SiPM developments at FBK Italy

Alessandro Montanari – INFN Bologna

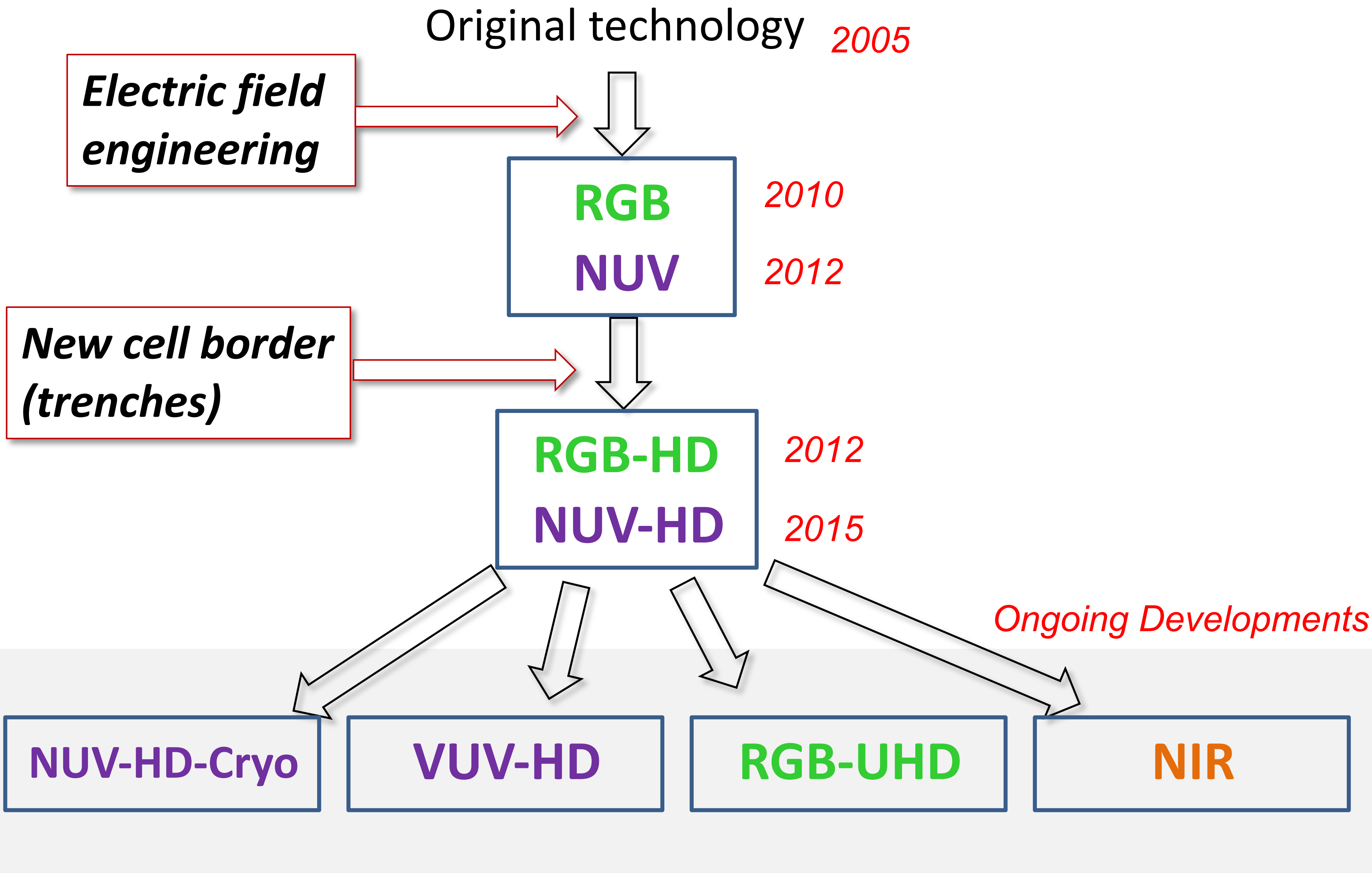
Outline

- Review of the state of art for SiPM produced at FBK
- Covers only types of device that can be eventually of interest for ND
- New developments and plans are not discussed because not yet public
- More details can be found in:

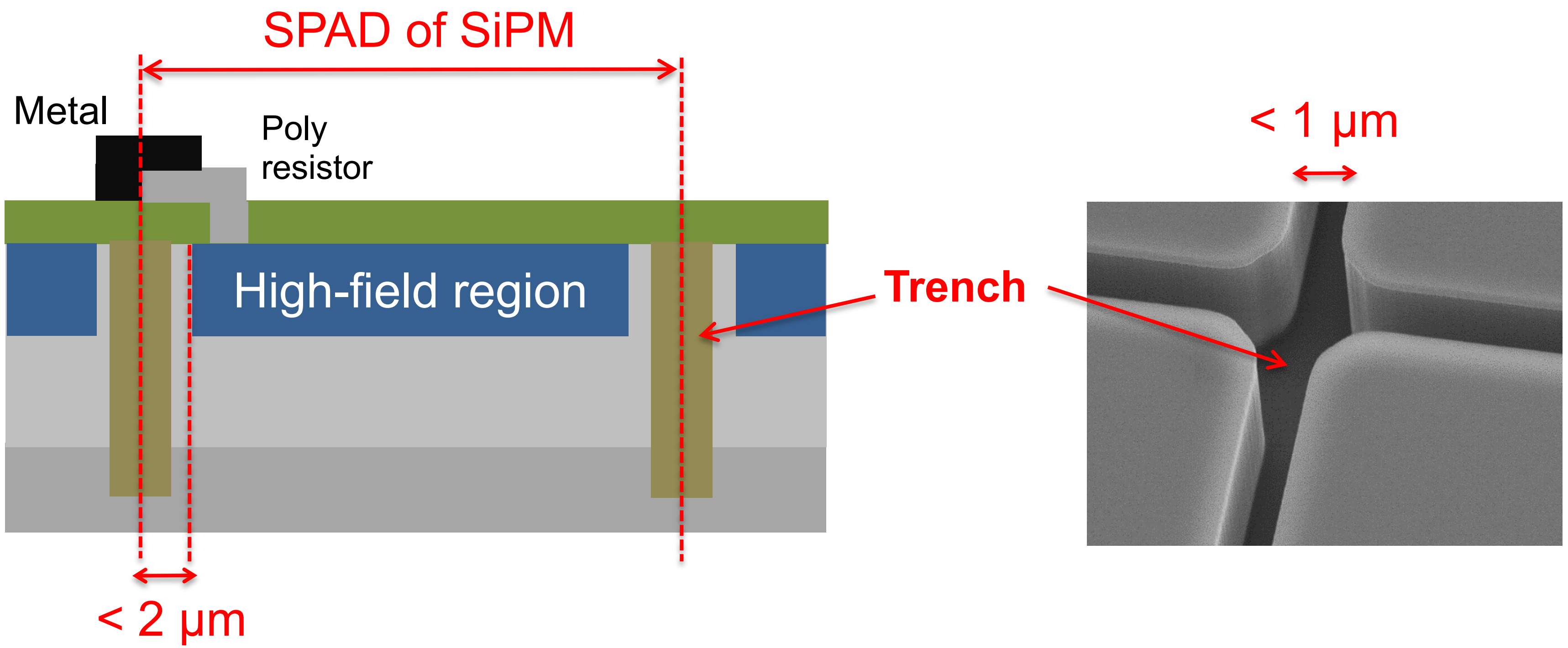
«NUV-sensitive Silicon Photomultiplier Technologies Developed at Fondazione Bruno Kessler», A.Gola et al., Sensors 2019,19, 308

Information and plots kindly provided by FBK

FBK SiPM technology roadmap

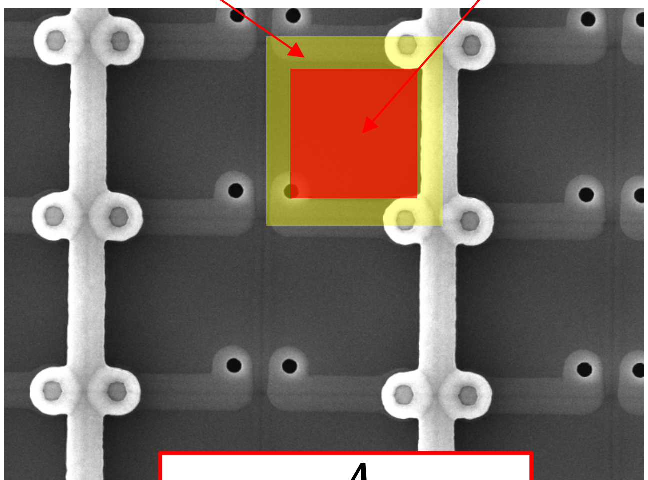


NUV-HD: the technology

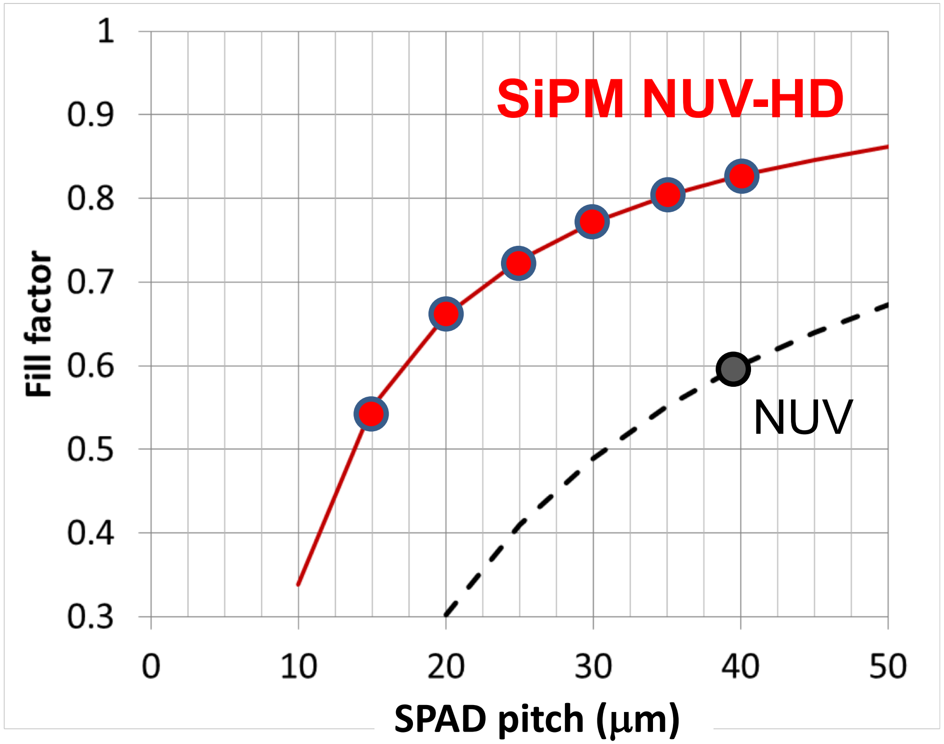


- p-on-n junction → higher Pt for UV light
- Narrow dead border region → Higher Fill Factor
- Trenches between cells → Lower Cross-Talk
- Make it simple: 9 lithographic steps

NUV-HD: Fill Factor



$$FF = \frac{A_{active}}{A_{total}}$$

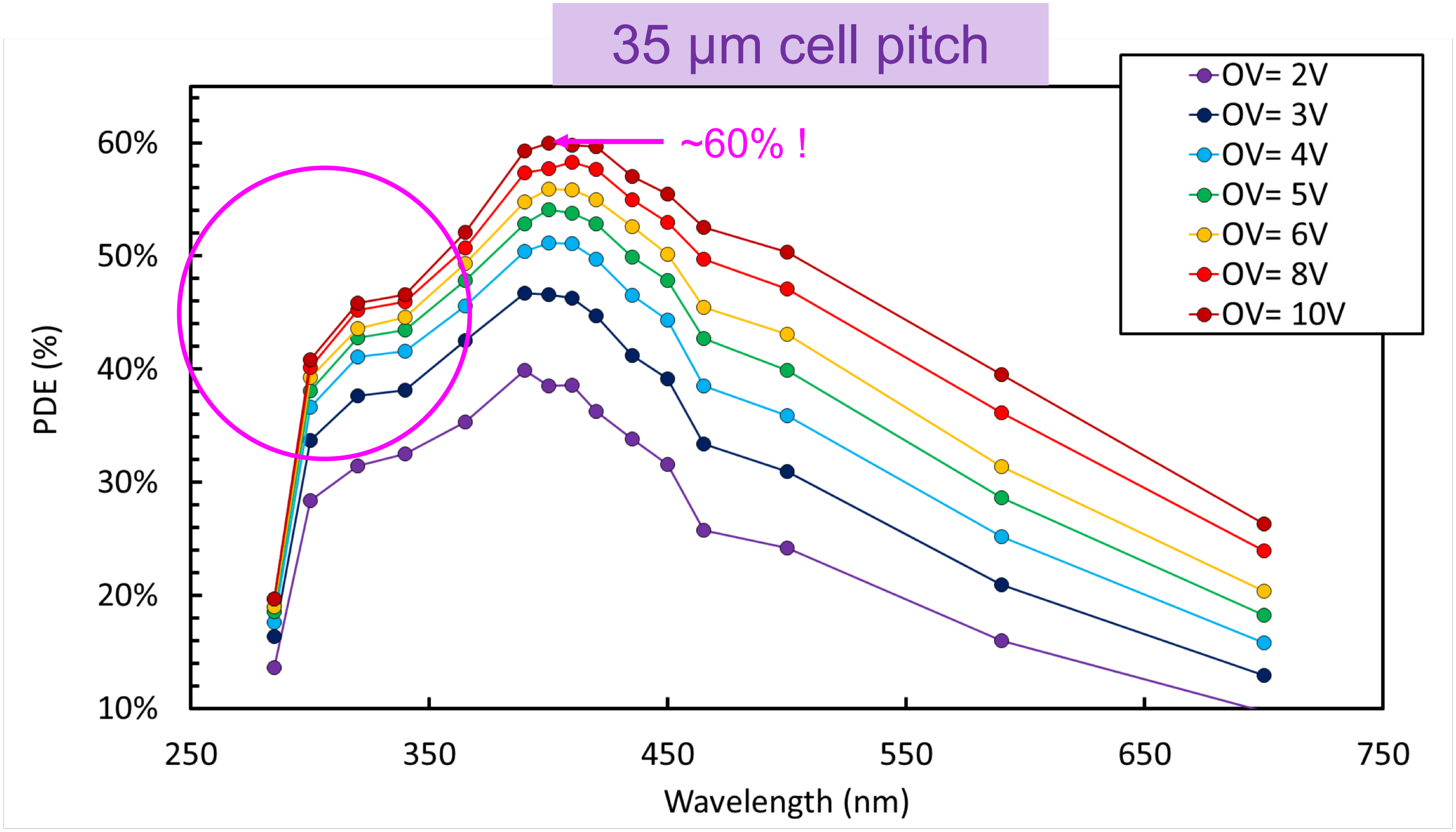


SPAD Pitch	15 µm	20 µm	25 µm	30 µm	35 µm	40 µm
Fill Factor (%)	55	66	73	77	81	83
SPAD/mm^2	4444	2500	1600	1111	816	625

High Dynamic Range, Fast recovery time (15–20 µm)

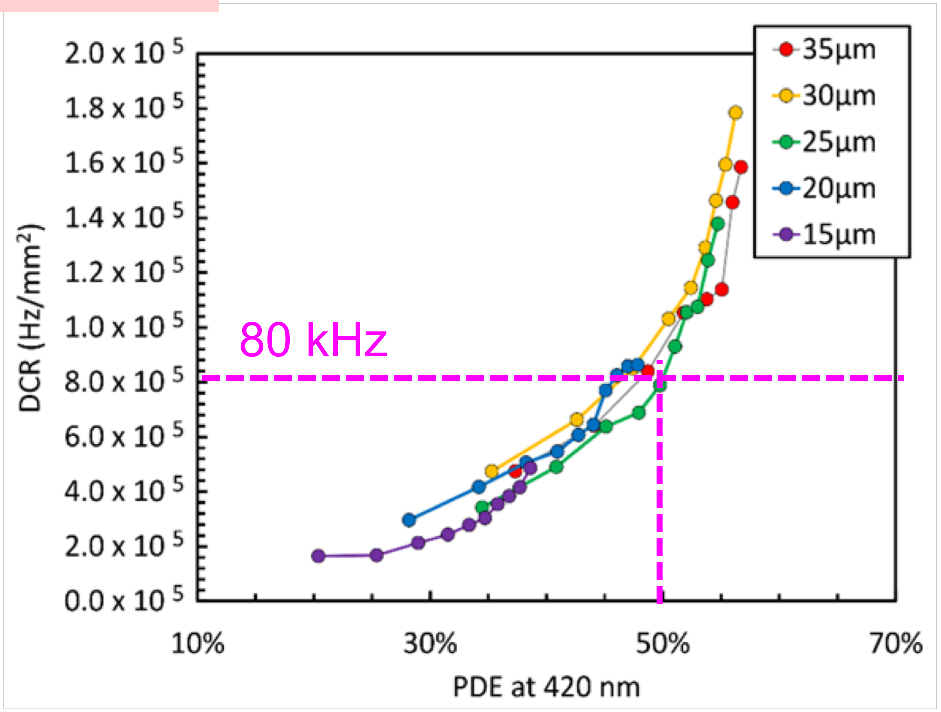
High PDE (35–40 µm)

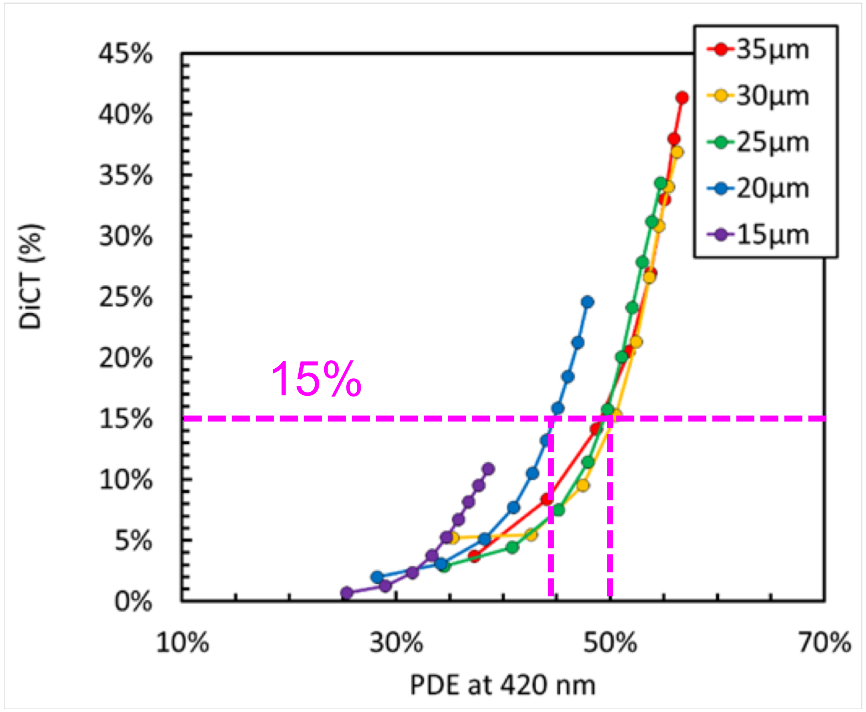
Photon detection efficiency



Dark Count Rate and Direct Crosstalk

T = 20 C

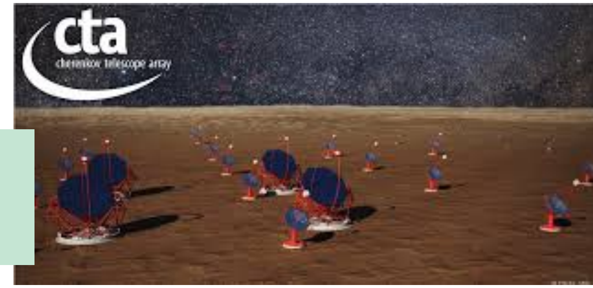




Dark Count Rate

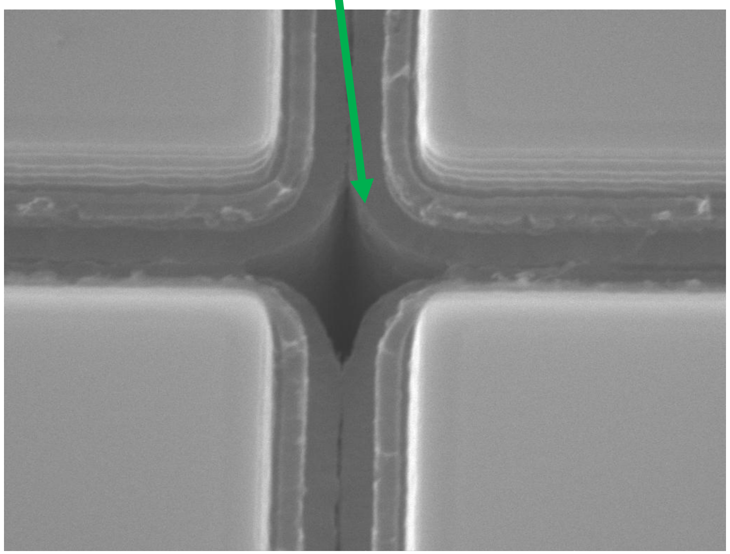
Optical Crosstalk
(Correlated Noise)

NUV-HD-LowCT



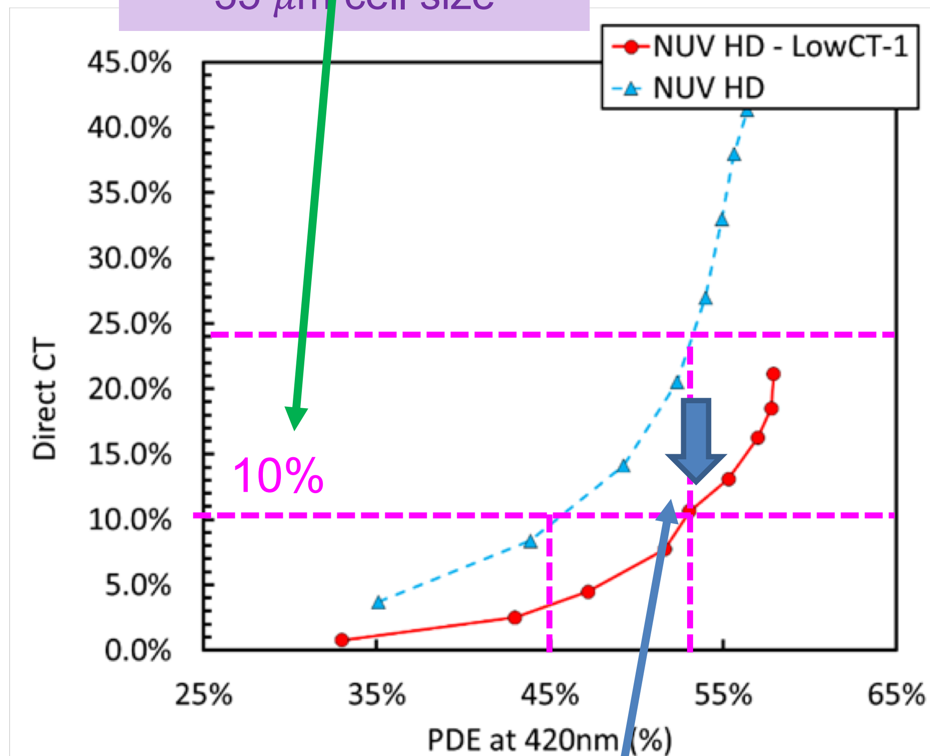
Applications such as CTA

Light absorbing material was inserted inside trenches, between adjacent microcells



SEM image of trenches, separating adjacent microcells.

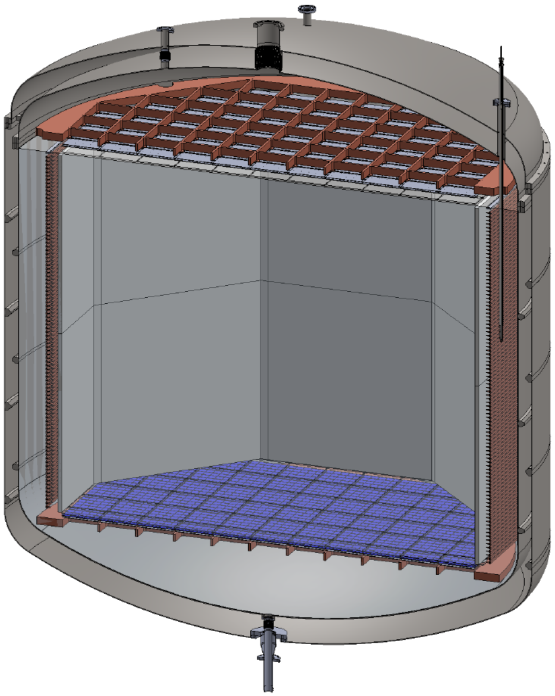
35 μm cell size



2.5x reduction of Optical Crosstalk at same PDE

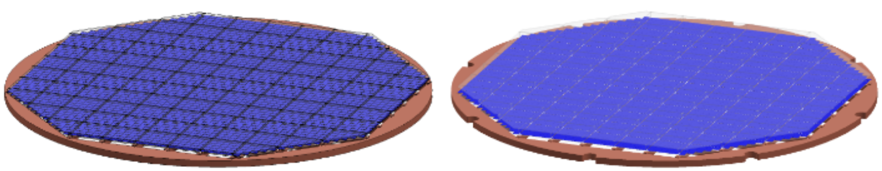
Cryogenic Applications of SiPMs

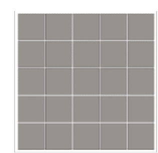
DarkSide-20k
SiPM-based TPC



~ 23t of UAr

TPB WLS:
emission at
400 – 450 nm





SiPM tiles

2 light readout planes: 15 m^2
(+ veto)

NUV-HD-Cryo

- Low electric (LF)field inside junction

  -> reduced DCR

- Low Afterpulse split

  -> reduced afterpulsing probability

- Modified quenching resistor

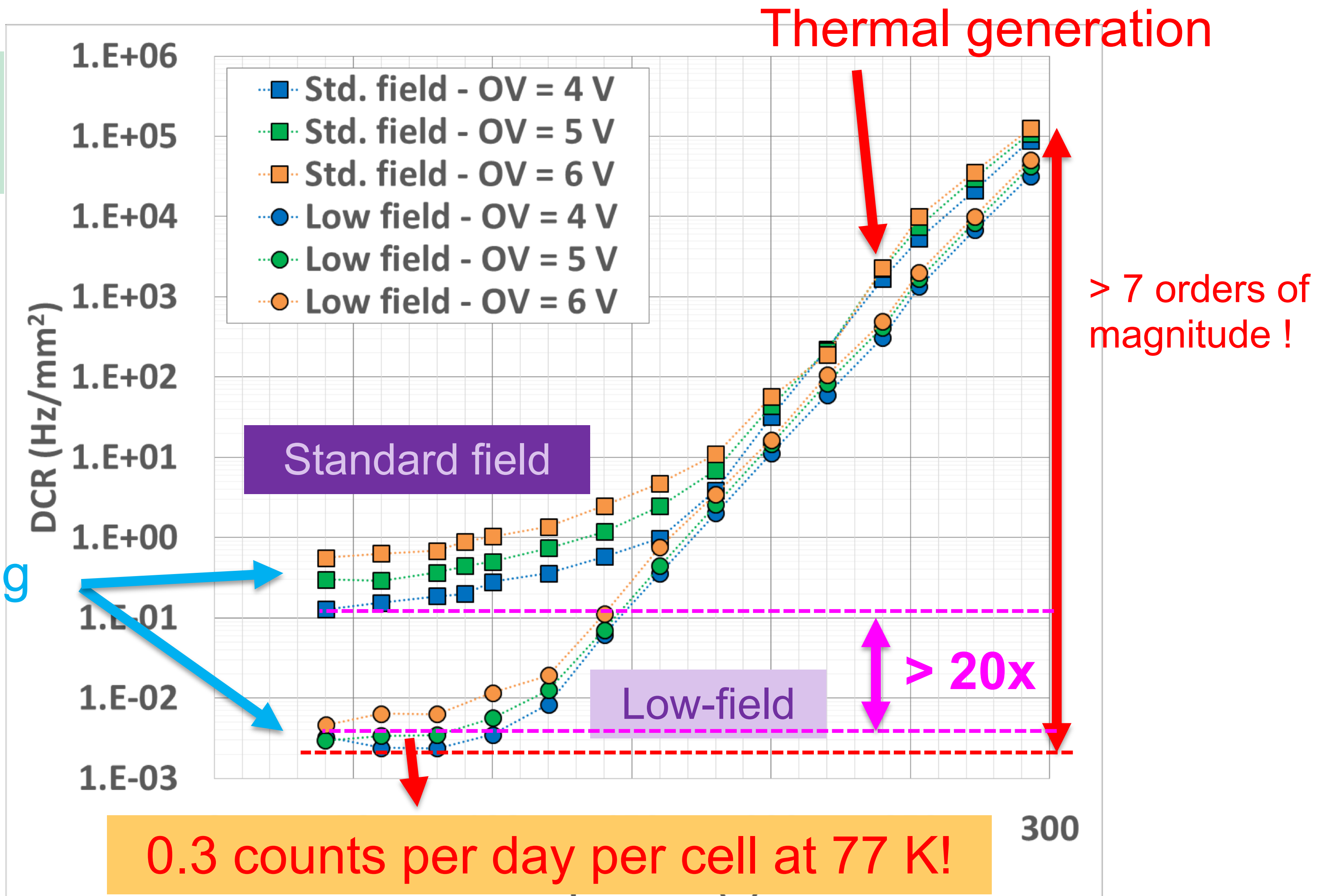
  -> **reduced temperature coefficient** and further reduced value of 6.5 Mohm at 77k

Table 1. Comparison of the main features of NUV-HD and NUV-HD–Cryo technologies, 25 µm cell size.

	NUV-HD		NUV-HD–Cryo	
	293 K	77 K	293 K	77 K
Breakdown Voltage (V_{BD})	26.5 V	21.5 V	32.8 V	27.1 V
V_{BD} temperature coefficient	27 mV/°C	20 mV/°C	35 mV/°C	21 mV/°C
DCR (5 V)	100 kHz/mm^2	0.2 Hz/mm^2	100 kHz/mm^2	2 mHz/mm^2
Quenching resistor	1.9 MΩ	120 MΩ	1.6 MΩ	6.5 MΩ
CT probability (5 V)	20%	16%	9%	13%
AP probability (5 V)	<1%	25%	<1%	12%
OV_{max}	12 V	8 V	25 V	20 V
Recharge time constant	80 ns	3.5 µs	65 ns	270 ns
Peak PDE (5 V, 410 nm)	48%	-	37%	-

NUV-HD-Cryo – DCR Measurements

25 um cell



A 10x10 cm² SiPM array would have a total DCR < 100 cps!

Reduced Afterpulse

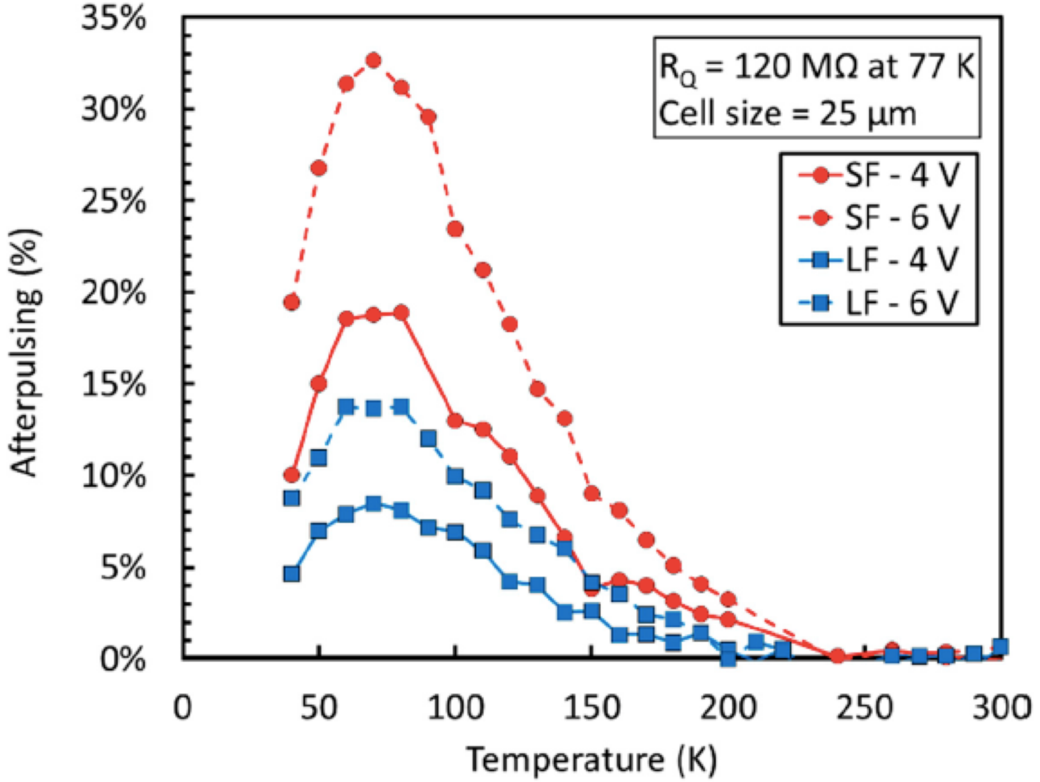
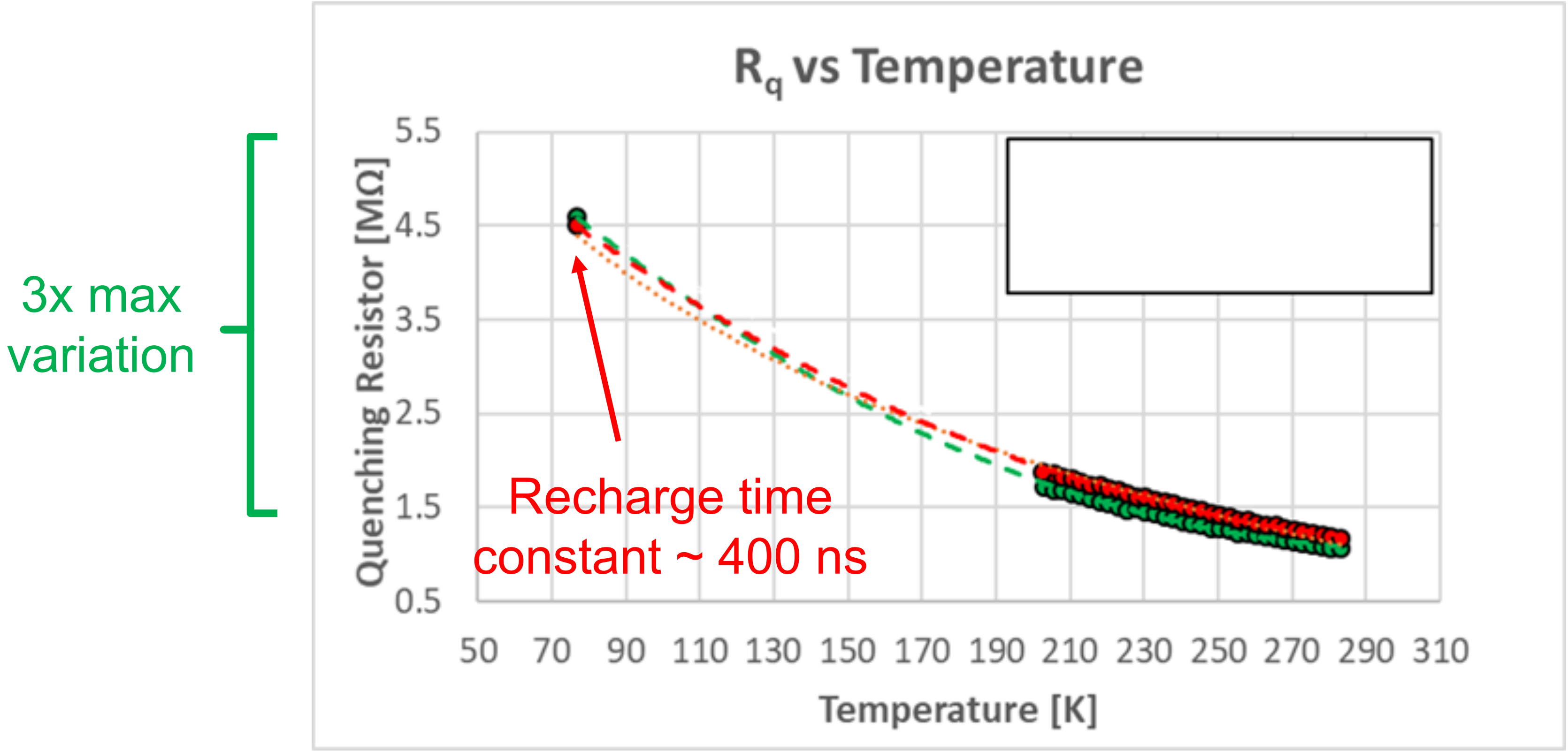


Figure 18. Afterpulsing probability (AP) as a function of the temperature for the NUV-HD and NUV-HD-LF technologies. Measures taken from Reference [36].

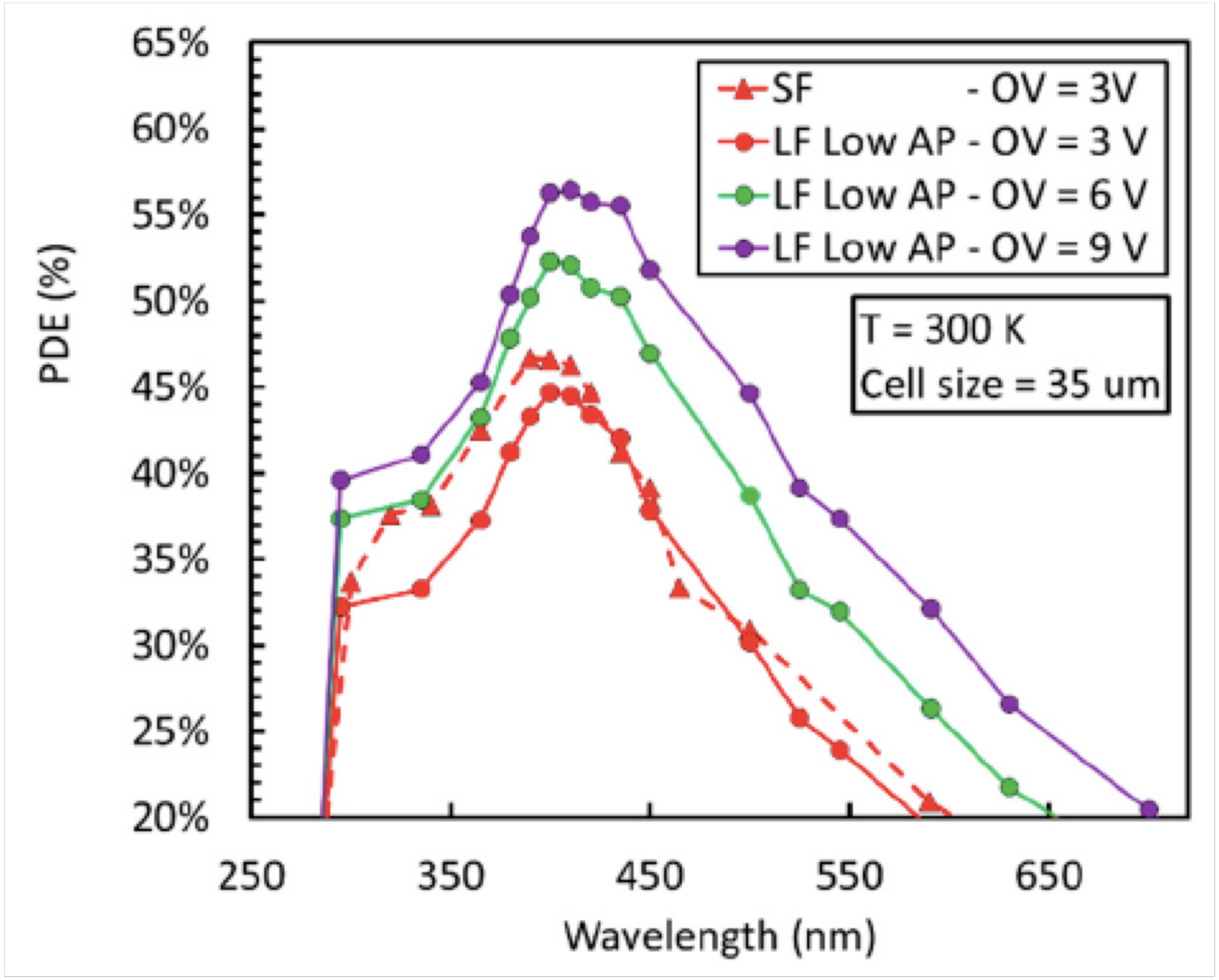
NUV-HD-Cryo – New polysilicon resistor

Thanks to the lower Afterpulsing probability, it is possible to reduce the microcell recharge time constant in LN

→ a new polysilicon resistor was developed with reduced temperature variations.



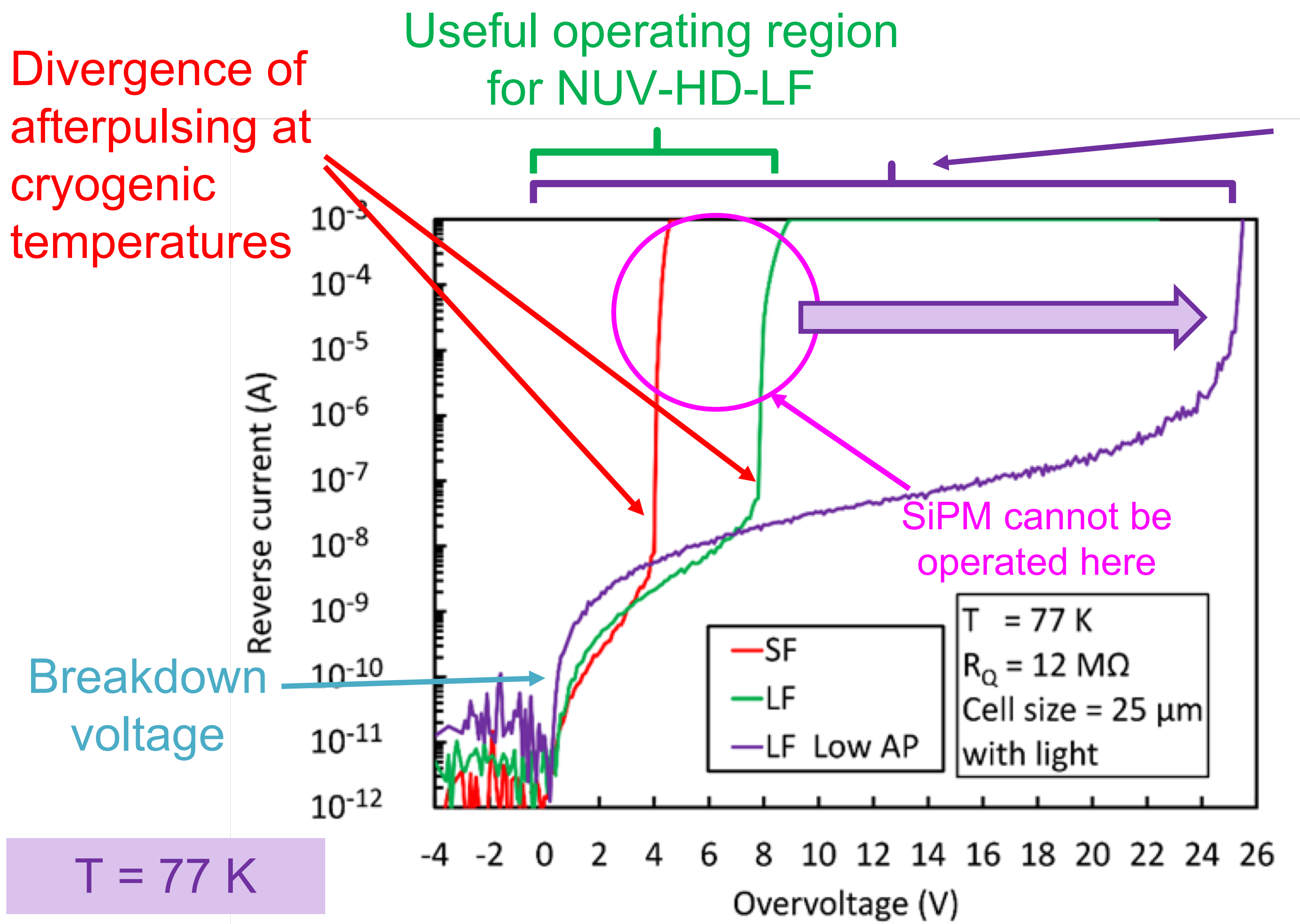
PDE



PDE (%)
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
250
350
450
550
650
Wavelength (nm)
SF - OV = 3V
LF Low AP - OV = 3 V
LF Low AP - OV = 6 V
LF Low AP - OV = 9 V
T = 300 K
Cell size = 35 um

NUV-HD-Cryo – reduction of afterpulsing

New NUV-HD-Cryo SiPM technology allows suppression of afterpulsing at cryogenic temperatures, allowing a much increased operating overvoltage

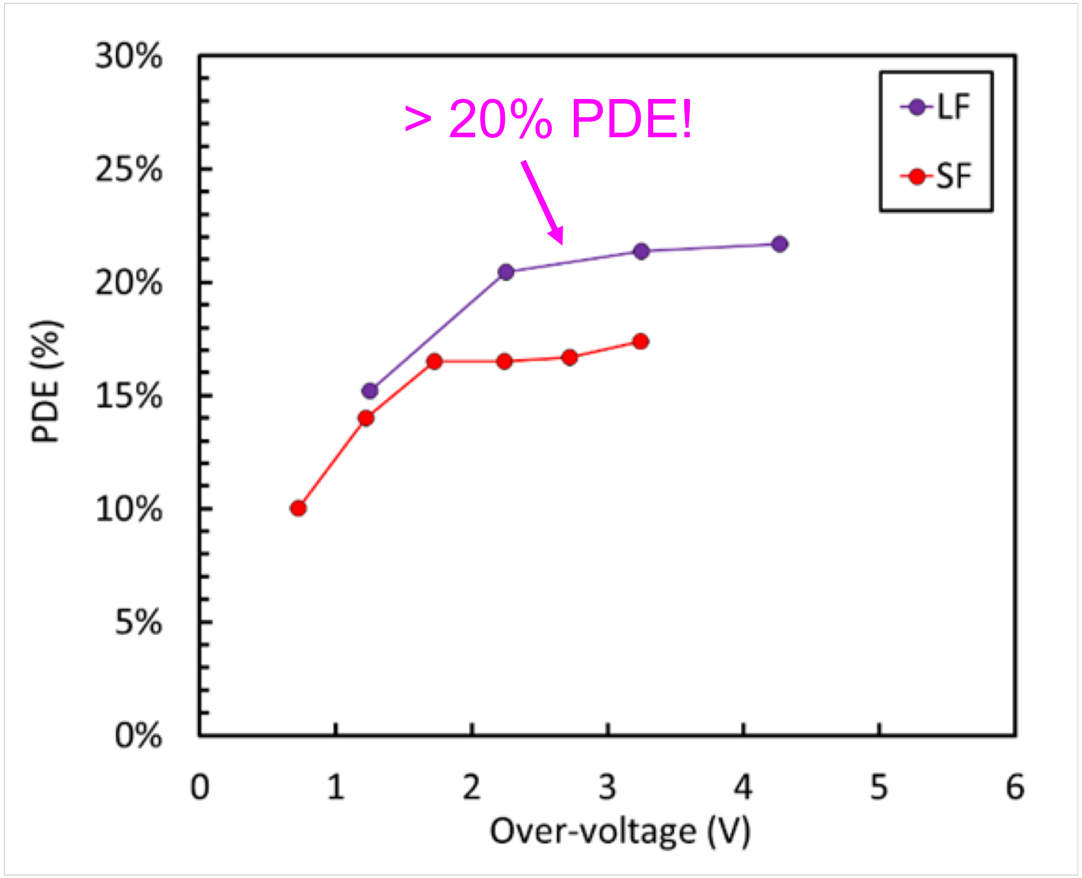


T = 77 K

Reverse IV measured on different NUV-HD SiPM technologies at 77 K

VUV-HD

NUV-HD is being modify to enhance efficiency in the VUV.



nEXO experiment

λ = 175 nm

T = -104°C (LXe)