ASPIDES Kick-off meeting

WP4 - SPAD design, characterization and modelling activities

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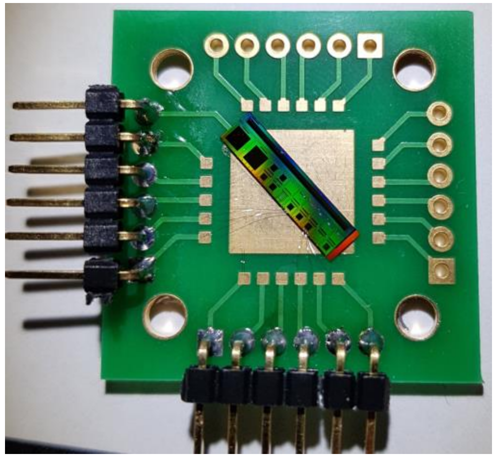
WP4 – from the proposal

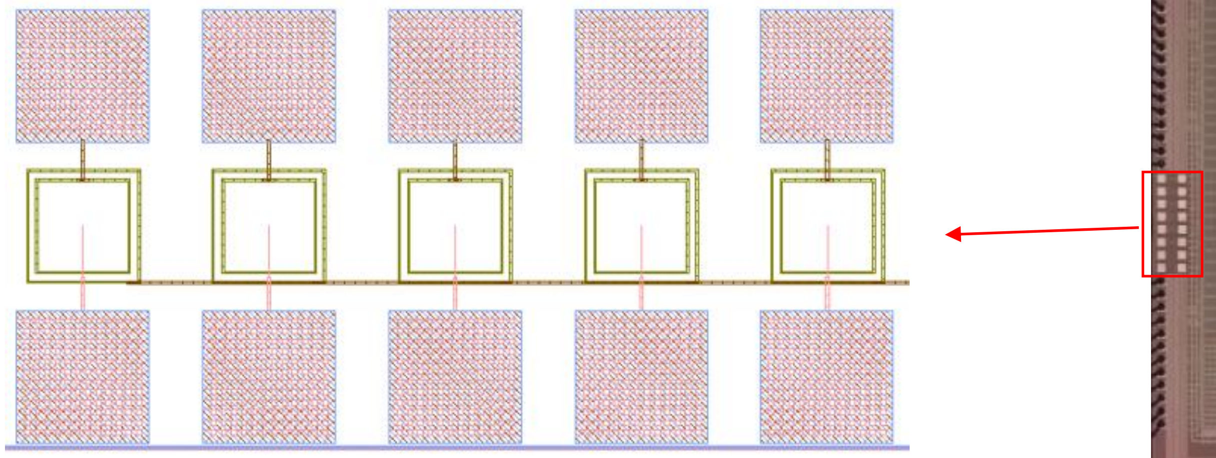
Physical level simulation and modeling of the SPADs – first steps

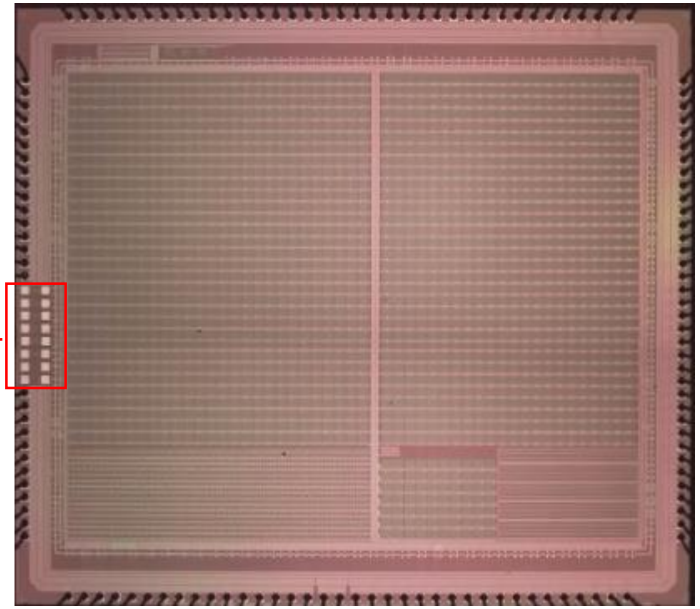
- **2025: Dedicated structures** integrated in the test chip and in the prototype chip **will be characterized**, in collaboration with WP2 and WP3, and used for **TCAD simulation tuning**.
- **2025:** The experimental data extracted after **irradiation** and from characterization at **cryogenic** temperatures will be in particular leveraged for **modeling** the effects of radiation and of cryogenic conditions on the device performance.

Characterization of plain standard SPADs w/o electronics

- Large test SPAD devices (50um x 50um) with probe pads available in chip **ASAP110LF**
- 5 chips in Trento – the others in Pavia
- IV and CV with probe station @ RT
- **IV at different T** on bonded devices (Napoli?)
- Trento has **small passive PCBs** for device bonding. Where can we do the bonding?





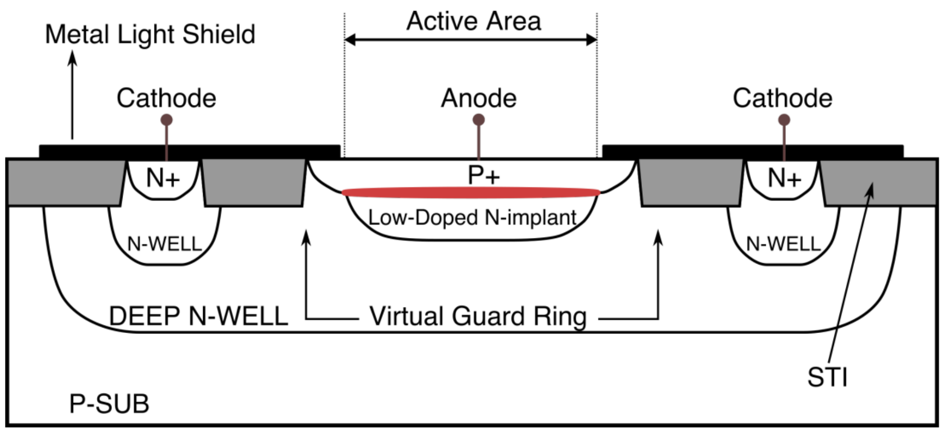


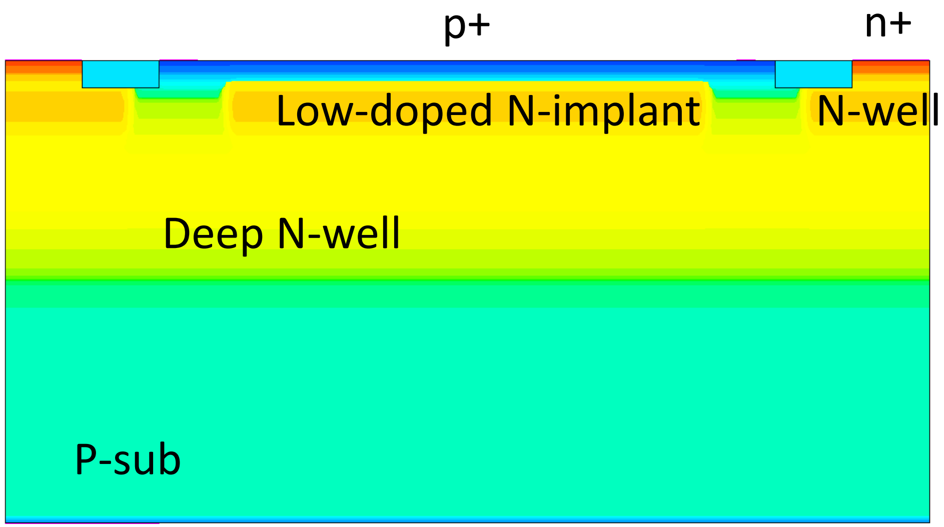
TCAD device simulation

- New **signed NDAs**: LFoundry provided information on doping profiles and PDK to Trento, and will soon provide the same data to Pavia and Napoli
- **Trento will share example simulation** based on standard profiles with Pavia and Napoli, as a base for:

Understand **existing devices** from chip ASAPLF110 (with help of profile estimation from CVs)
2025

Start design of **new devices** with improved cryo and radiation hard operation (new Low-Doped N-implant)
Later - 2025-2026



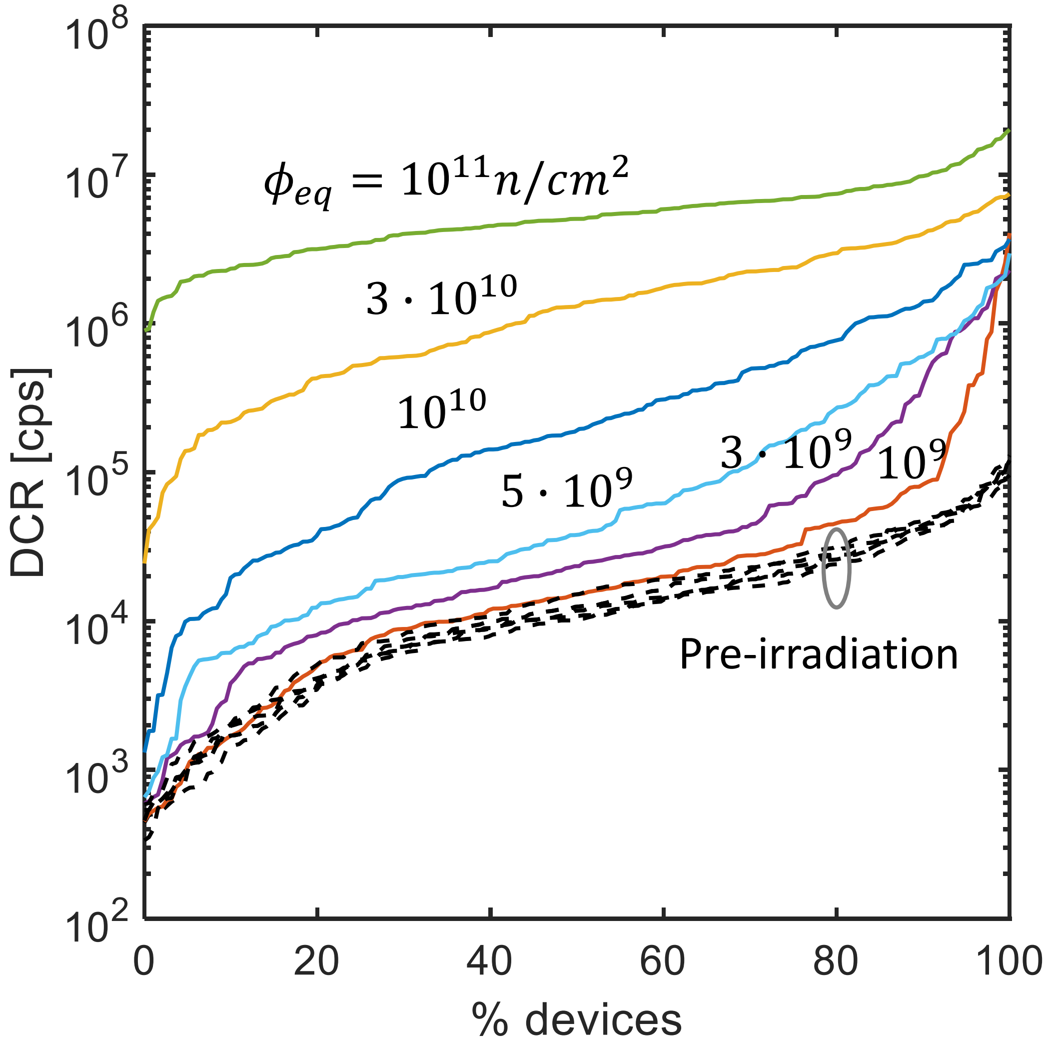


Device simulations

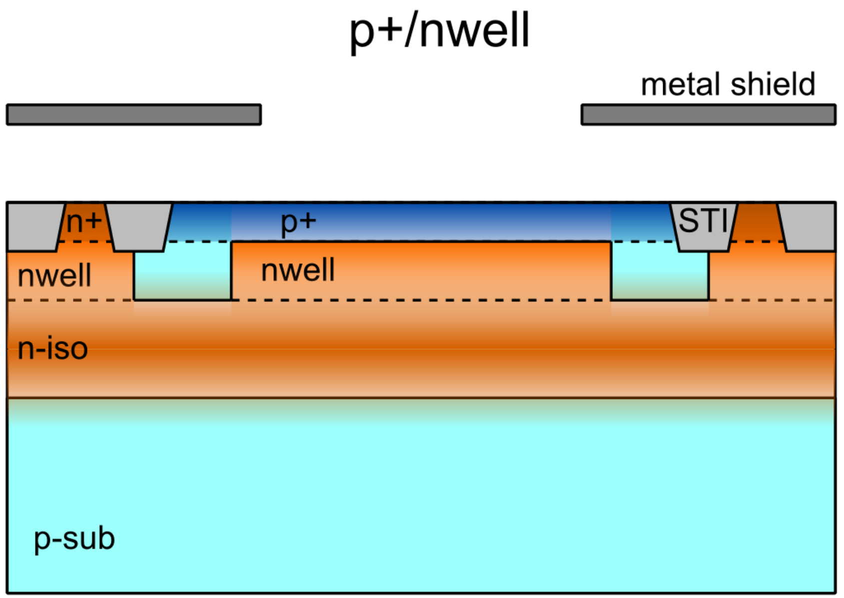
- IV curves in the dark
- IV curves with light (sub-Geiger)
- Avalanche triggering probability vs. overvoltage (Geiger)
- Effect of T on :
  - Breakdown voltage
  - Dark count rate
  - Avalanche triggering probability
- Effects of radiation damage on DCR (example in the next slides)

To be **compared with experimental data**

Radiation damage – LF150 SPADs with 43µm x 45µm active area



Effect of neutron irradiation on DCR: cumulative distribution



Simulation model

TCAD 1D model:

- Drift-diffusion
- Breakdown probability P_b with local impact ionization model: Van Overstraeten and De Man ionization coefficients
- Slotboom band gap narrowing
  [J. W. Slotboom and H. C. de Graaff, Solid-State Electron., 19 (10) 1976]
- Hurkx Trap-Assisted Tunneling (TAT)
  [G.A.M. Hurkx et al., IEEE Tran. Electron Dev., 39 (2) 1992]
- Poole-Frenkel effect

Simulation model

Radiation-generated trap model based on Perugia model

[M. Petasecca et al., IEEE Tran. Nucl. Sci., 53 (5) 2006]

3 trap levels:

1. Ec – 0.42eV, related to $VV^{(-/0)}$ defect
2. Ec – 0.46eV, related to $VVV^{(-/0)}$ defect
3. Ev + 0.36eV, related to C_iO_i complex

} Deep acceptors

Defect cross sections slightly modified to match α coefficient [Moll] at low field and Room Temperature.

$$DCR = A \int_{x_1}^{x_2} G(x)\, P_b(x) dx$$

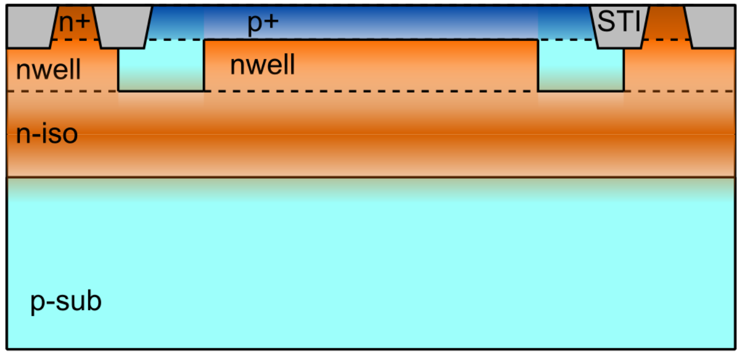
with $G(x)$: generation profile

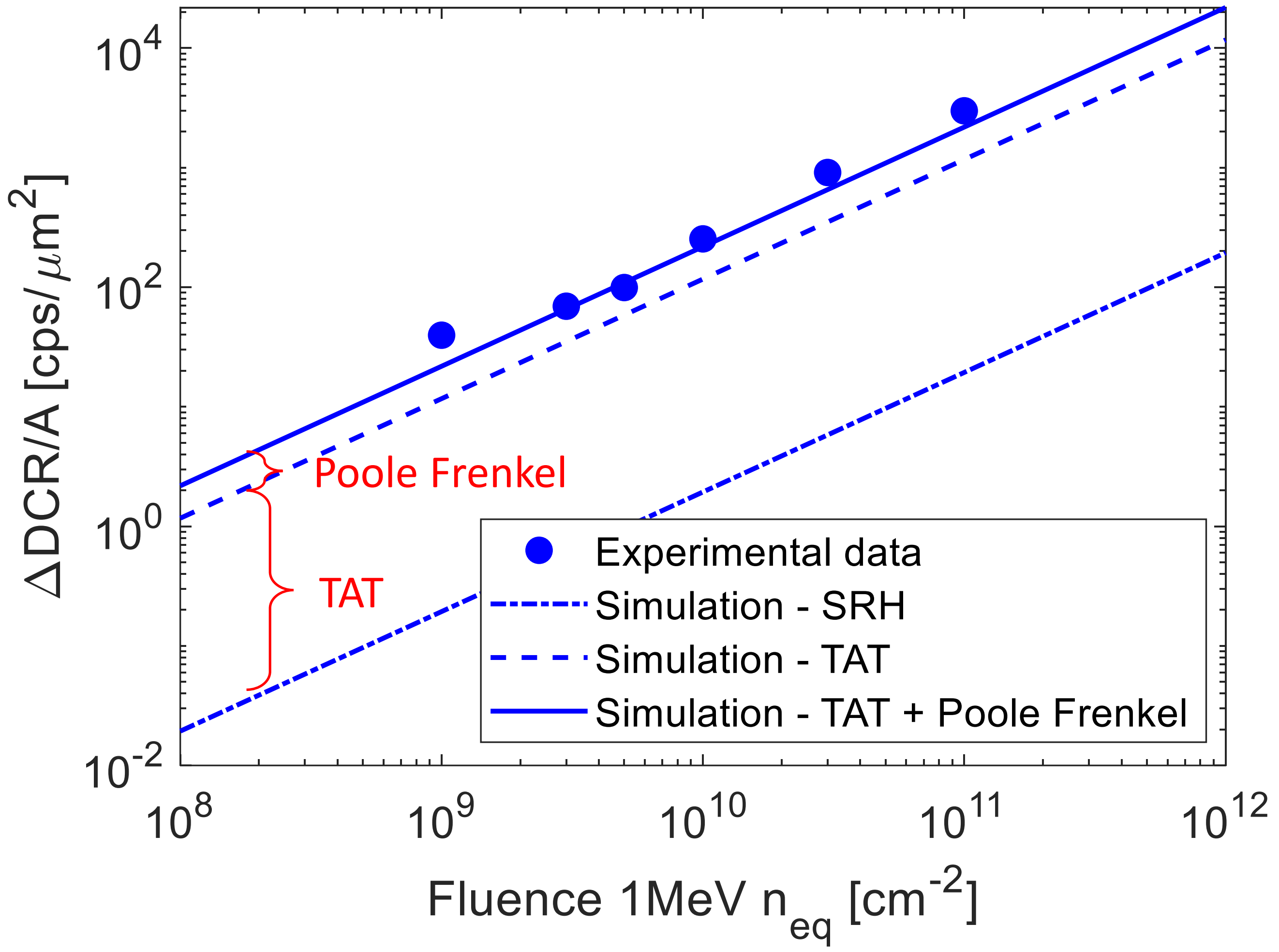
$P_b(x)$: joint e-h breakdown probability

Average DCR simulation: field-enhanced generation

p+/nwell SPADs:

2 orders of magnitude increase introducing field enhanced generation mechanisms





Literature analysis: effects that are not modelled in TCAD

Some effects may not be modeled in sentaurus TCAD: calculations based on custom code or post-processing will be used

Example:
optical Xtalk in cryo devices: secondary light emission vs. T

The number of photons emitted during an avalanche **slightly increases** at cryogenic T

arXiv > physics > arXiv:2402.09634

Search

Physics > Instrumentation and Detectors

[Submitted on 15 Feb 2024 (v1), last revised 25 Sep 2024 (this version, v2)]

Stimulated Secondary Emission of Single Photon Avalanche Diodes

Kurtis Raymond, Fabrice Retière, Harry Lewis, Andrea Capra, Duncan McCarthy, Austin de St Croix, Giacomo Gallina, Joe McLaughlin, Juliette Martin, Nicolas Massacret, Paolo Agnes, Ryan Underwood, Seraphim Koulosousas, Peter Margetak

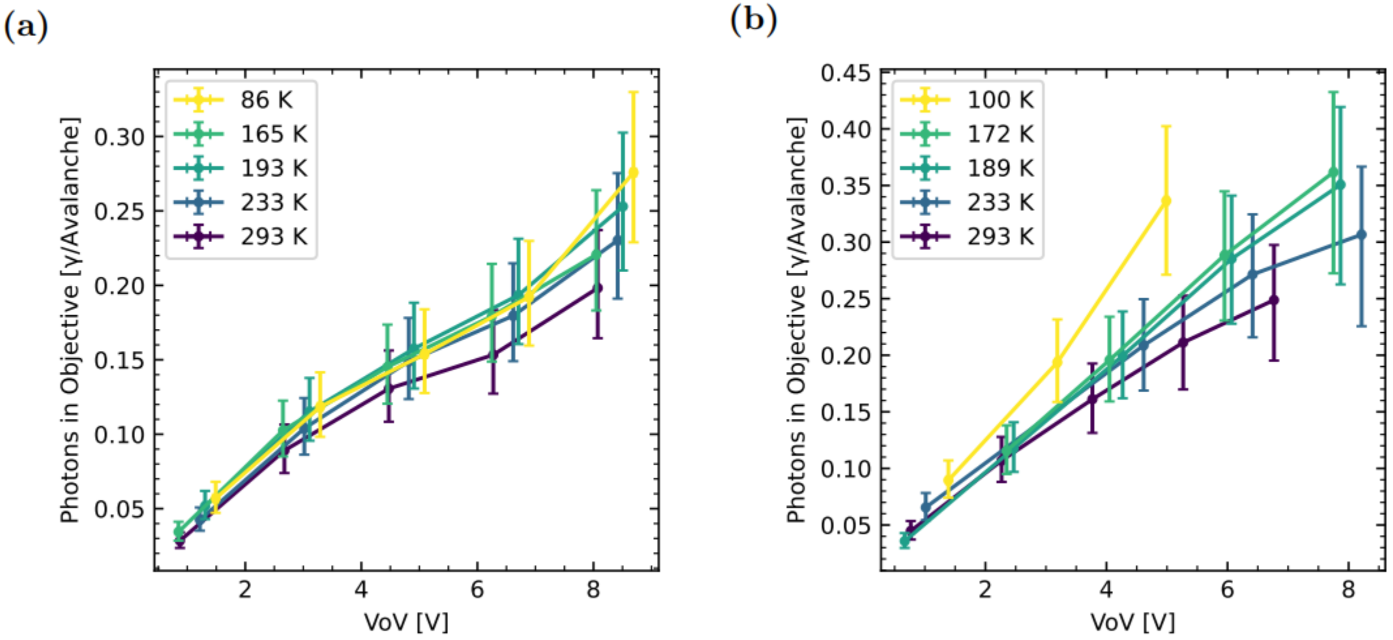
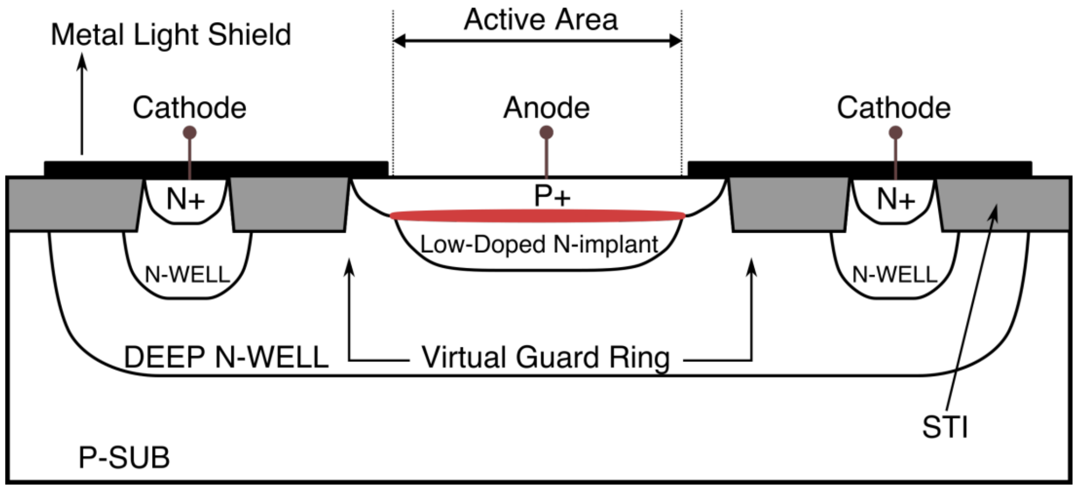


Figure 6: Photon yield integrated between 550 nm and 1000 nm for the HPK (a) and FBK (b) SiPM into a 0.45 NA objective at different temperatures. Systematic errors are included. The spread of points in the FBK device at high over voltages is due to applying the N_{cda} correction from near LXe temperatures to other temperatures.

Phase 2: device optimization

After modeling currently available devices:

- Optimization of **device termination**
- **Customizing** Low-Doped N-**implant** for cryogenic operation and radiation hardness: cost of dedicated additional implantation to be discussed with LFoundry



Support to circuit design: standard SPAD cell

LF 110nm library SPAD:

- Standard flow with additional dedicated implant (developed by FBK – IRIS group)
- Can be included in test chips as an **IP cell** (with possibility of resizing the cell)
- No direct access, but support to chip layout provided by Trento in collaboration with FBK (I will be the interface with FBK, as done in the past with APIX/ASAP projects):
  1. Providing a **placeholder cell** for layout design and verification (DRV + LVS)
  2. Replacing placeholder with real SPAD cell in final design and repeating verification with real SPAD
  3. Iterating on 1 and 2 if needed

Information on large cells can be obtained from ASAPLF110 chip, but I will check if more information on small cells are available from FBK