *Martinelli, Milano-Bicocca*

WG5 SciFi & TR detectors *Jakobsen, CERN*

WG6 Novel / far-future R&D *Özkorucuklu, Istanbul*

WORK PACKAGES

funded projects · goals, milestones, deliverables

WP1 Solid-state photodetectors *Pestotnik, Ljubljana*

WP2 Vacuum-based photodetectors *Laktineh, Lyon*

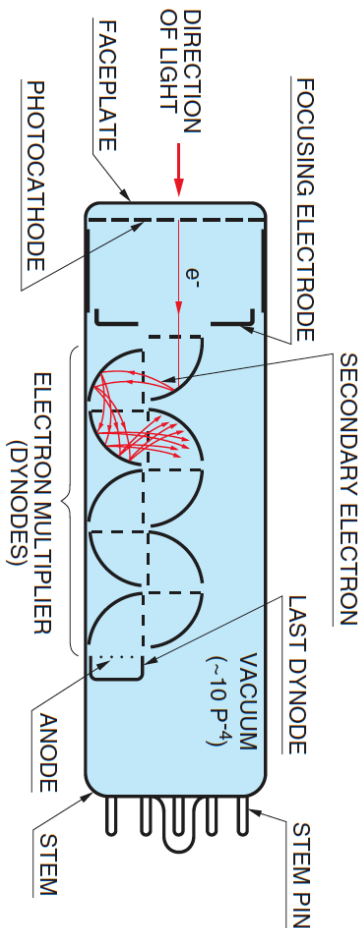
WP3 RICH & imaging detectors *Cardinale, Genova*

WP4 Time-of-Flight detectors *Lapington, Leicester*

WP5 SciFi tracking & TR *Leverington, Heidelberg*

Vacuum Photo-Detector

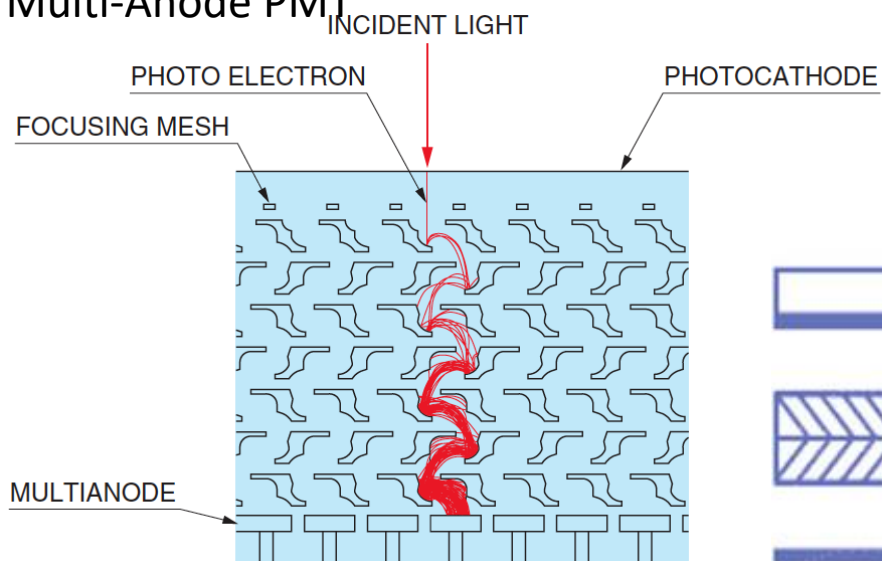
Conventional PMT



• Pros

- High gain and low dark noise
- Excellent timing resolution for MCP
- Good efficiency

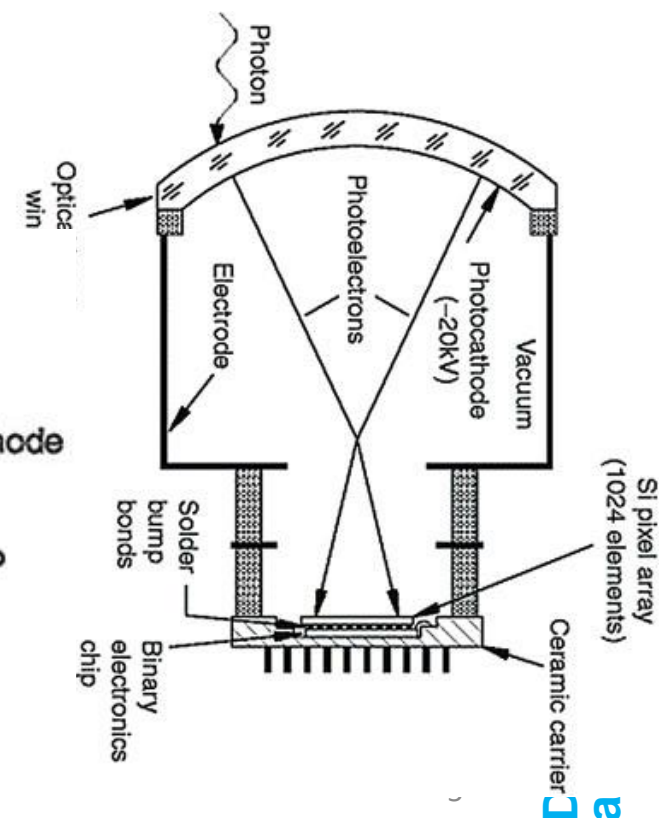
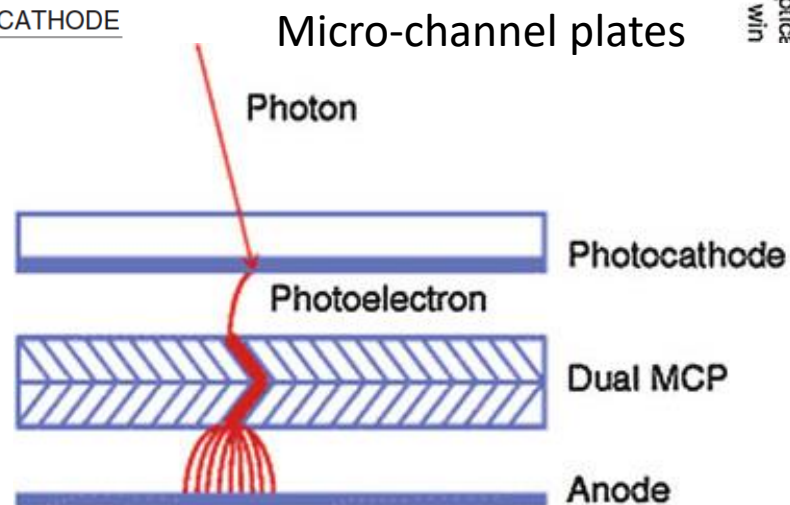
Multi-Anode PMT



• Cons

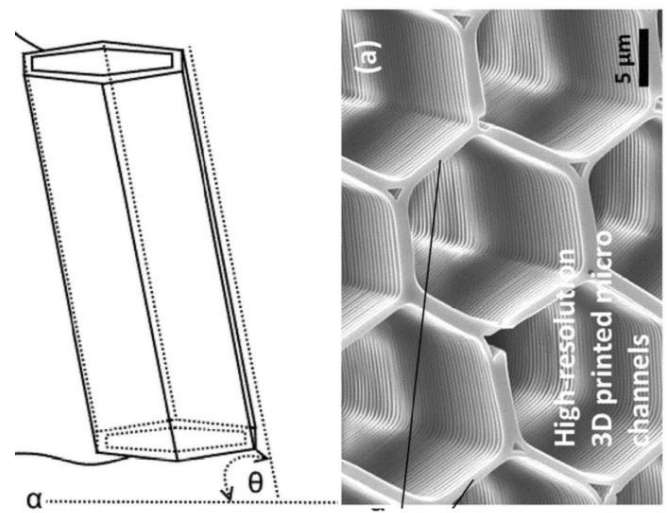
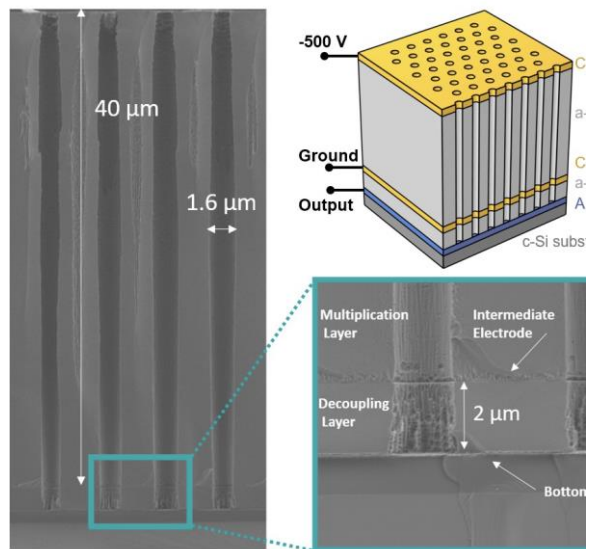
- Specialized manufacturing
 - Limited suppliers
- Fragile
- Bulky

Hybrid-Photodetector

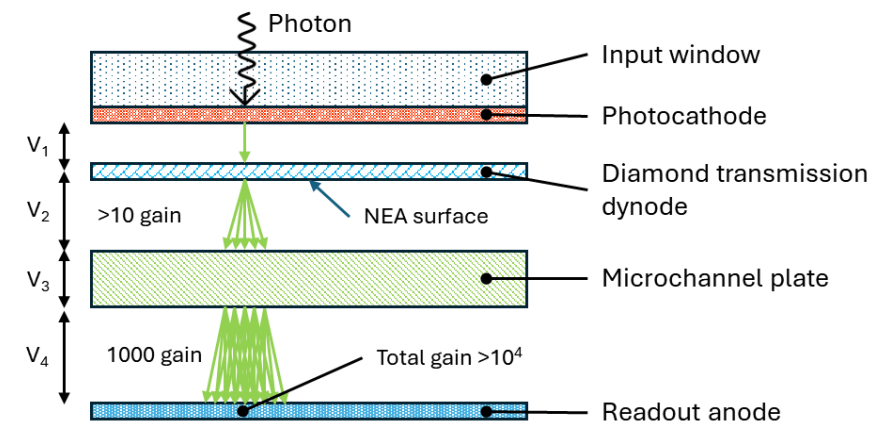


Vacuum photo-detector moving towards enhanced integration

- MCP fabrication over silicon substrate
- 3D printed MCP
- Transmission dynode
- All these technique enables integration with CMOS – TimePiX4, PICMIC



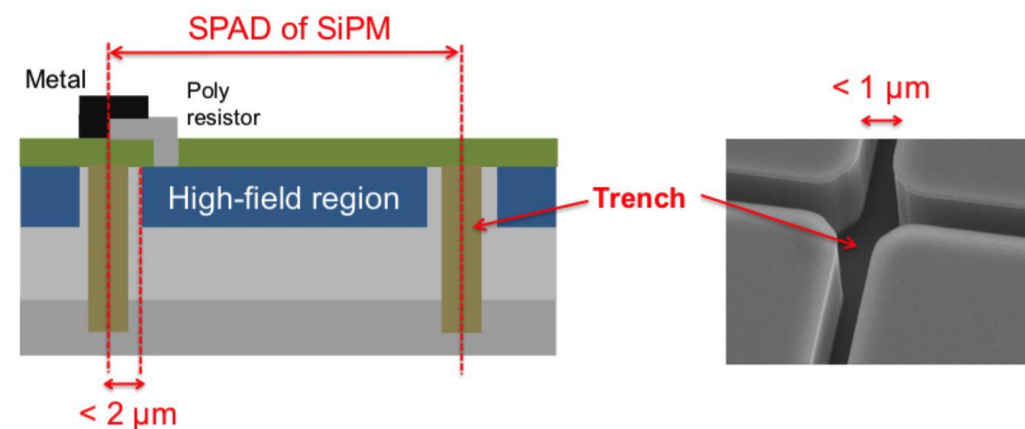
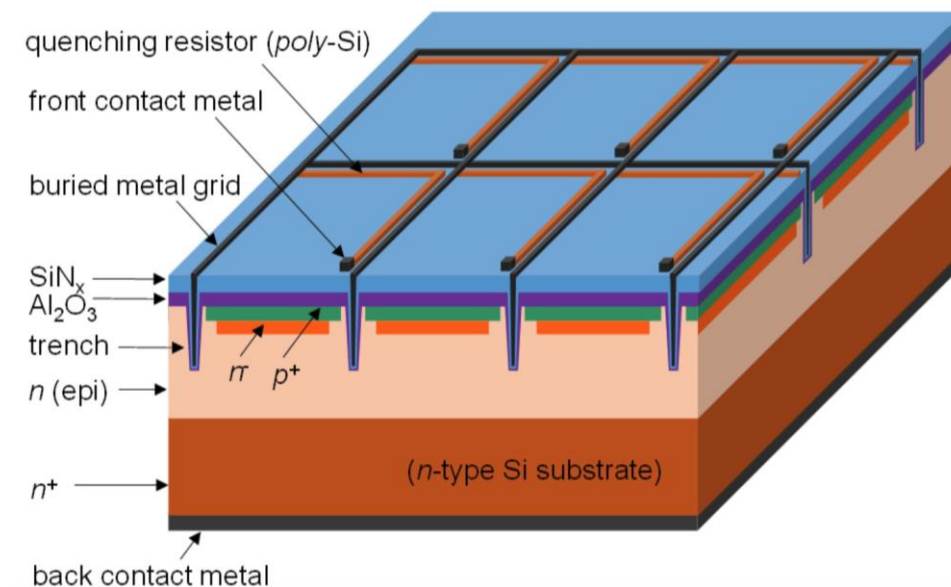
C. Ertley (Proc. of SPIE Vol.13093, 130935S)



J. Lapington (RICH 2025)

Single Photon Avalanche Diode Arrays (SiPMs)

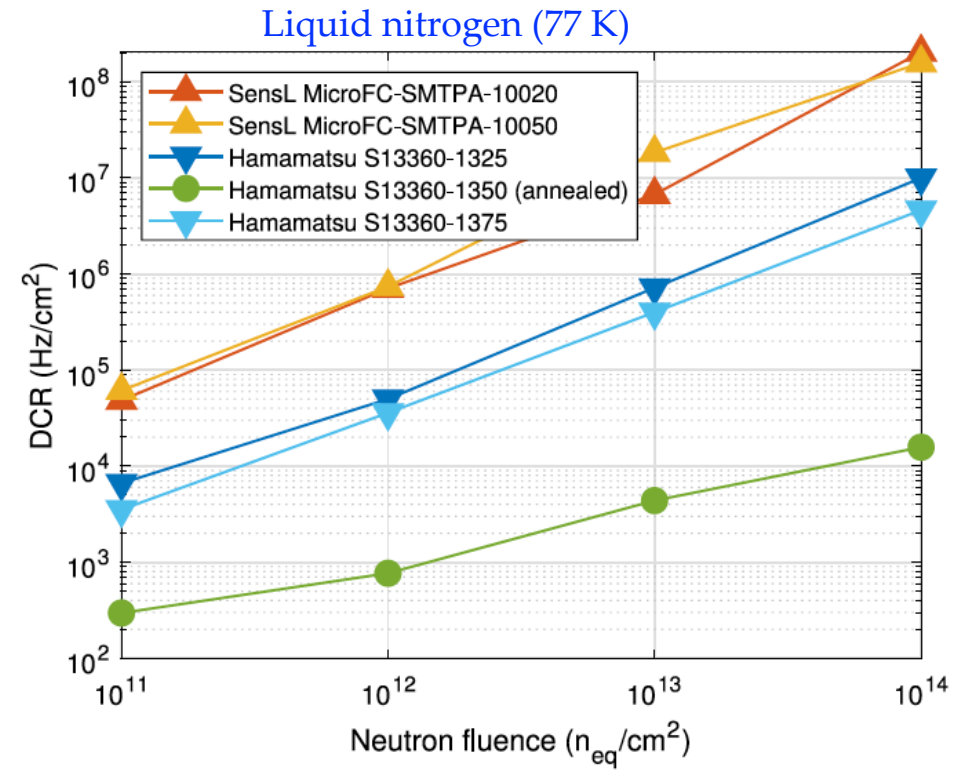
- Pros:
 - High gain ($\sim 10^6$) and single photon separation
 - Excellent time resolution
 - Good granularity
 - Insensitive to magnetic fields; low V operation
 - Compact
- Cons:
 - High dark count rate. typ. ~ 100 kHz/mm²
 - correlated avalanches (afterpulse, crosstalk) & emits light
 - Very sensitive to neutrons and ionizing particles



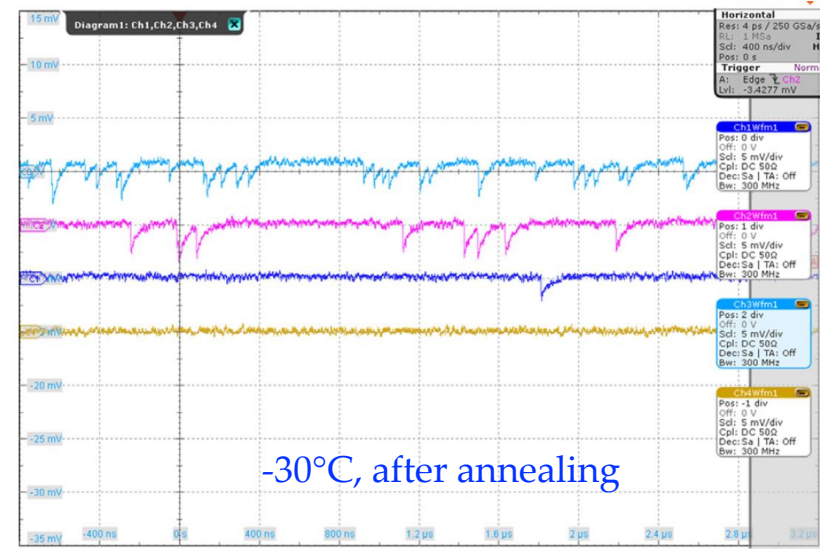
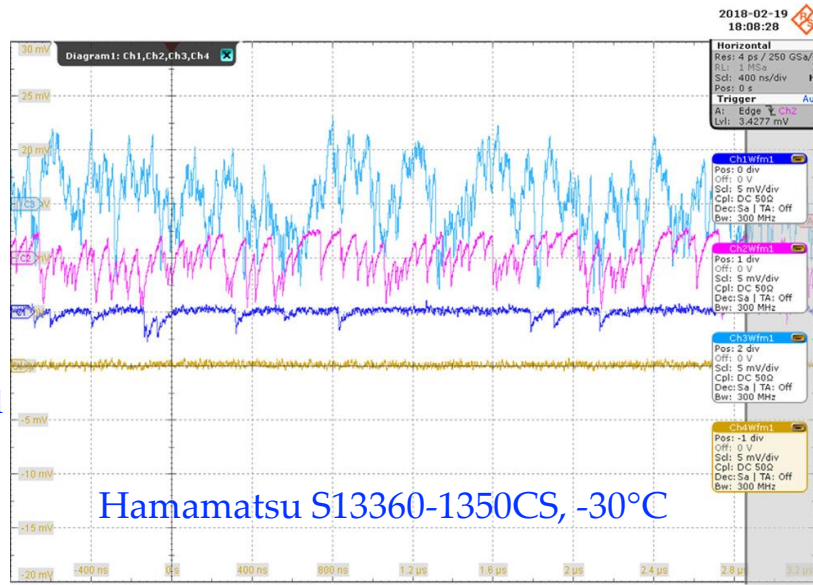
WP 1, task 3 radiation hardness

- DCR highly depends on temperature and irradiation
- Can be mitigated by cooling (and annealing after irradiation)

M. Calvi (NIM A 952 161788, 2020)



$10^{13} n_{eq}/cm^2$
 $10^{12} n_{eq}/cm^2$
 $10^{11} n_{eq}/cm^2$
 non irradiated



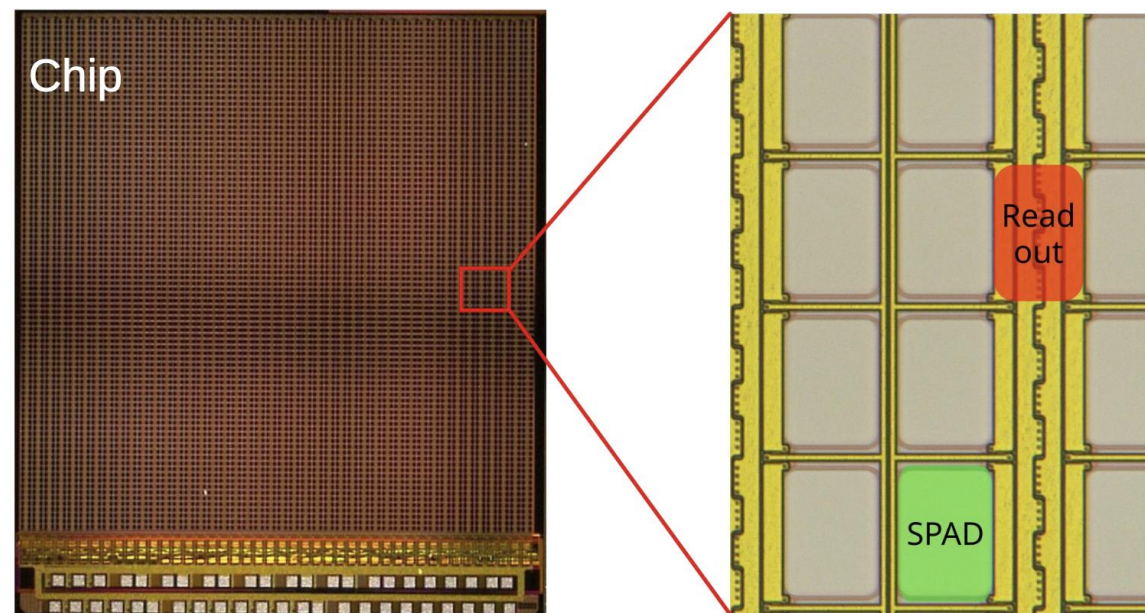
CMOS SPAD

- Pros
 - “no” power dissipation when idling
 - Tailor performances to needs. E.g. dynamic range, timing, imaging,...
 - Less complex at system level
 - Lower dark noise by SPAD elimination
- Cons
 - In 2D, some efficiency loss
 - More complex at chip level
 - Mass production not demonstrated (by HEP)

Digital SiPMs for DARWIN

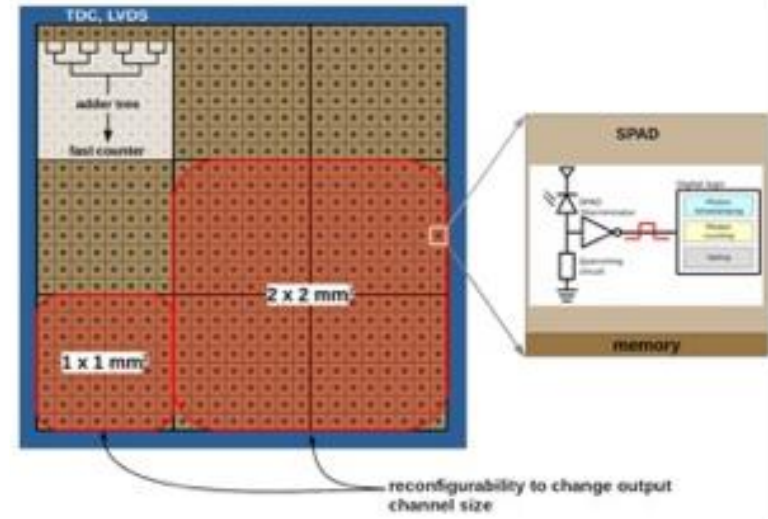
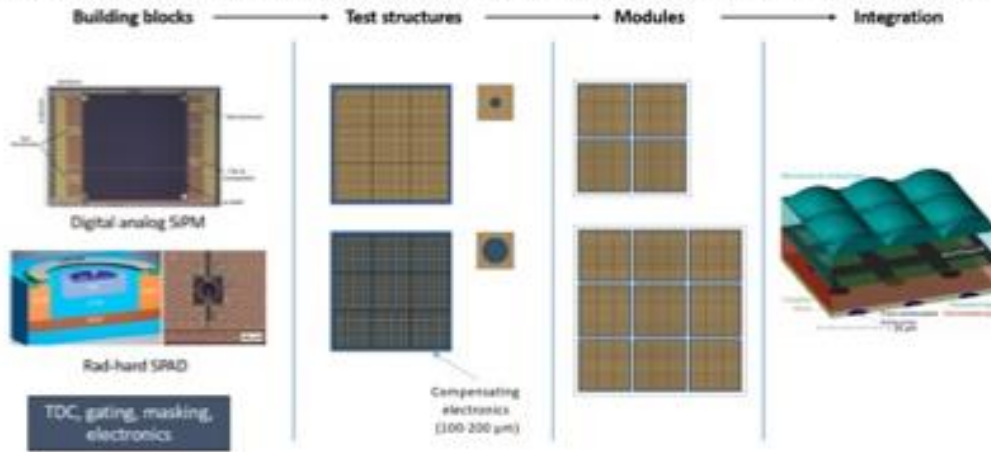
Michael Keller, Peter Fischer, Robert Zimmermann, Michael Ritzert – University of Heidelberg

DARWIN Collaboration Meeting 2023 at University of Heidelberg

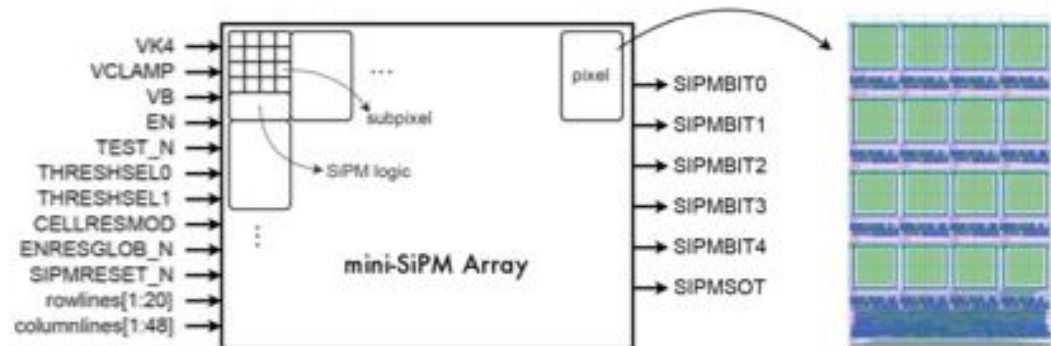


CMOS SPAD within DRD4

spadRICH - Radiation-hard digital analog silicon photomultipliers for future upgrades of Ring Imaging Cherenkov detectors



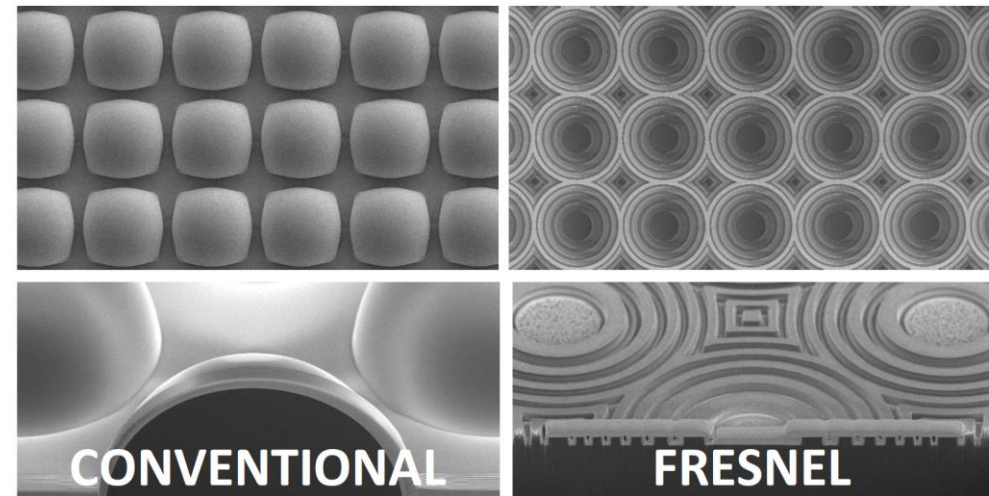
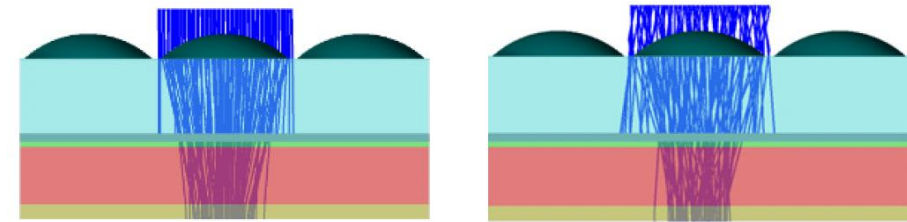
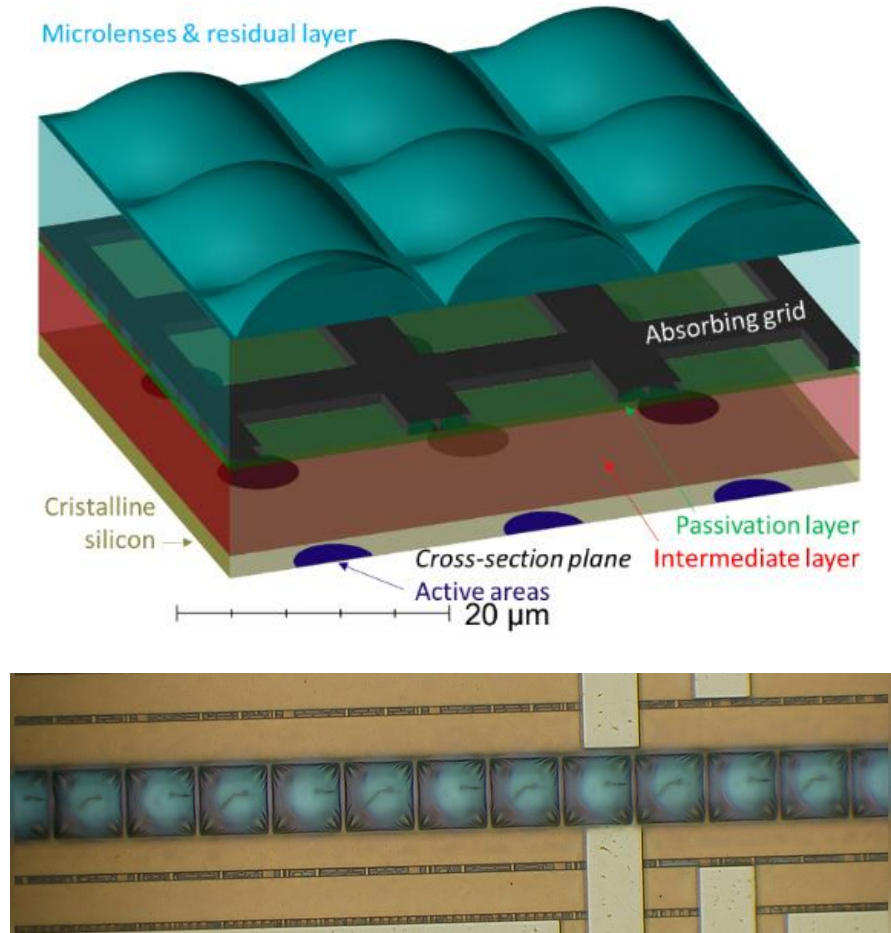
ASPIDES -Development of a technology platform for the design, production and commissioning of dSiPMs



PLATON (EPFL, ETHZ – D. Sgalaberna)

Scintillating fibres as active neutrino target
Towards dedicated dSiPM: 272x192 SPAD pixels, per-cluster TDCs (200-800 ps LSB), low data rate (1-2 LVDS connections sufficient per chip)

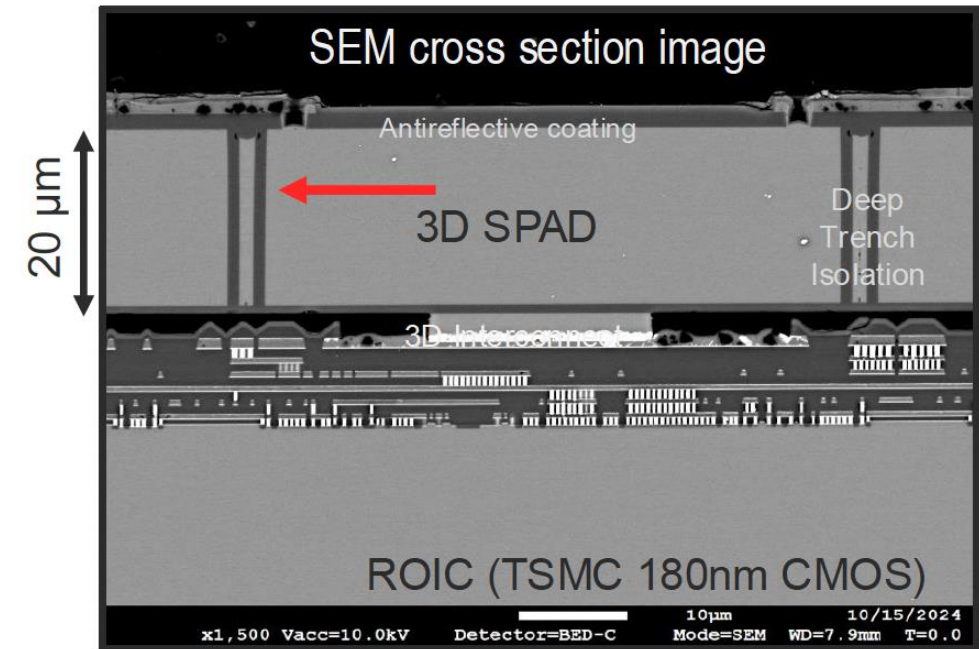
Leveraging the nano-optics revolution



C. Bruschini

3D integration

- Industry is leading:
 - CANON, SONY for single photon imager
 - STMicroelectronics and smaller companies for LIDAR
- In HEP, University of Sherbrooke, Canada (S.Charlebois, J.-F. Pratte) is leading with Photon to Digital Converter
 - Development driven by astro-particle physics, nEXO, ARGO
 - SPAD array and CMOS readout 3D-stacked to form a single heterogeneous detector chip
 - Made in Canada: SPAD array and 3D integration in Teledyne MEMS, Bromont, Quebec

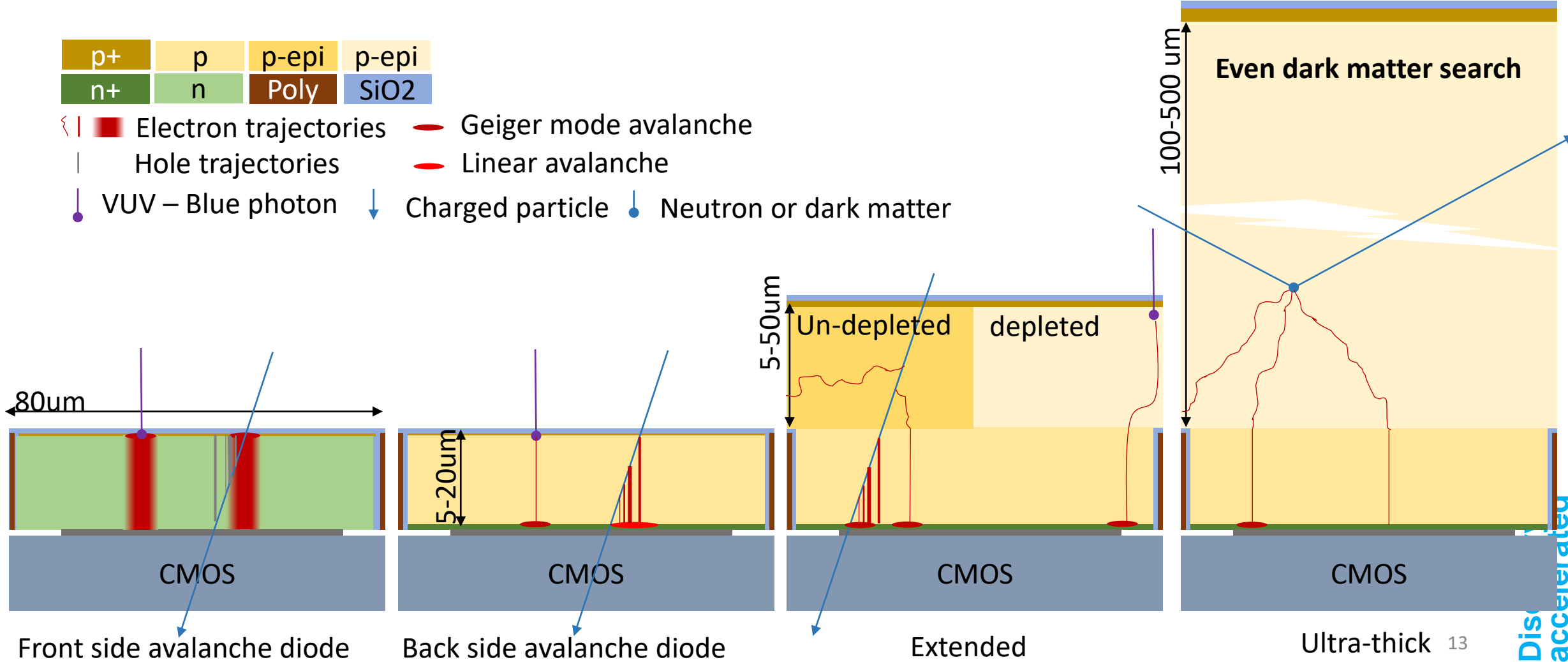


S. Charlebois (PD 2025)

Back-side illumination is the next step for versatility

p+	p	p-epi	p-epi
n+	n	Poly	SiO2

- Electron trajectories
- Hole trajectories
- VUV – Blue photon
- Geiger mode avalanche
- Linear avalanche
- Charged particle
- Neutron or dark matter



Canada FCC and photo-detectors

- Canadian effort can no longer be sustained only by astro-particle physics
- Both TRIUMF and Sherbrooke are drifting to applied projects
 - Neutron imaging. Sherbrooke - ORNL
 - Air analysis. TRIUMF – SenseNet
 - Neutron spectrometry. TRIUMF – General Fusion
 - Expansion through non NSERC SAP grants
- Canada photo-detector effort needs FCC interest
 - DRD4 is LHCb biased. About 50% of the community
 - And DRD4 is also fibers, optics,...
- Canada has very strong industrial assets in photonic
 - Teledyne-MEMS
 - And broad industry
- Strong opportunity to catch up with industry if we can create critical mass

Merci / Thank you