Latest analog-SiPM developments at FBK.

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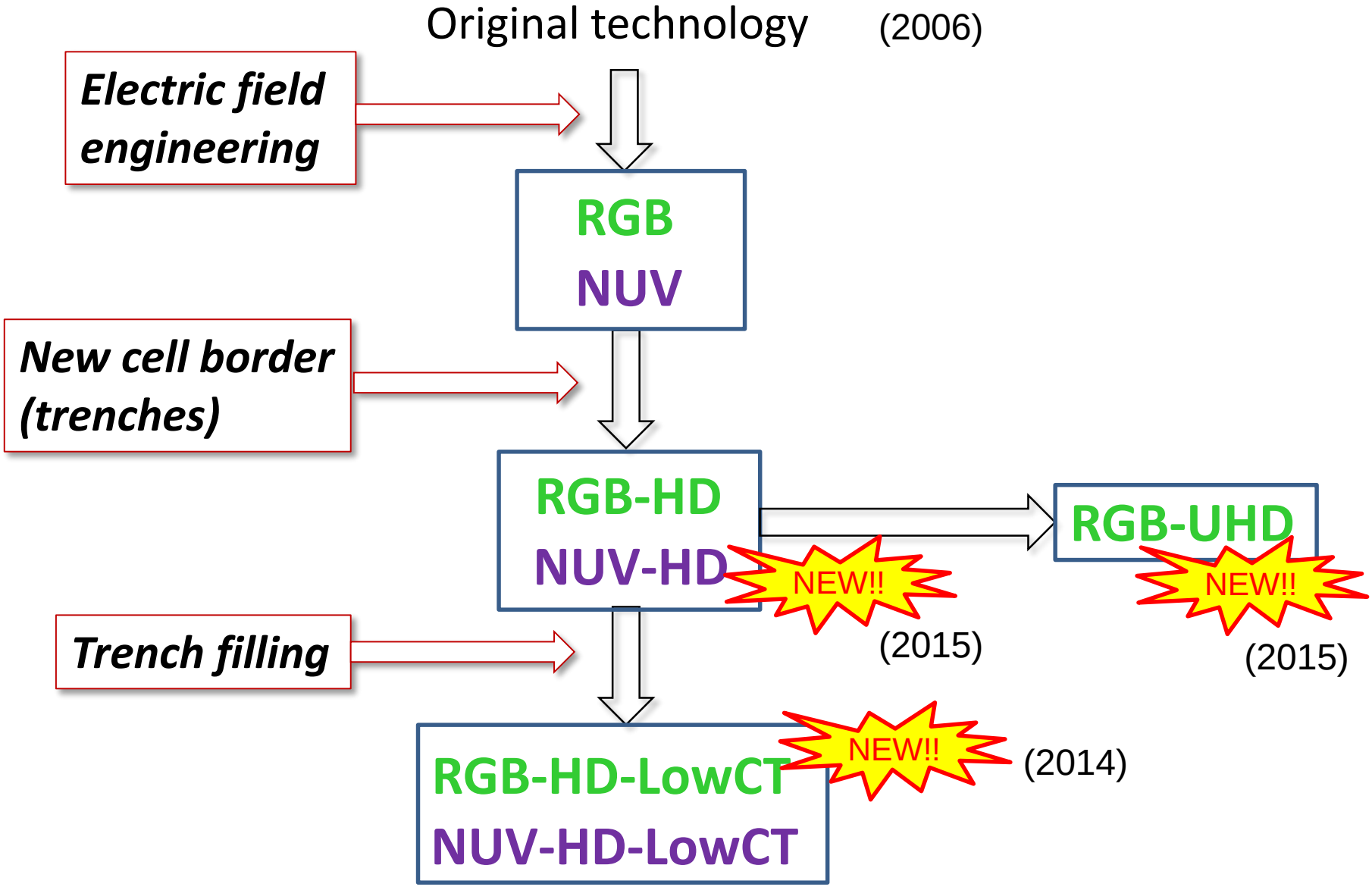
A. Gola, G. Paternoster,
V. Regazzoni, G. Zappala', N. Zorzi

Outline

- Technology Roadmap
- RGB-HD
- NUV-HD
- Large-area arrays
- Ongoing activity

SiPM technology roadmap



Base technologies

cell pitch: 40μm (625 /mm²)

Fill factor: 60%

RGB SiPM
Peak PDE: 33% @ 550nm
DCR ~ 300 kHz
Direct CT: ~25%
After-pulsing: ~15%

NUV SiPM
Peak PDE: 35%@ 400nm
DCR ~ 100kHz
Direct CT: ~30%
After-pulsing: <5%

Breakdown uniformity: max variation 0.2V at wafer level.
Breakdown Temp. coefficient: 25mV/C

Performance of NUV for PET

IOP Publishing | Institute of Physics and Engineering in Medicine
Physics in Medicine & Biology

Phys. Med. Biol. 60 (2015) 4635–4649
doi:10.1088/0031-9155/60/12/4635

Sub-100 ps coincidence time resolution for positron emission tomography with LSO:Ce codoped with Ca

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[1] CERN, Geneva 23, CH-1211, Switzerland
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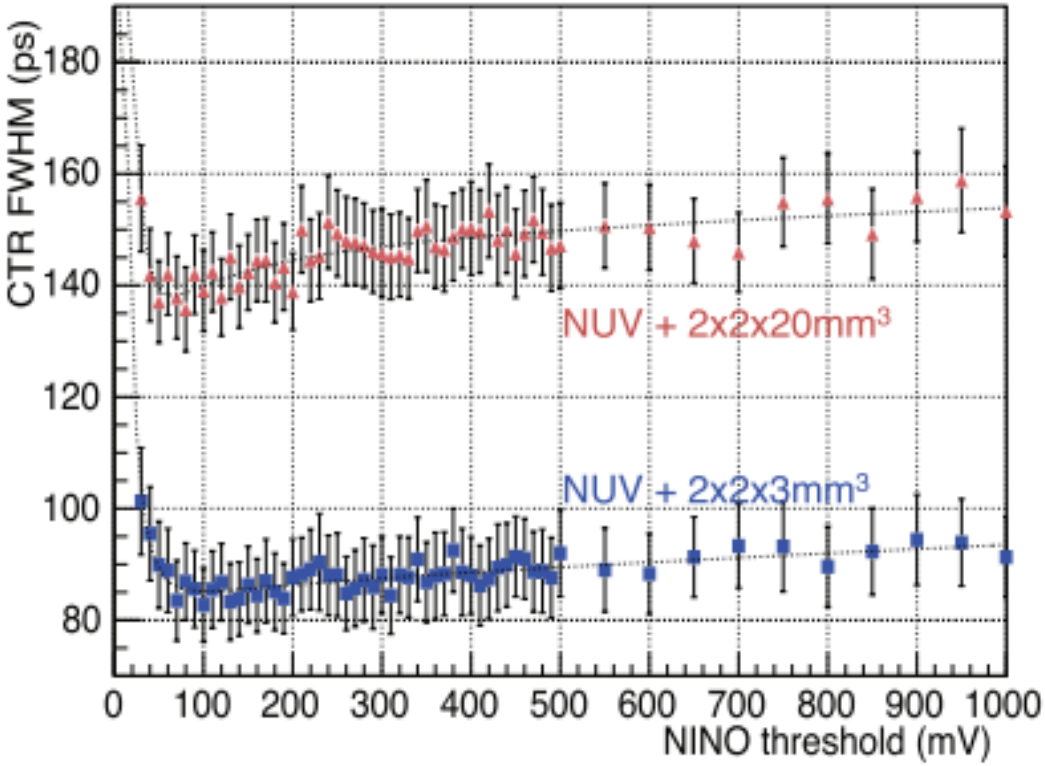

3x3mm^2 NUV SiPM

read-out: NINO ASIC

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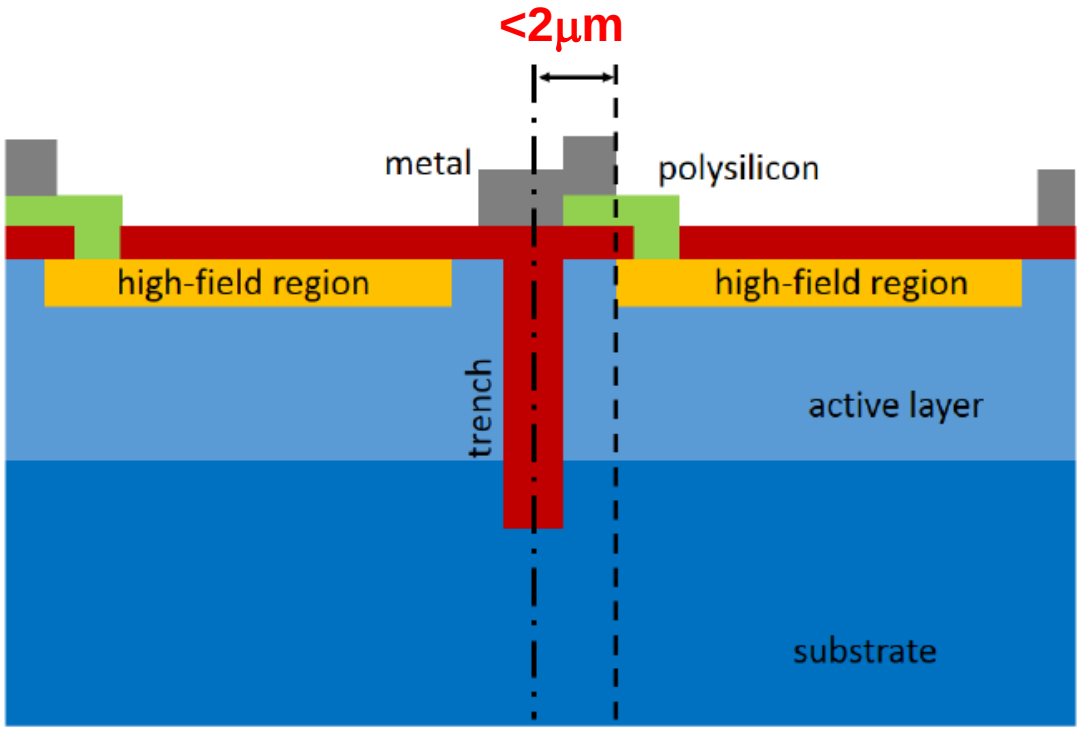
…let’s move to the more recent

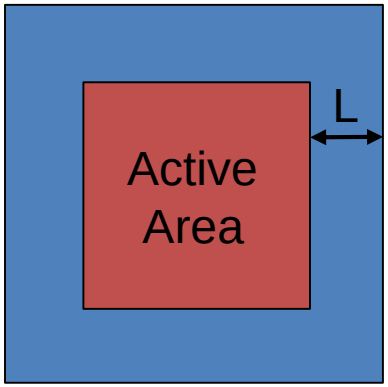
HD technology

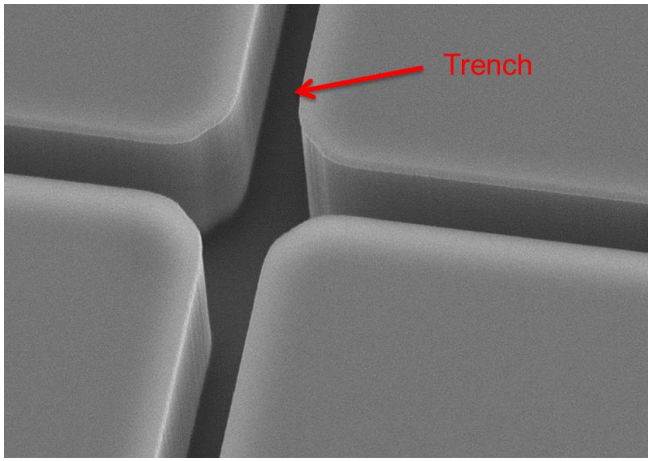
HD technology

Narrow border region around each SPAD

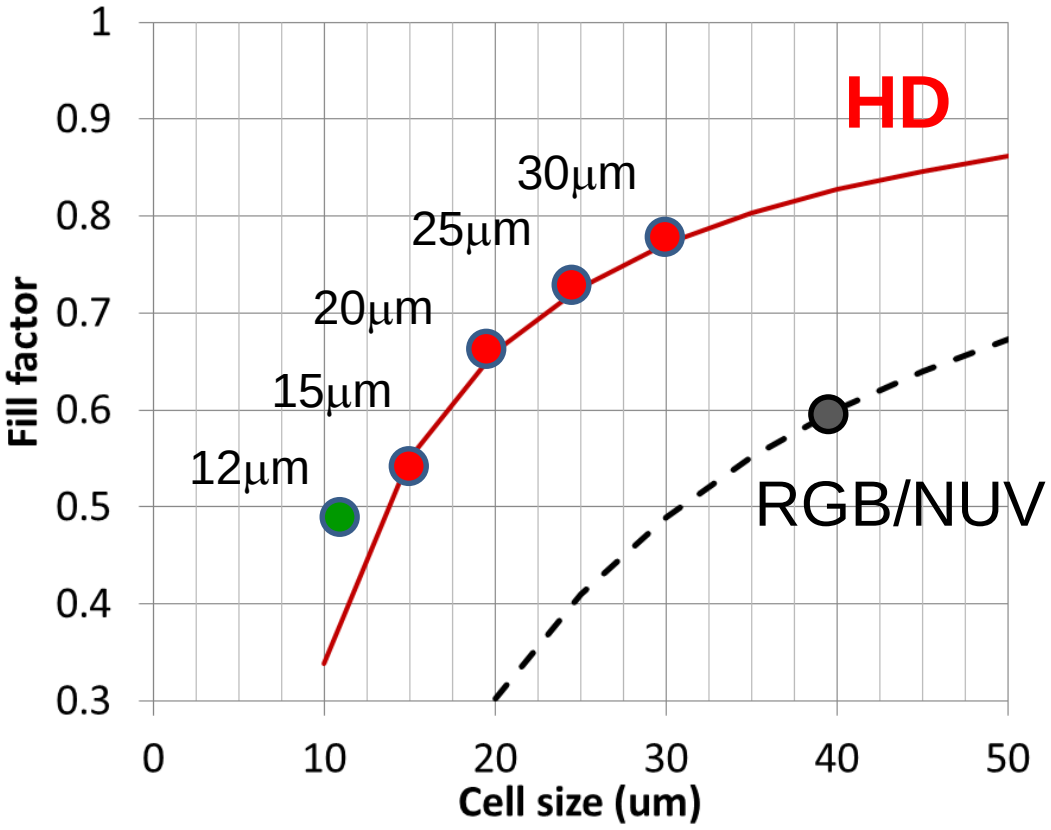


SiPM Cell, top view





HD technology: small cells

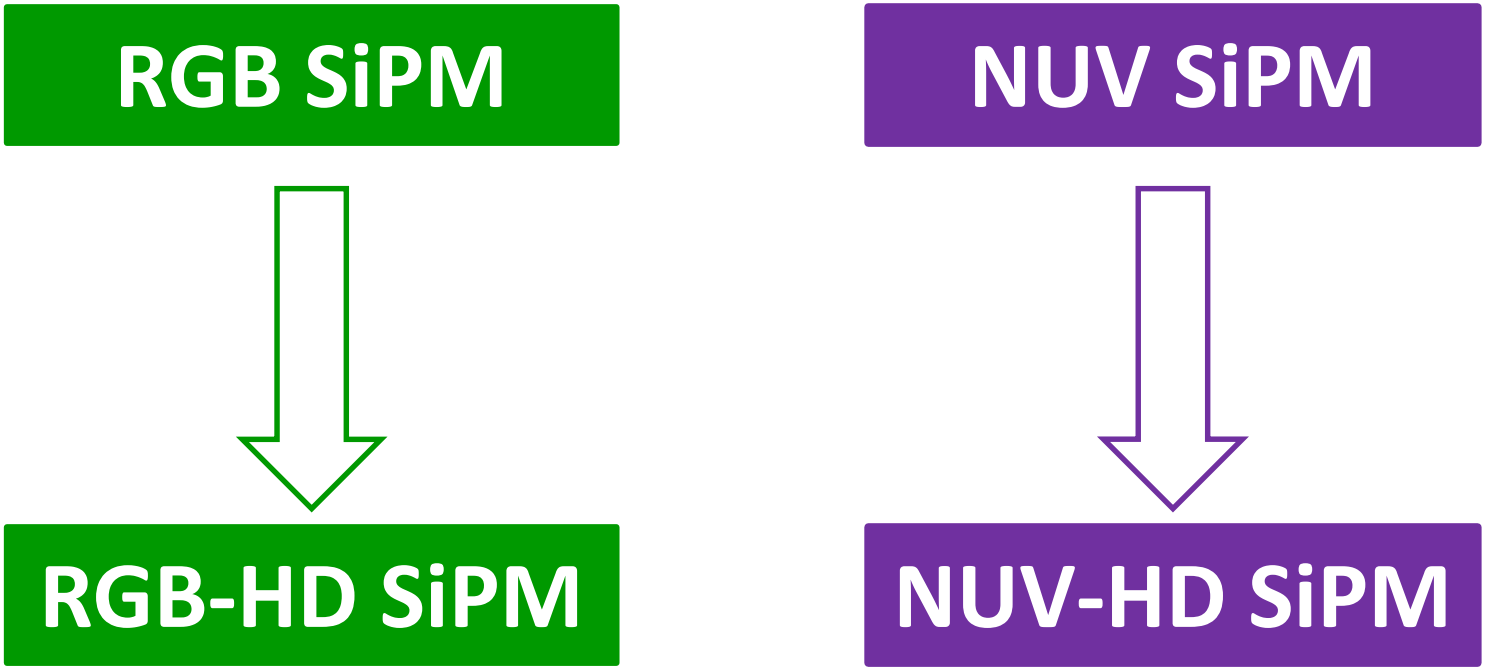


cell pitch (µm)	cells/mm²
12	7000
15	4500
20	2500
25	1600
30	1100

Small SPADs=small gain:

- lower after-pulse
- lower photon emission
- faster recharge
- higher dynamic range

Application of HD technology



several lots produced, stable behaviour

advanced development

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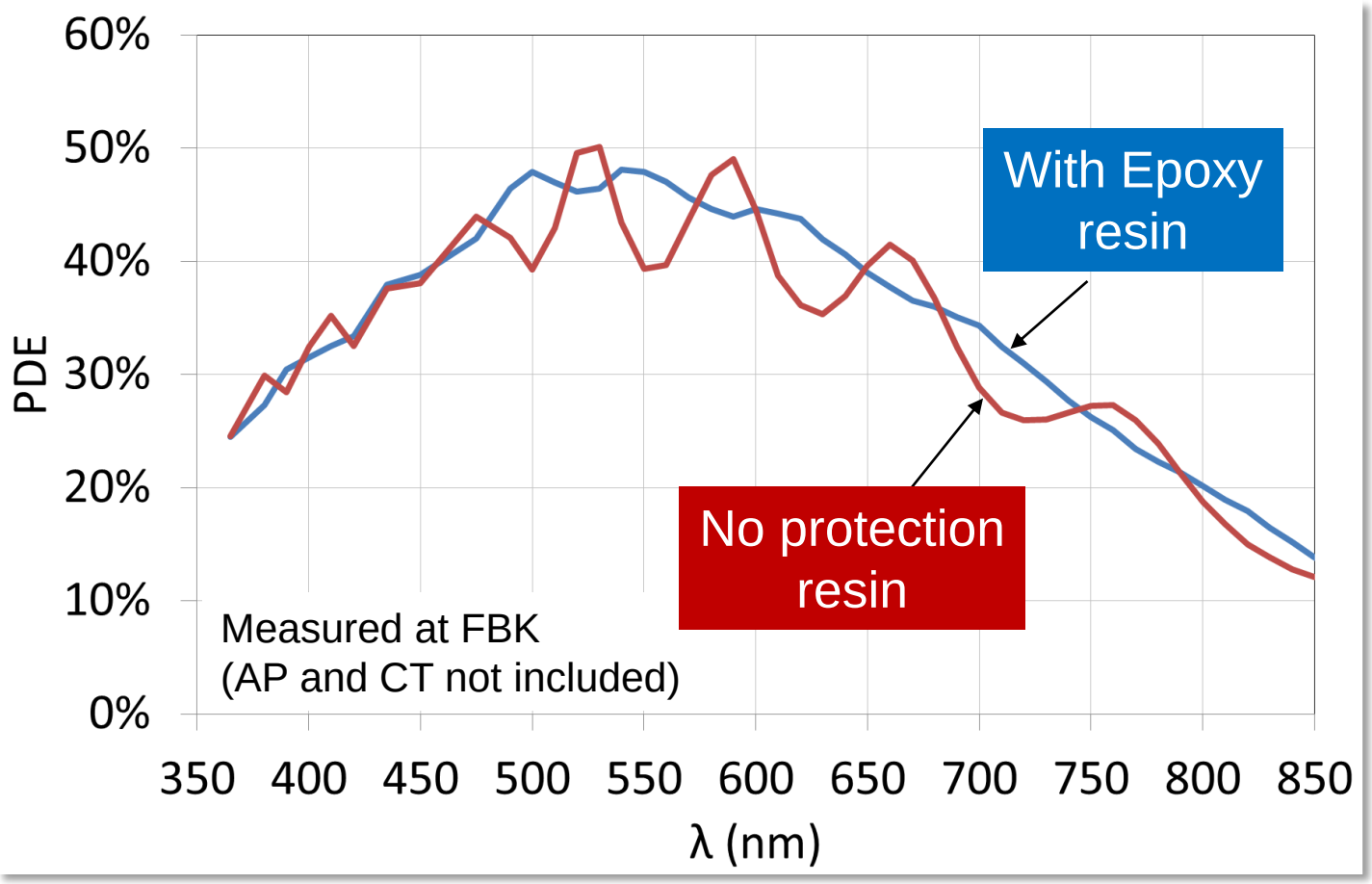
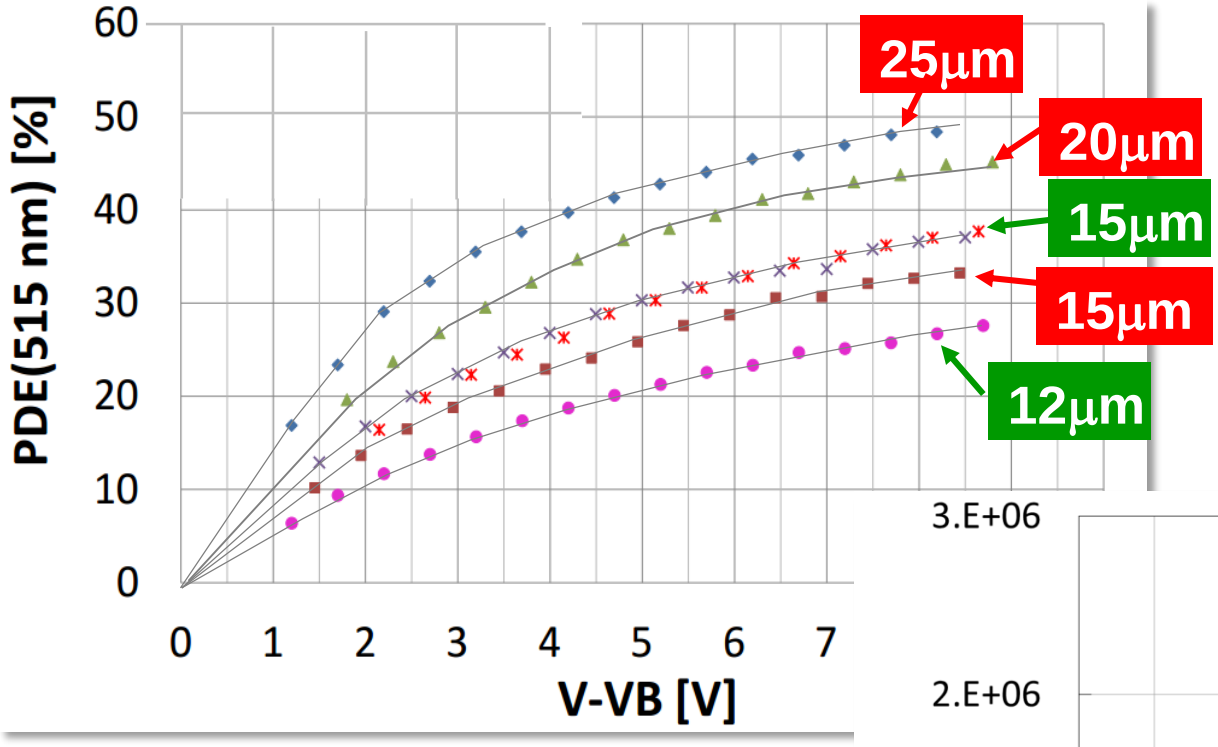
RGB-HD SiPM

RGB-HD: PDE vs λ

- RGB-HD 25μm
- Over-voltage = 9 V



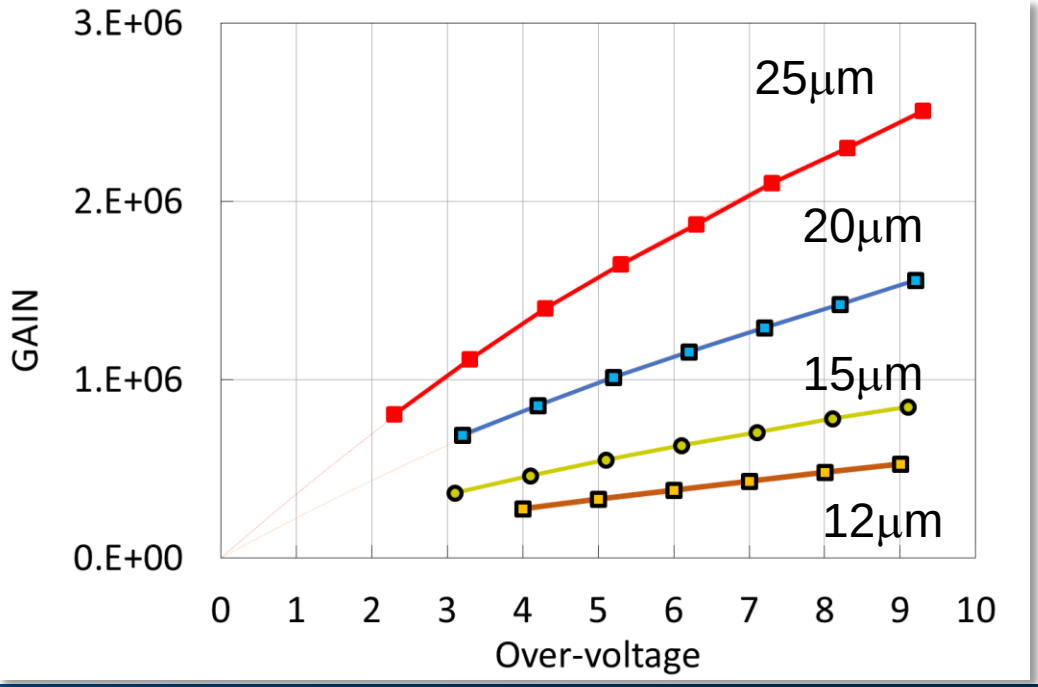
RGB-HD: PDE, GAIN



L1 = 1.7µm

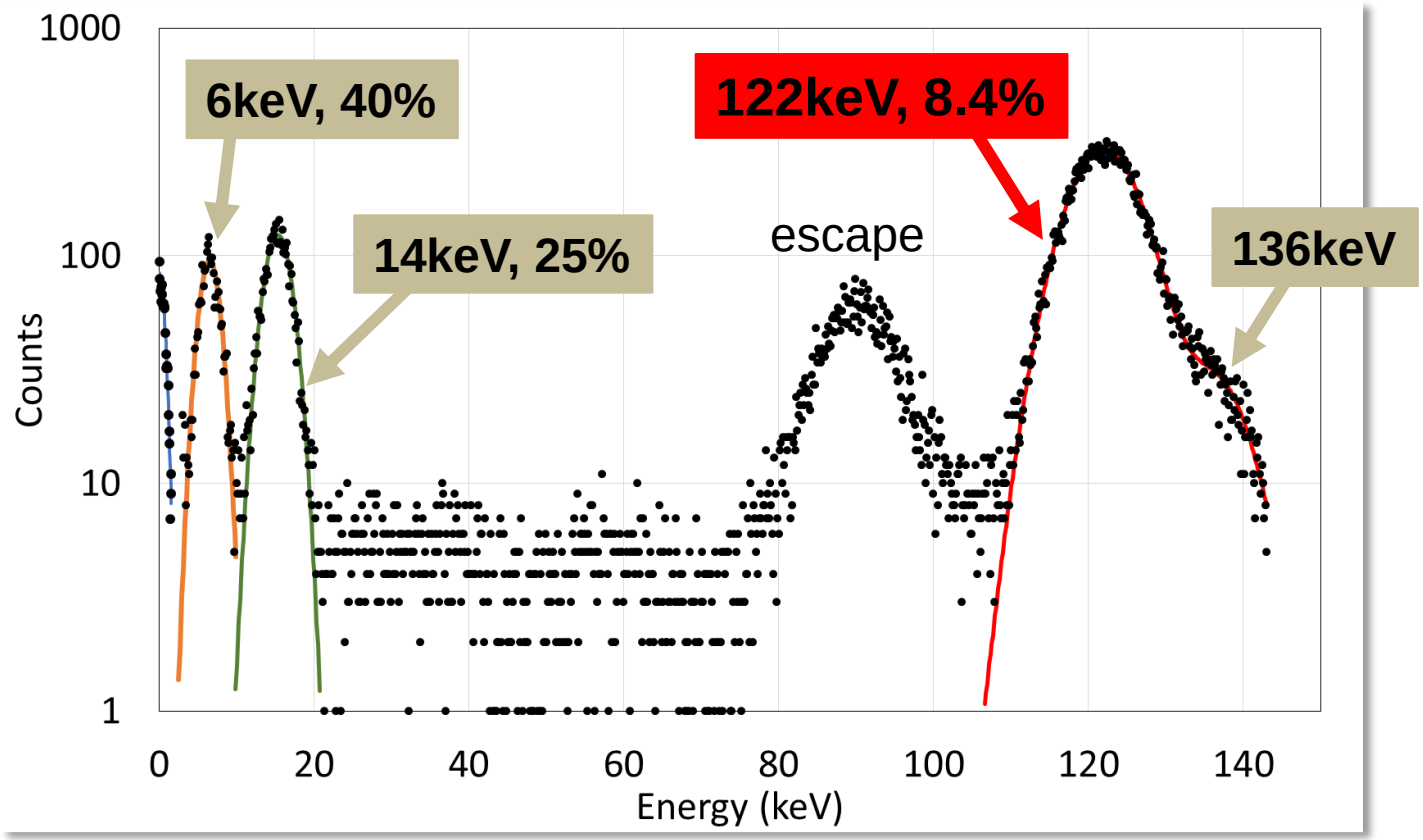
L2 = 1.4µm

Measurements by Y. Musienko (CERN)



RGB-HD with CsI(Tl) for SPECT

- **4x4mm² 25x25µm² RGB-HD** SiPM
- 3x3x10mm³ **CsI (Tl)** (Hilger)



- T = 20 C
- T_{int} = 12µs
- V_{OV} = 4V

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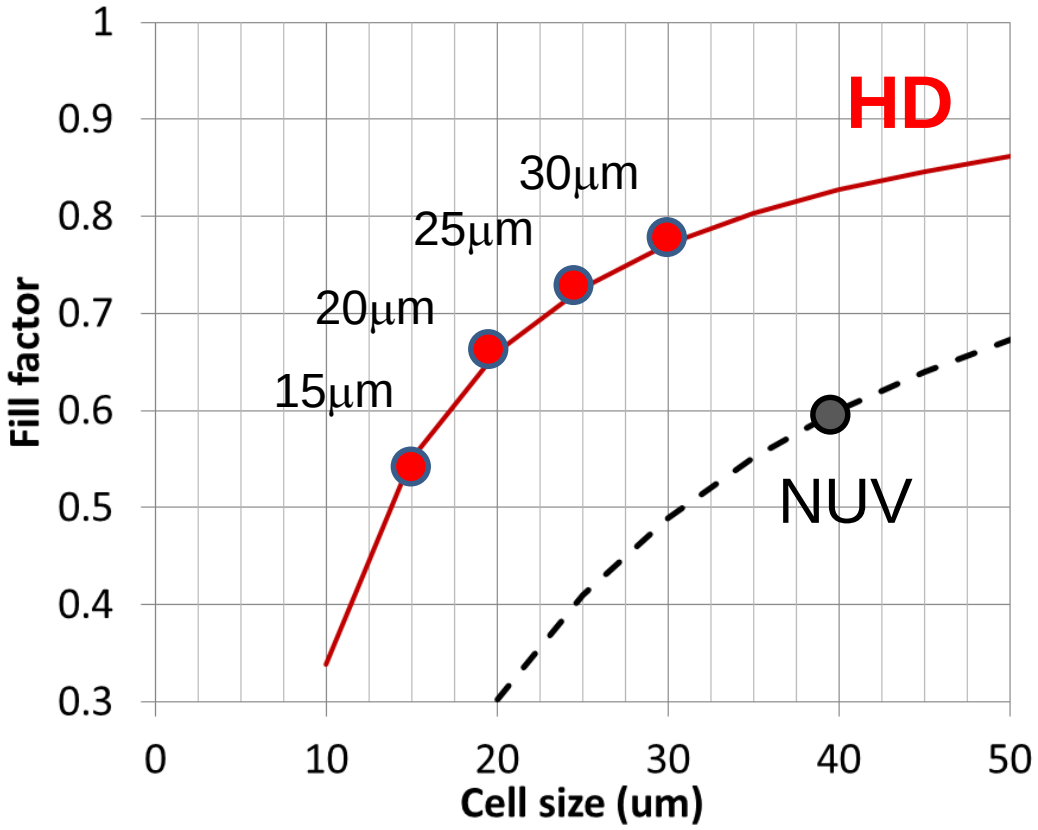
NUV-HD SiPM

NUV-HD

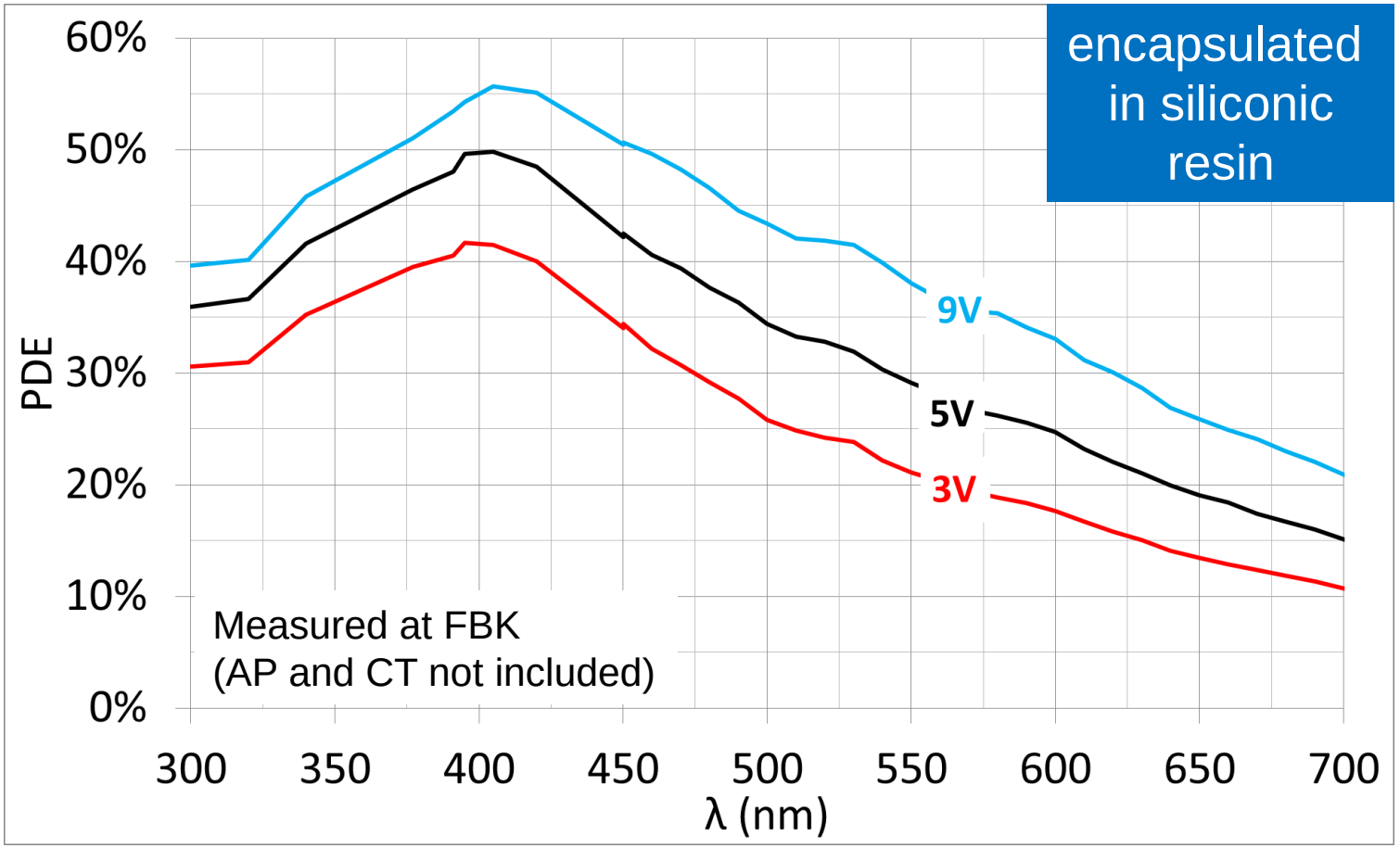


cell pitch (μm)	cells/mm²
15	4500
20	2500
25	1600
30	1100

1x1, 4x4, 6x6mm² SiPM prototypes so far

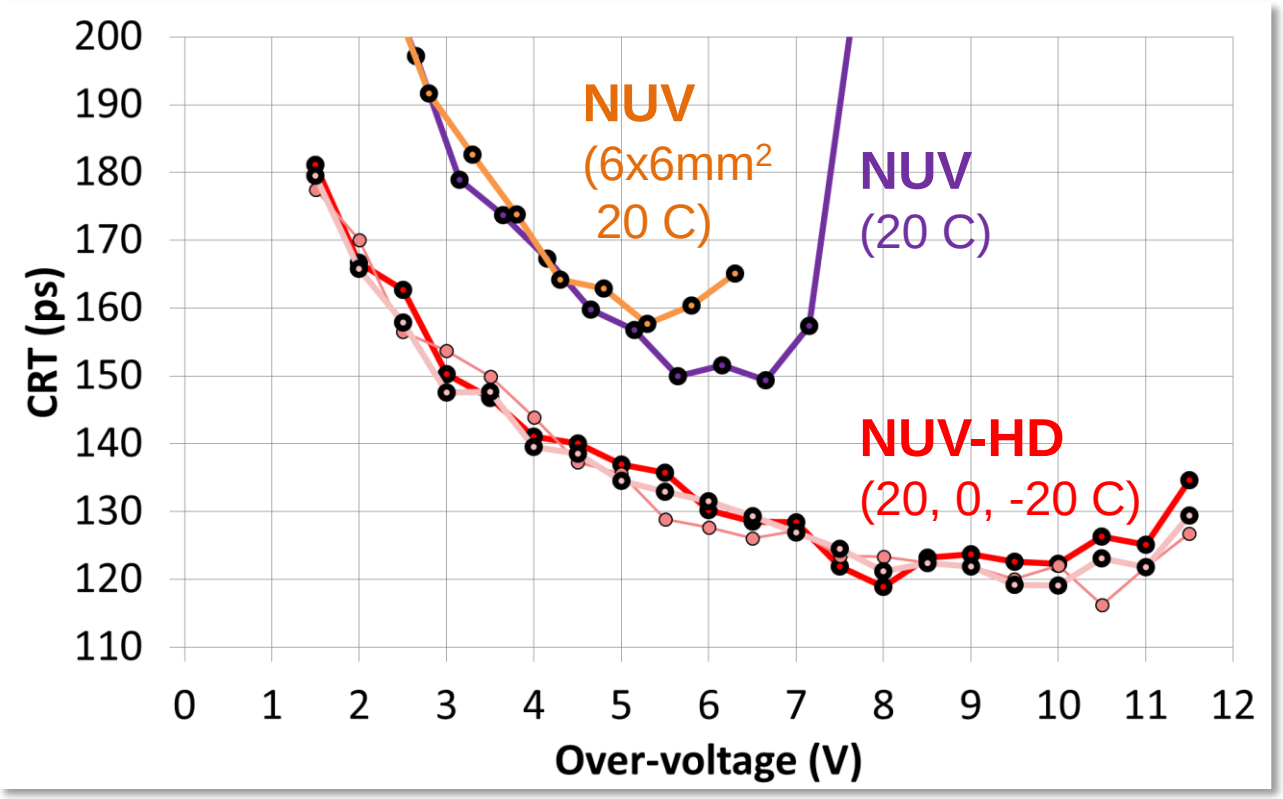
NUV-HD: PDE vs λ

30μm cell pitch (77% fill factor)



Timing performance of NUV-HD

- **4x4mm2** SiPM
- **25µm** cell pitch
- **LYSO 3x3x10**mm^3



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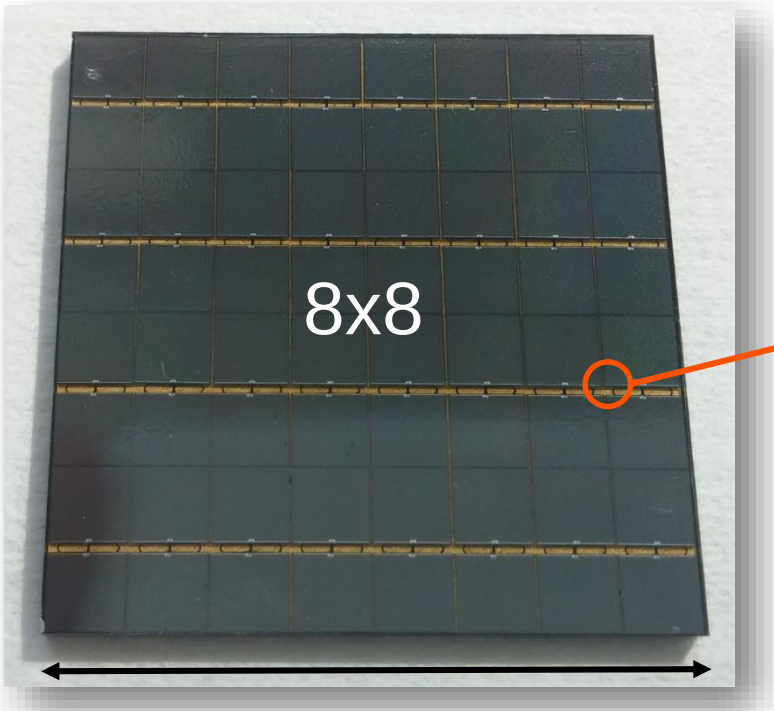
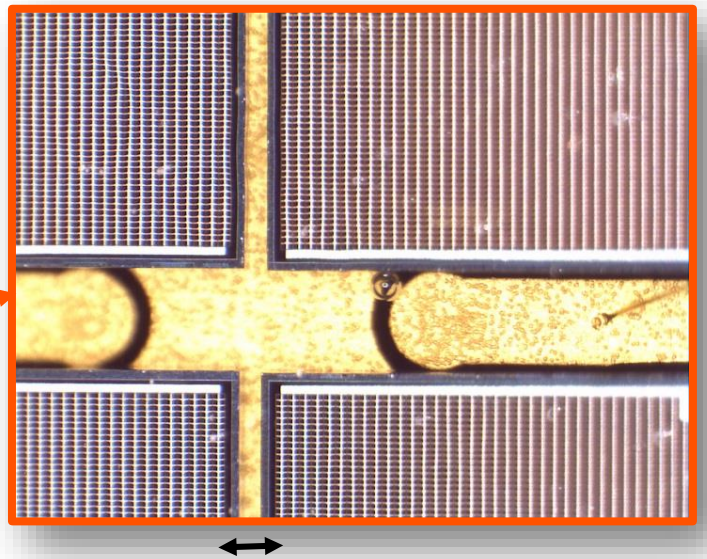
Large arrays

3 examples of highly integrated SiPM arrays (wire bonded)

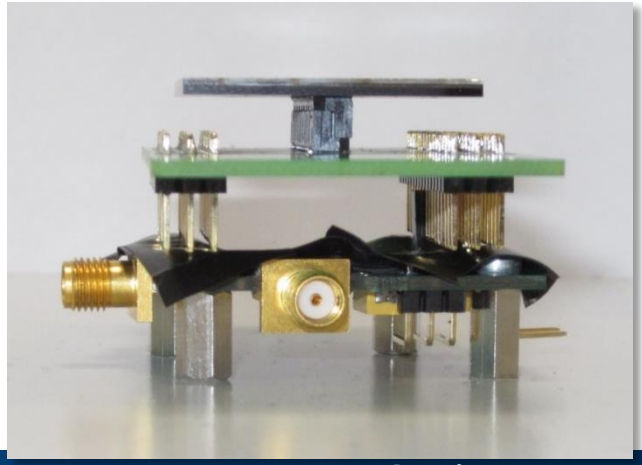
TOF-PET Tile (1st approach)





~ 200μm active-to-active distance

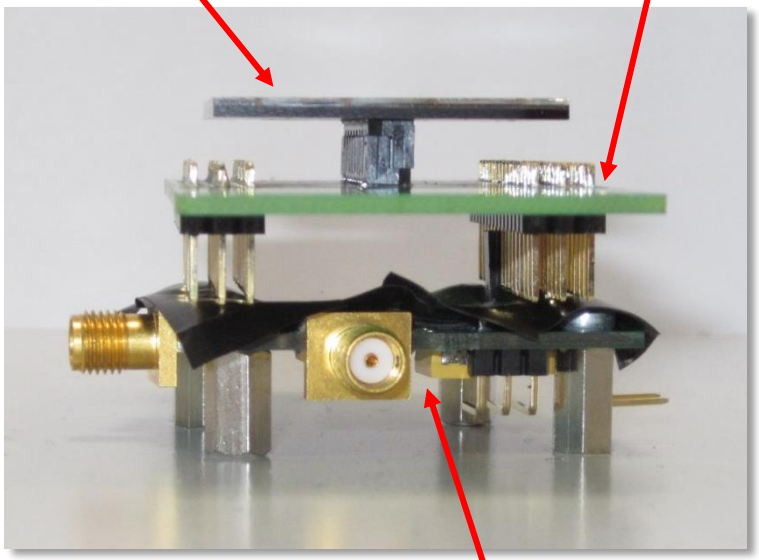
- 4mm pitch in x and y
- **85% (packaging) fill factor**
- SiPMs: RGB-HD 25μm



TOF-PET tile: test set-up

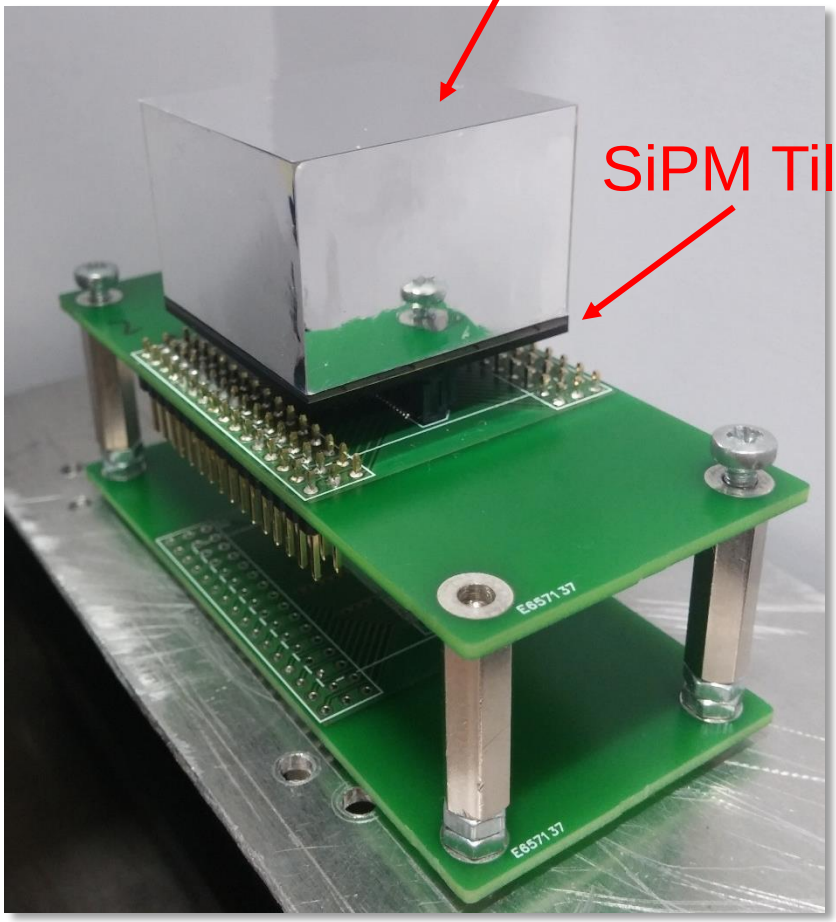
SiPM Tile

Adapter board



Discrete amplifier

8x8 LYSO array
4x4x22mm² pixel



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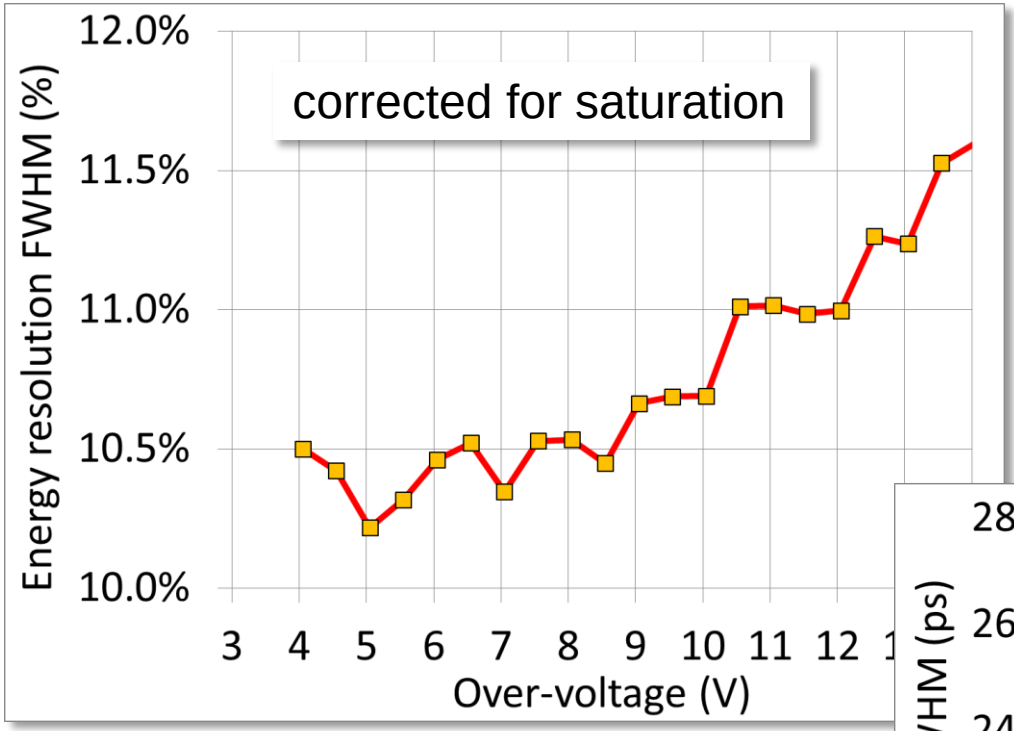
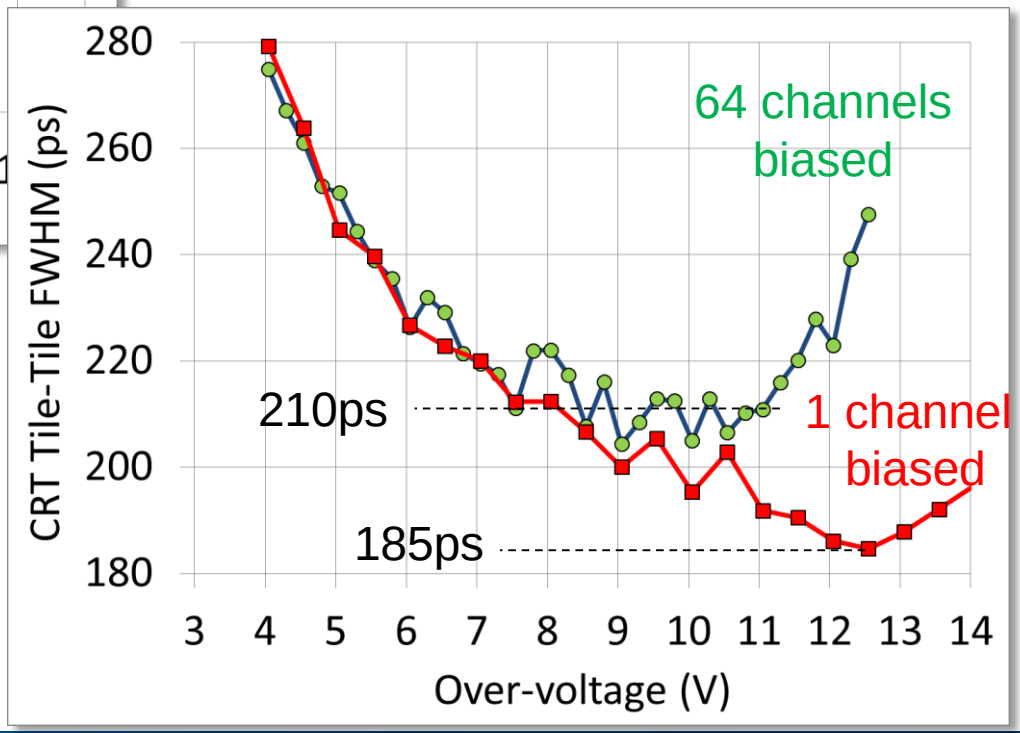
TOF-PET tile with RGB-HD



Test conditions:

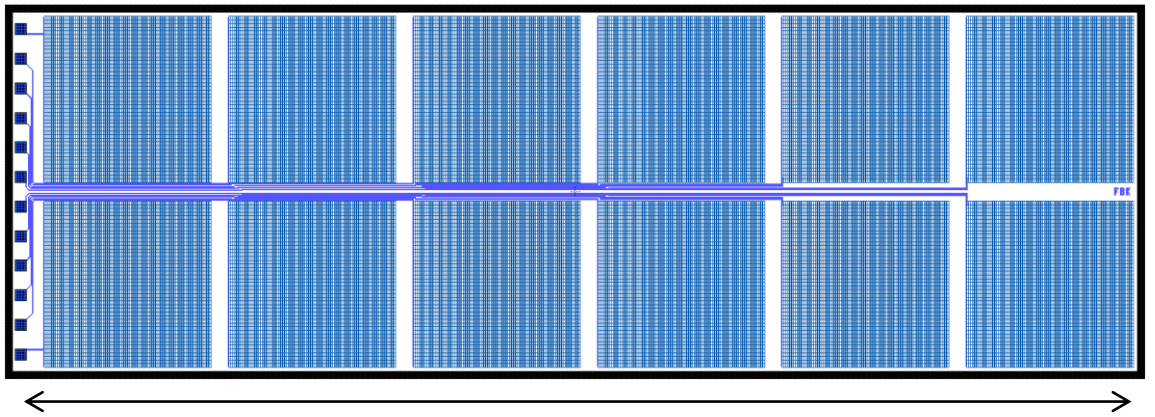
- ^{22}Na source
- T = 10 C
- 4x4x22mm^3 LYSO pixel
- SiPMs: **RGB-HD** 25μm

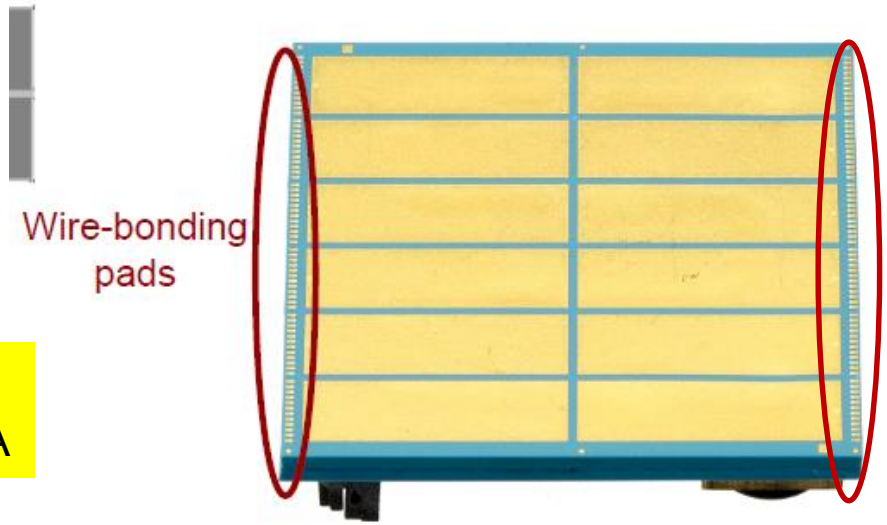


- Tile in coincidence with single channel reference
- Tile CRT unfolded

Tile (2nd approach)

Monolithic 6x2 SiPM array. 2.5mm SiPM pitch.

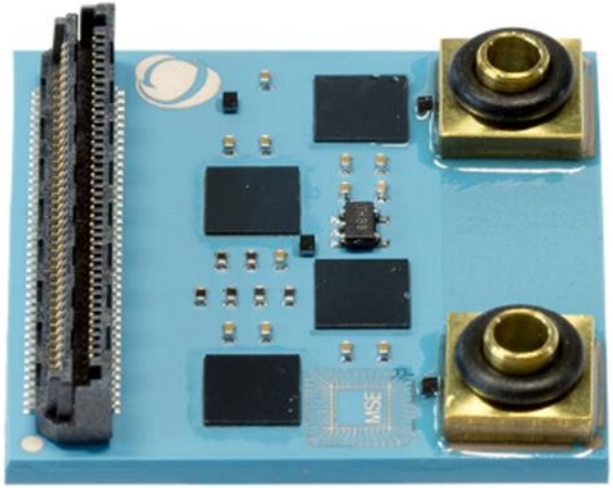


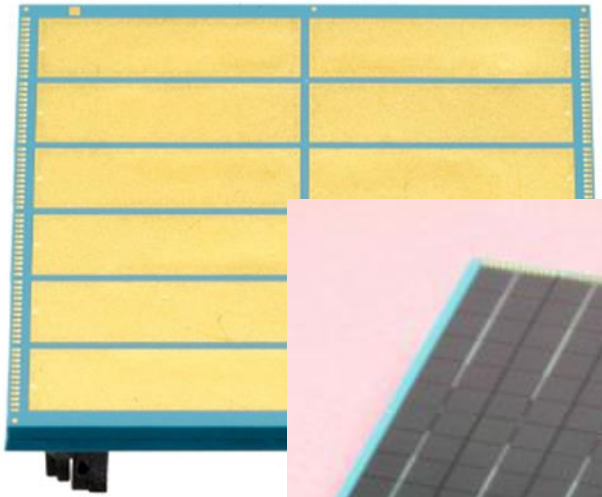


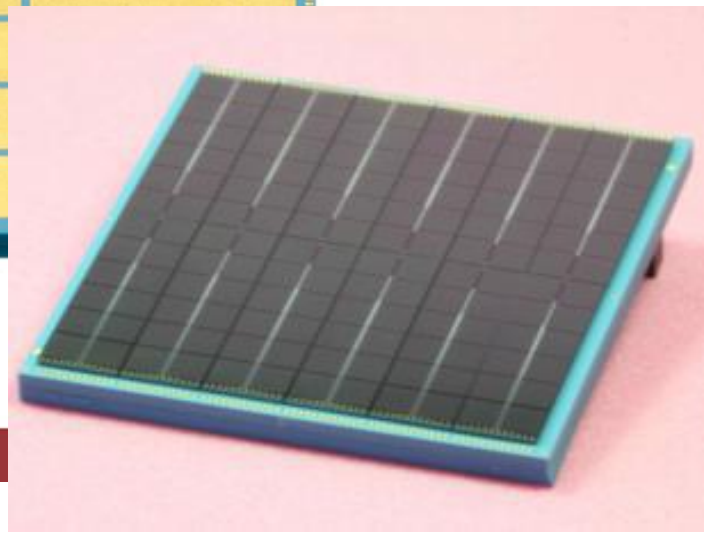
Tile developed within FP7 project SUBLIMA

A Compact & Water-Cooled Module

- 11 Layer LTCC Substrate – 2.1 mm thick
- **4 PETA5 ASIC** - bump-bonded naked on the LTCC substrate
- **144 Readout** channels per module
- Almost no external components required
- Inlet and outlet for the internal channel are glued on the substrate



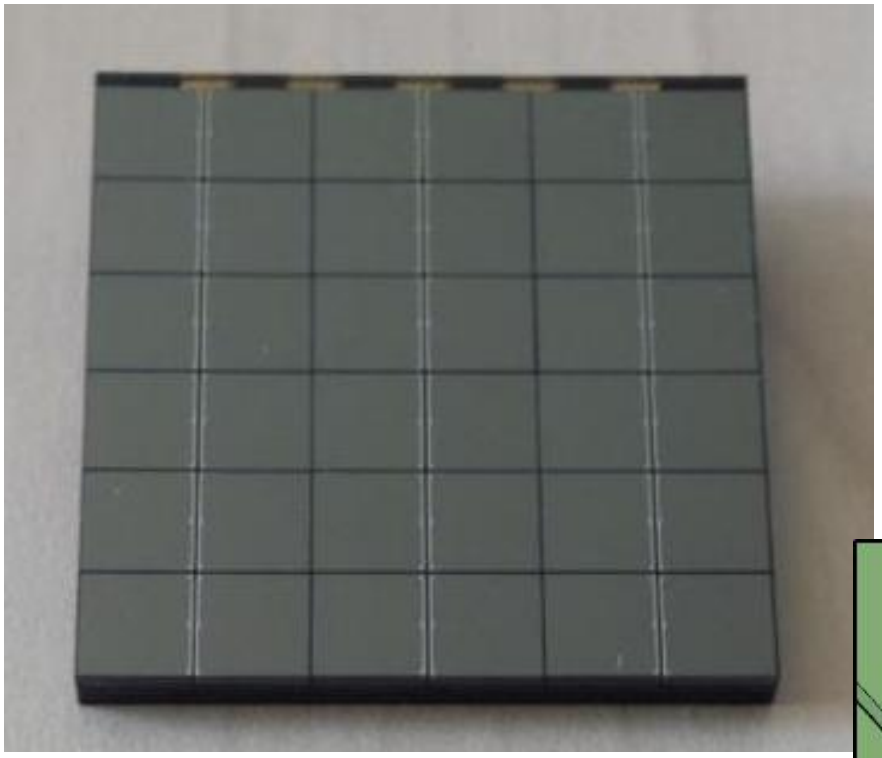




Only decoupling capacitors and termination resistors

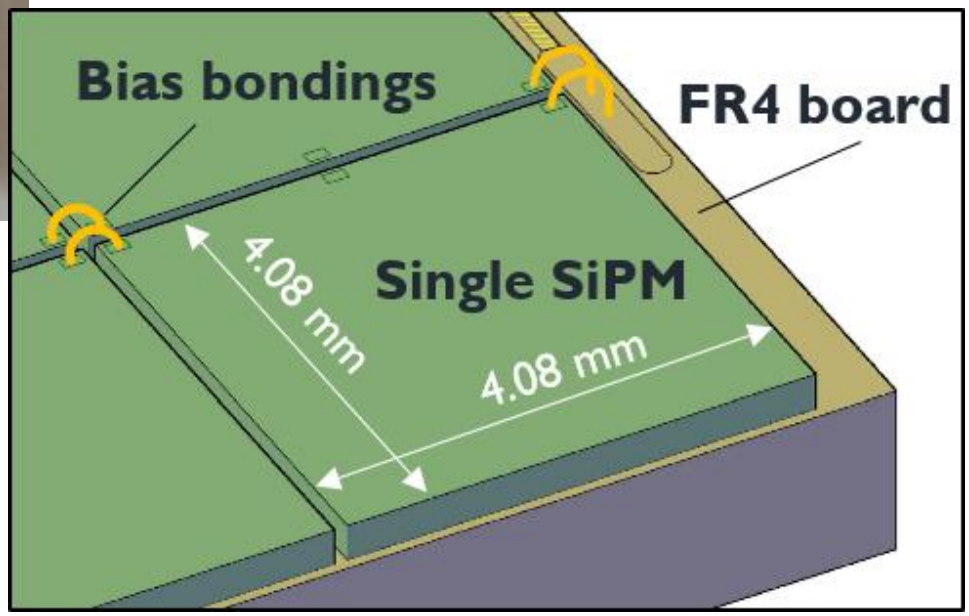
SiPM Tile – 3rd approach

Tile developed within FP7 project INSERT

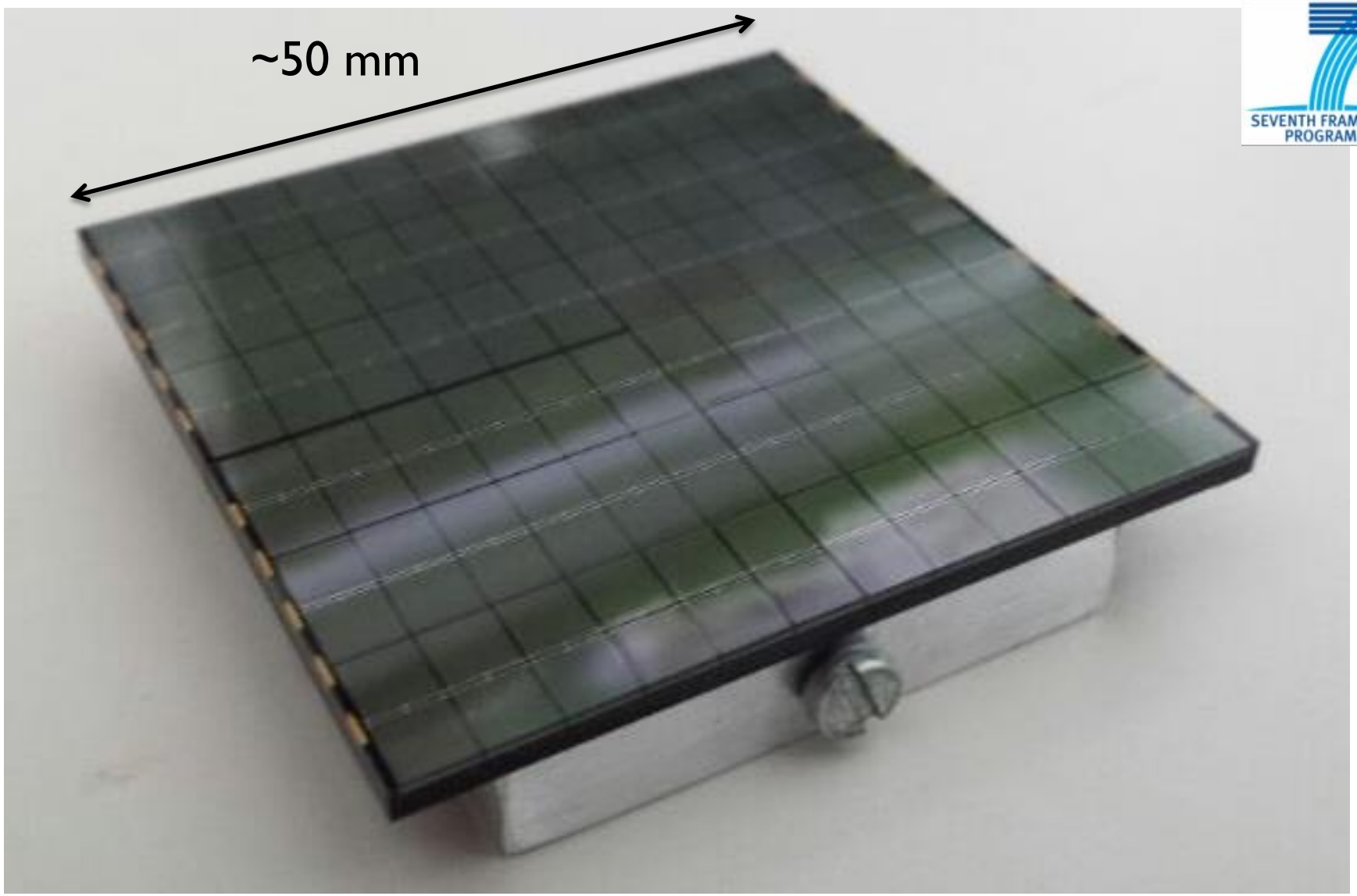


~25 mm

- 6x6 SiPM array
- Mounted on a FR4 board
- Covered with an optical resin
- SiPM active area: 4x4 mm^2
- Fill factor: 89%



SiPM Module (INSERT project)



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Main ongoing developments

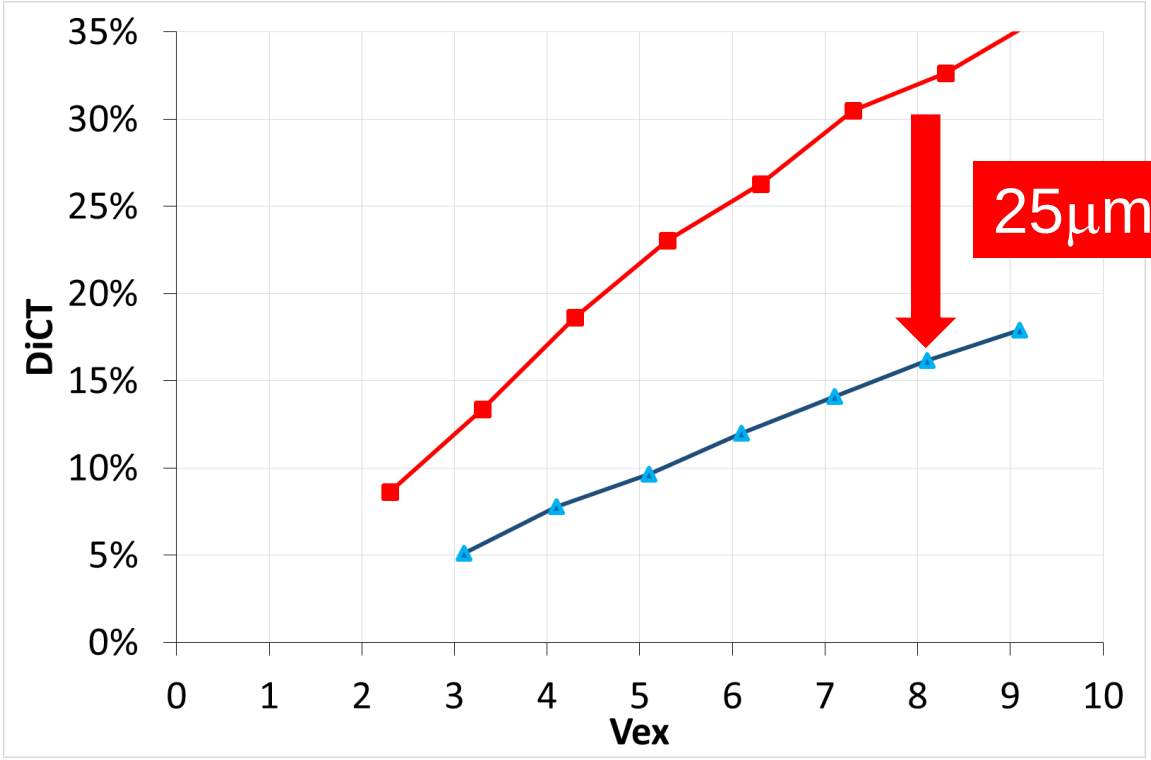
- **Low cross-talk HD technology**

- **Ultra High-Density RGB**

- **VUV sensitive SiPMs**

LOW-CT HD technology

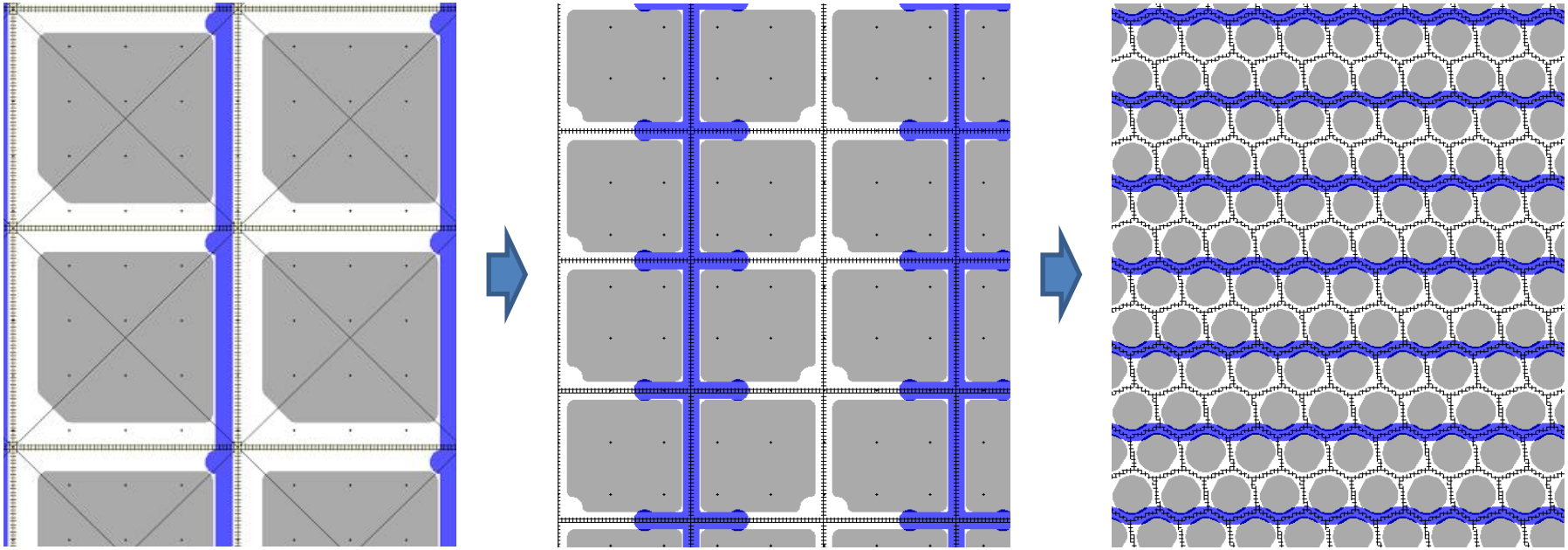
First results for RGB-HD technology



- First implementation on next NUV-HD prototypes
- Technology tuning for further CT reduction

Ultra High-Density Technology

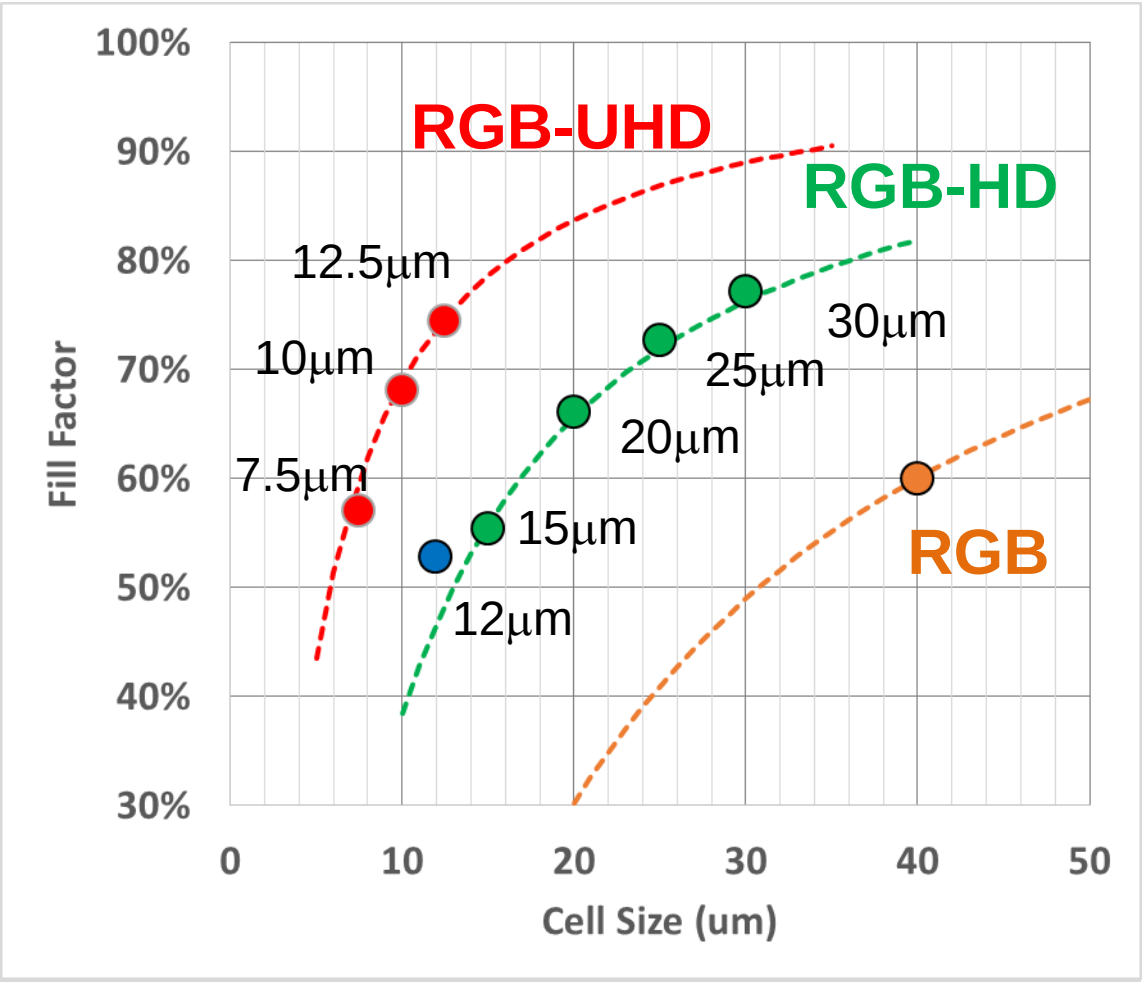
40 um cell | **25 um cell** | **<7.5 um cell**



RGB SiPMs | **RGB-HD SiPMs** | **RGB-UHD SiPMs**

Development for CMS experiment (A. Heering, I. Musienko, R. Ruchti)

Ultra High-Density Technology



RGB-HD

cell pitch (µm)	cells/mm²
12	7000
15	4500
20	2500
25	1600
30	1100

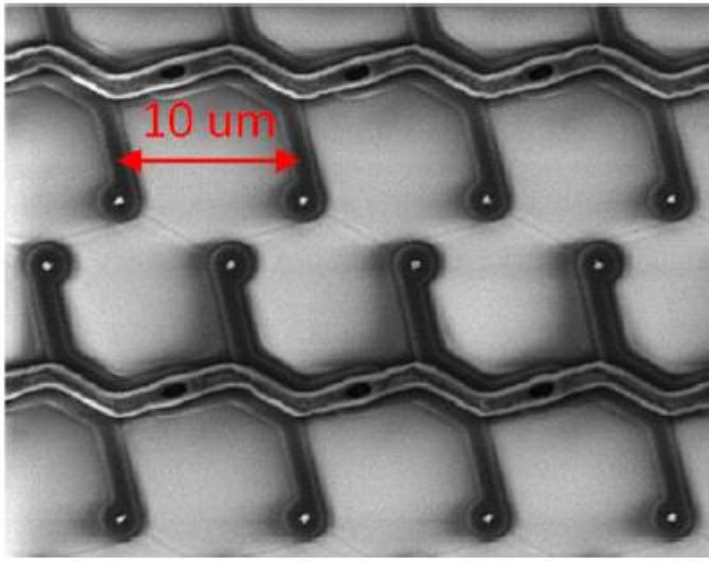
RGB-UHD

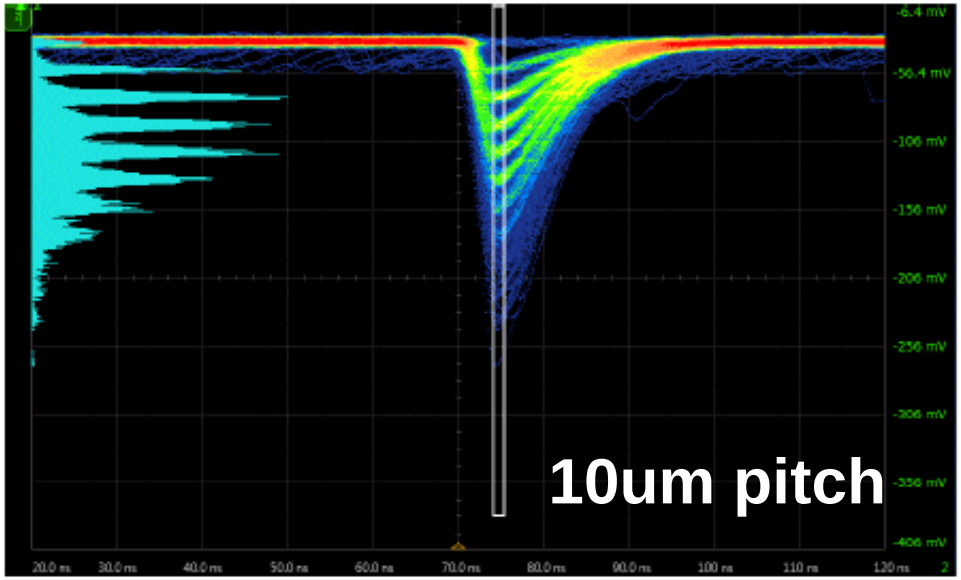
cell pitch (µm)	cells/mm²
7.5	**20530**
10	**11550**
12.5	**7400**

Preliminary Results

Circular SiPMs Φ = 1.5 mm

Preliminary results.

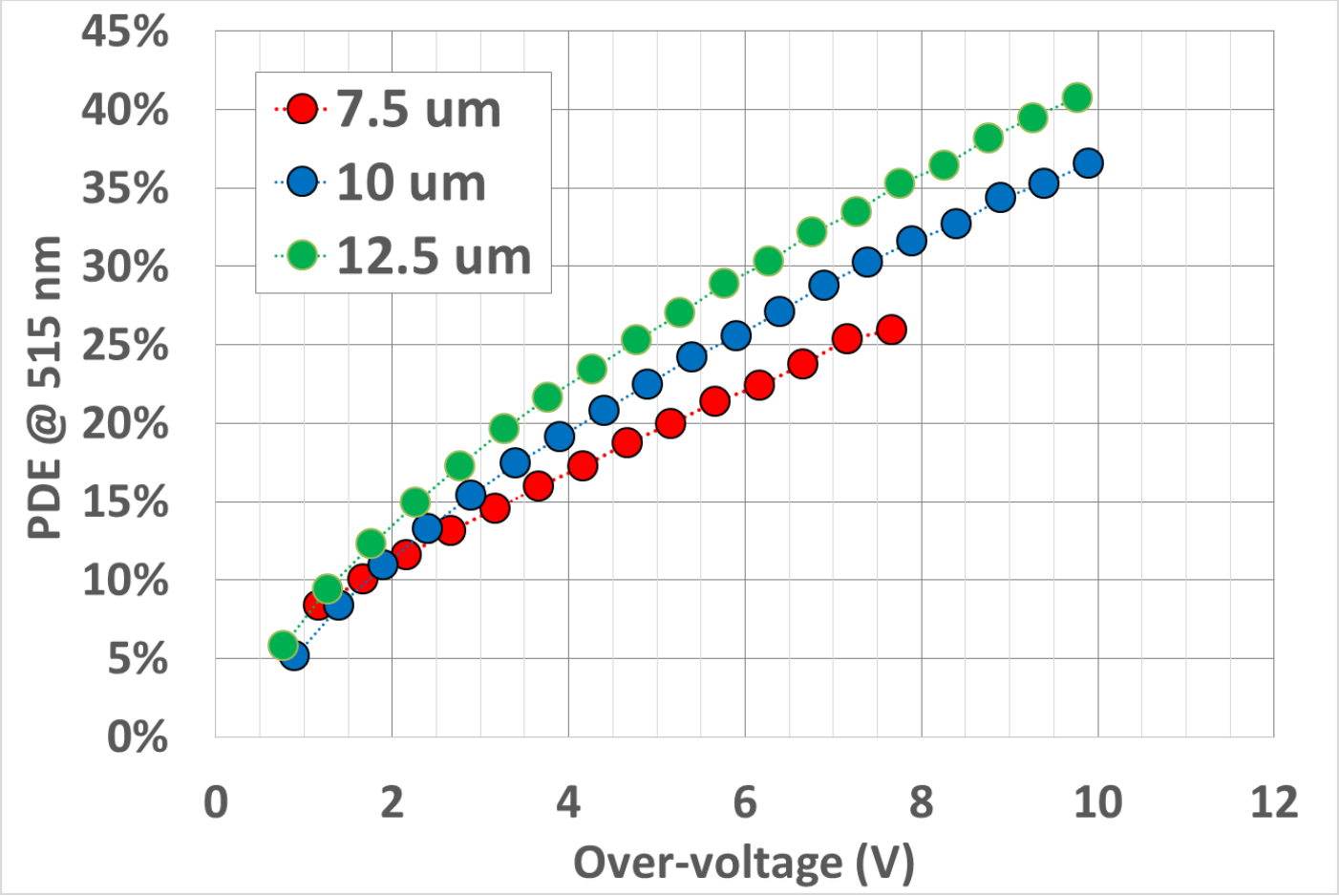




cell pitch (μm)	Recovery time const. (ns)
10	4.5
7.5	3.5

Preliminary results

PDE @ 515 nm



Conclusion (on NUV-HD)

- RGB-HD and NUV-HD most recent technologies available from FBK

- NUV-HD provides excellent performance for the detection of light from 300 to 450nm.
  → TOF-PET with LSO/LYSO and LaBr
  LYSO: CRT ~ **100ps** with 3x3x5mm^3
  CRT ~ **140ps** with 3x3x20mm^3
  SiPM: **4x4mm^2**, **25x25um^2** cell pitch

- Improvements are ongoing on the FF and correlated noise are ongoing.