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Characterization of the new FBK NUV SiPMs with low cross-talk probability

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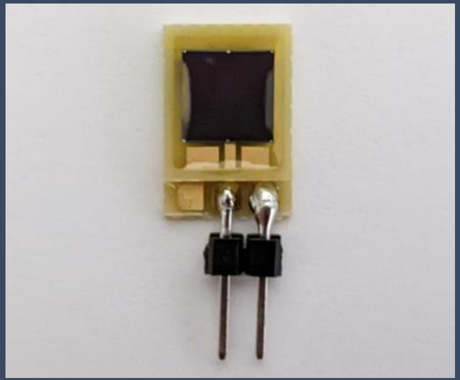
Silicon PhotoMultipliers (SiPMs)

- PMTs used as photo-detector from the beginnings of astroparticle physics
- SiPMs have entered the scene in the last decade as a highly attractive alternative to PMTs

Hamamatsu R6236 photomultiplier tube.



FBK NUV-HD3 SiPM.

Pros:

- Low consumption
- High PDE/Gain
- Compactness of the technology
- Insensitivity to Magnetic field
- Time resolution

Cons:

- Temperature dependance of SiPMs noise performances
- Correlated noise (depending on the application)
- Radiation damage effects

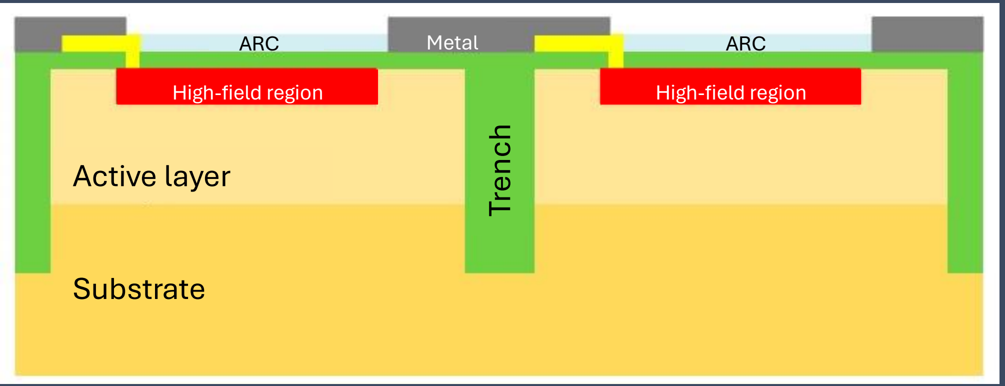
Silicon PhotoMultipliers at FBK

FBK NUV-HD technology has trenches between single cells filled with silicon oxide:

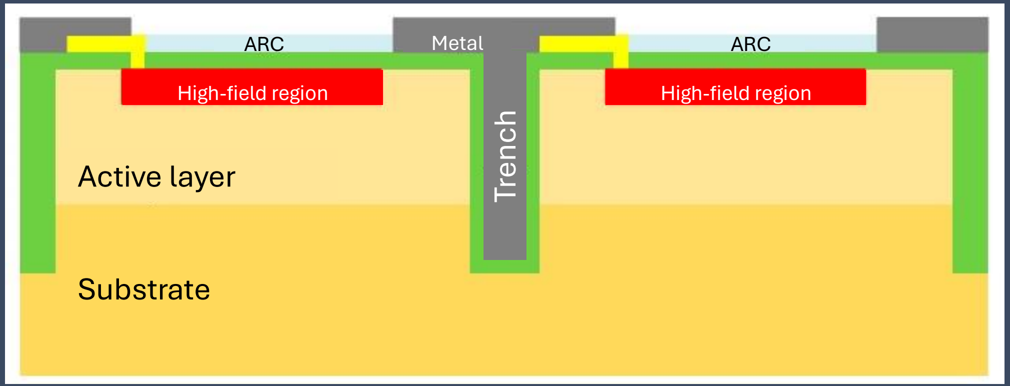
- Excellent electrical insulation, partial optical insulation (A.Gola *et al.* 2019)

NUV-HD Metal-in-Trench (MT) has an extra opaque/reflective metal layer inside the deep trench isolation:

- Expected suppression of the photon transmission between cells
- Internal Optical Cross-Talk (OPT) of the device reduced (S. Merzi *et al.* 2023)



Structure of the cells of the NUV-HD technology.



Structure of the cells of the NUV-HD technology with Metal-in-Trench.

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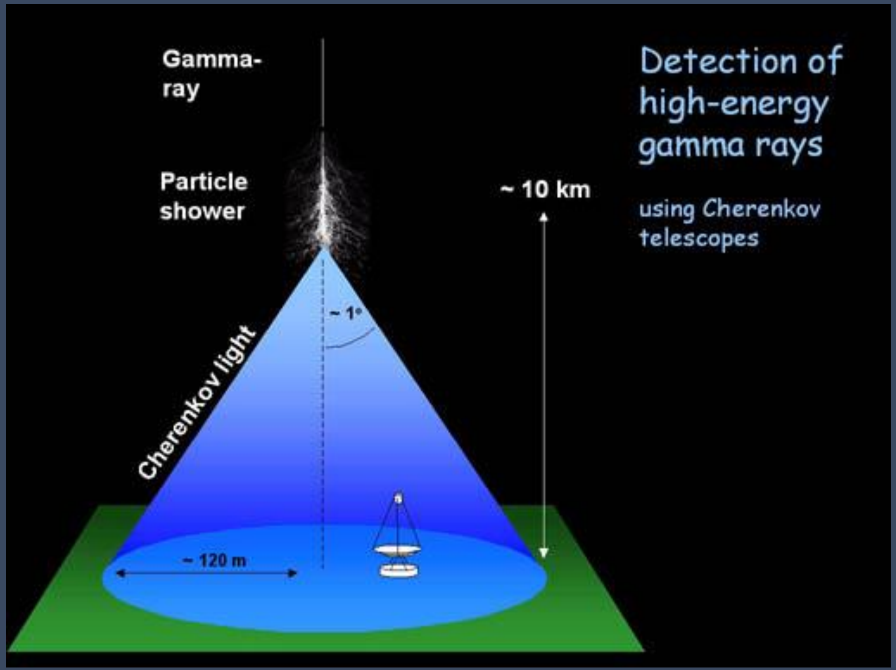


Attractive feature for Astroparticle Physics experiments on ground! (es. OPT<10% for Imaging Atmospheric Cherenkov Telescopes)

FBK NUV-HD MT: functional characterization

Measurements performed in FBK laboratories in Trento in the framework of my Master Degree internship (2023)

- Dark condition at $20^\circ C$
- With LED illumination
- I-V ⟹ Breakdown Voltage at $20^\circ C \sim 32.4V$

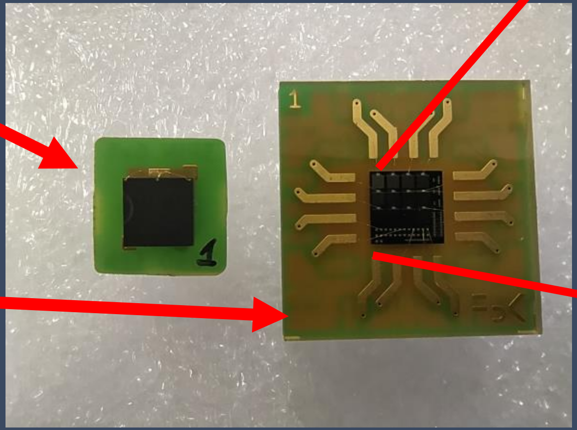
Tested SiPMs:

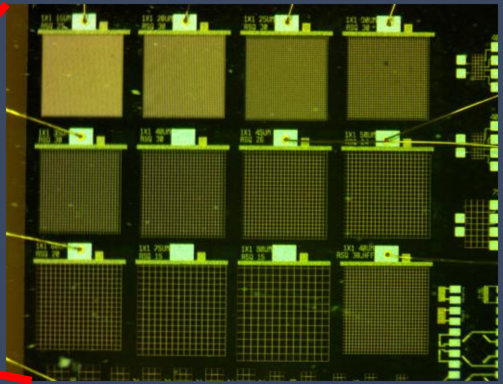
- 6x6 mm^2 FBK NUV-HD MT (no coating)

  With cell pitch: 30 μm, 40 μm, 45 μm, 50 μm, 60 μm, 75 μm

- 1x1 mm^2 FBK NUV-HD MT (with epoxy layer)

  With cell pitch: 25 μm, 30 μm, 45 μm, 50 μm, 60 μm, 75 μm



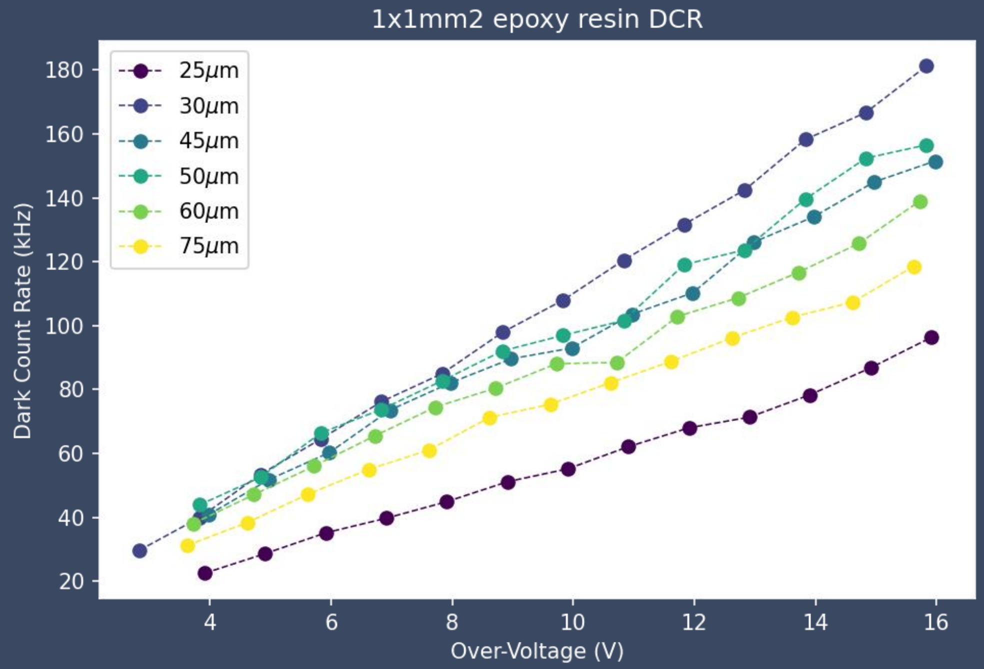


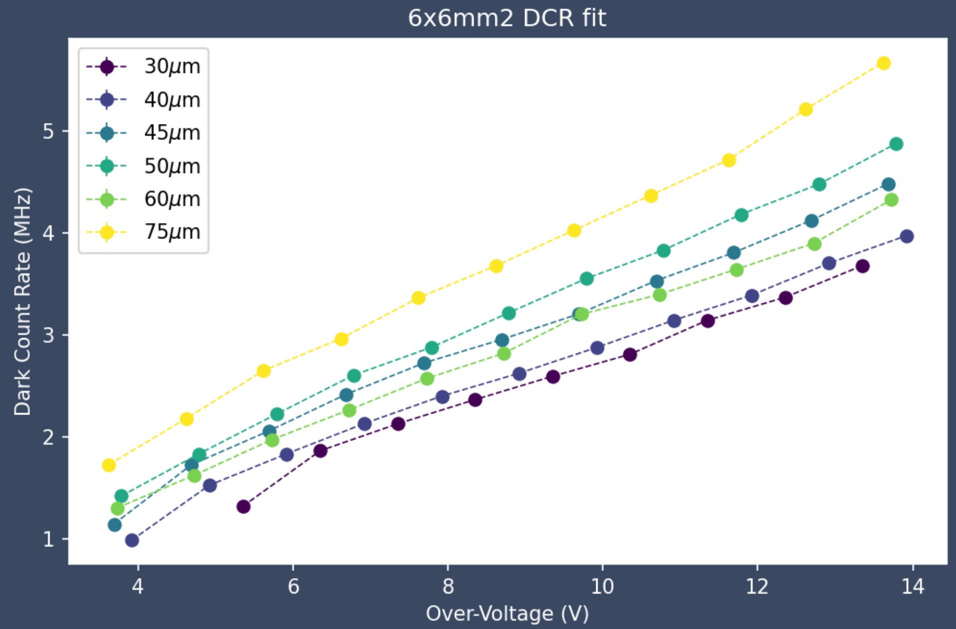
Test structure zoom-in with 1x1 mm^2 SiPMs samples

FBK NUV-HD MT: Functional characterization in dark conditions

DCR estimated by the distribution of the time differences between consecutive dark pulses, following the method described in (C.Piemonte *et al.* 2012)

- No evident correlation between DCR and cell pitch has been observed
- DCR changes between samples ranging between 55 kHz/mm^2 and 83 kHz/mm^2 at 8V of excess bias for 6x6 mm^2 SiPMs





FBK NUV-HD MT: Functional characterization in dark conditions

Three type of correlated noise:

- Afterpulsing

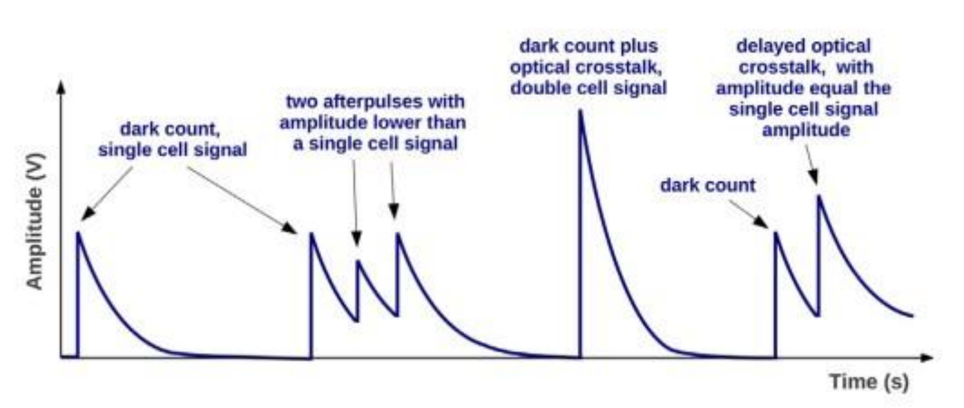
  Carriers trapped in the high-intensity field region and released later

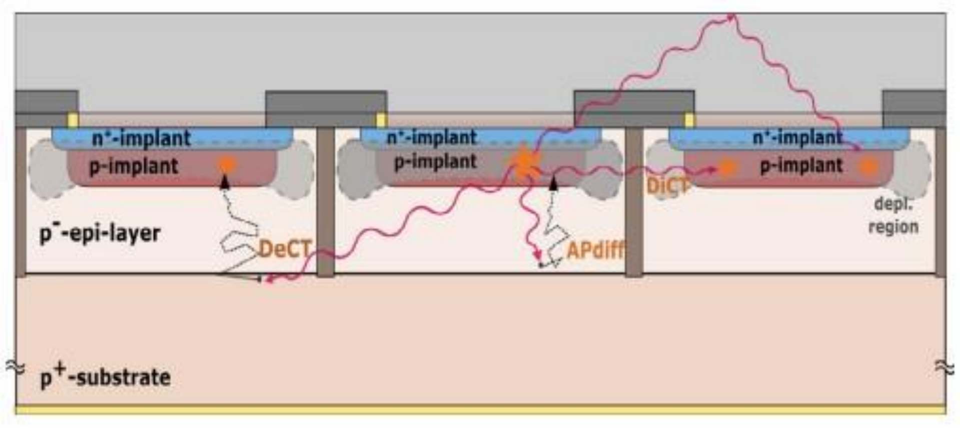
- Direct Cross-Talk (DiCT)

  Avalanches started in neighboring cells by secondary photons generate during the primary charge multiplication

- Delayed Cross-Talk (DeCT)

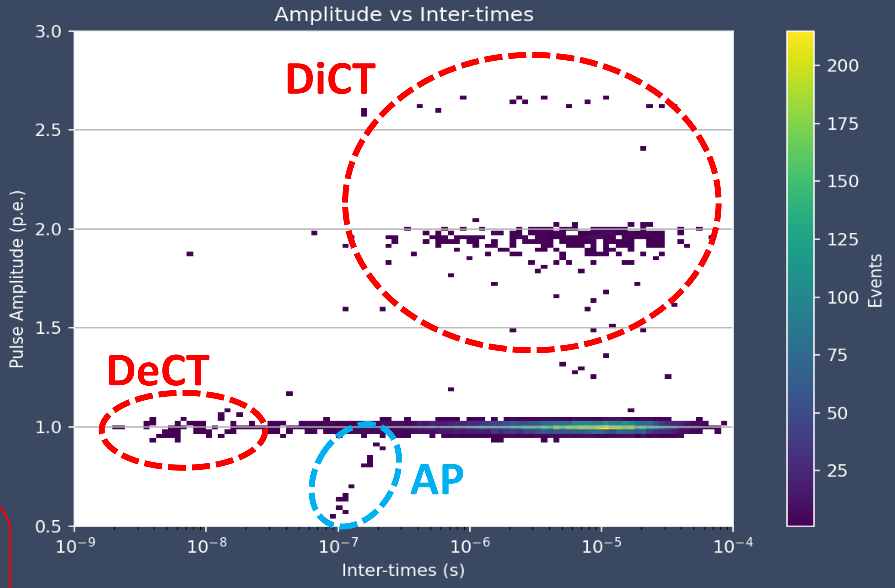
  Same as DiCT but the photon absorption happens in the region surrounding the depleted one

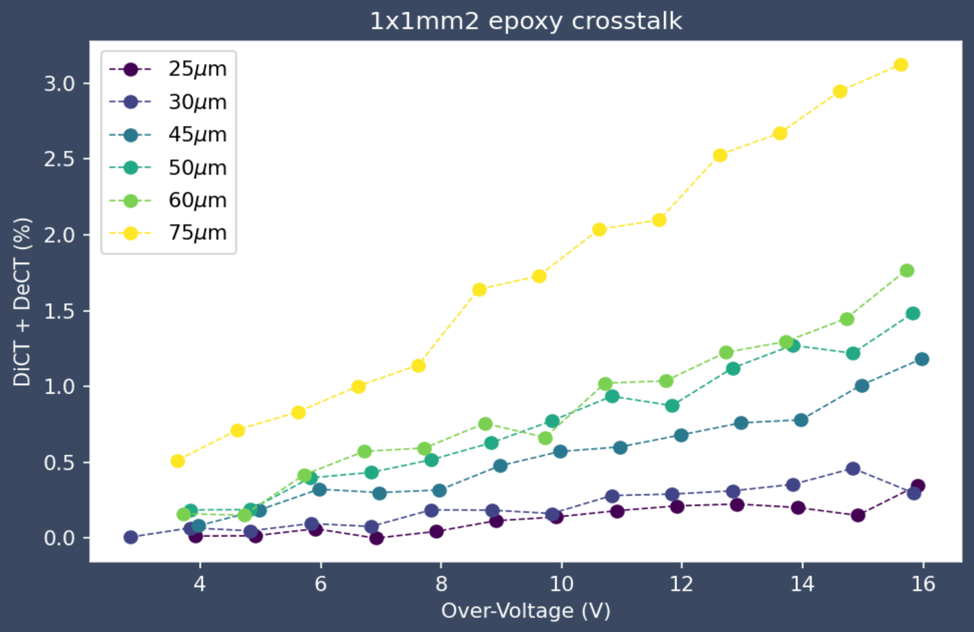




F. Acerbi and S. Gundacker, *Understanding and simulating SiPMs*, 2019

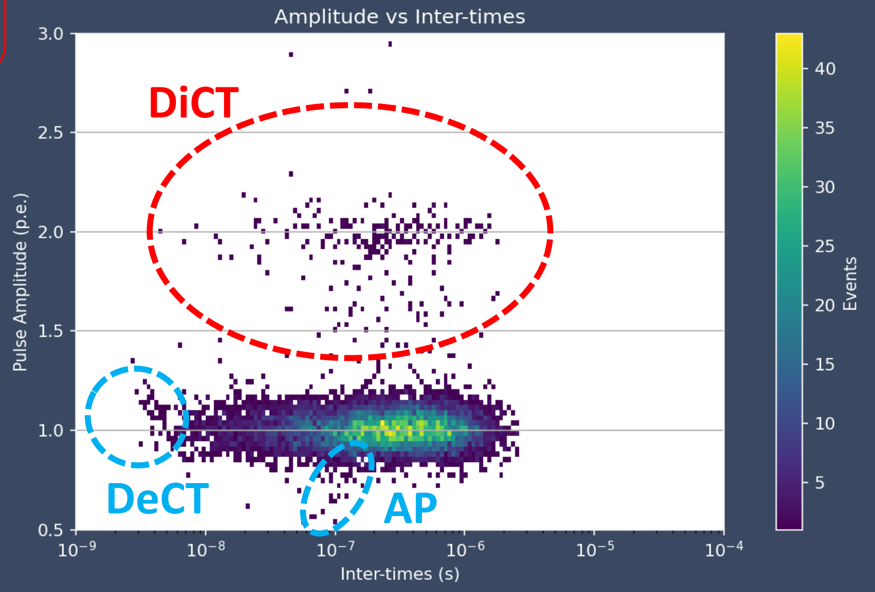
$1 \times 1\ mm^2$
$50\ \mu m$
$14\ V_{ov}$

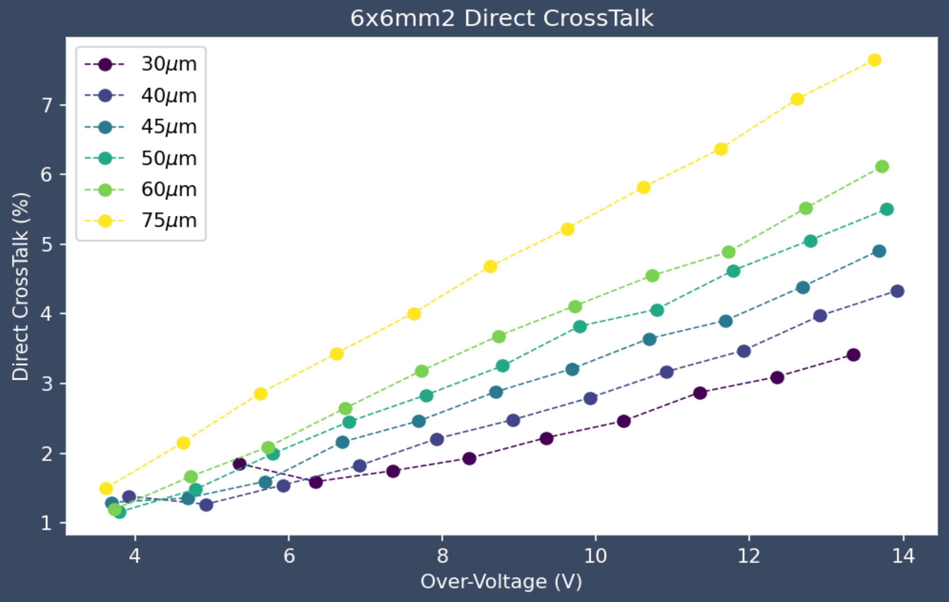




Circled in red are the measurements shown in the left plots

$6 \times 6\ mm^2$
$40\ \mu m$
$10\ V_{ov}$





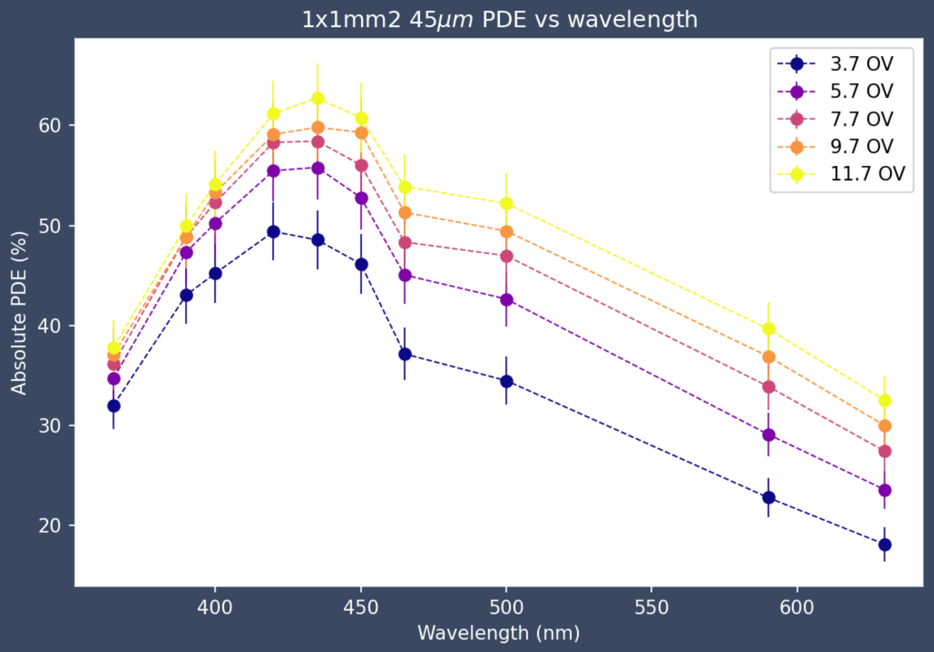
FBK NUV-HD MT: Functional characterization in light conditions

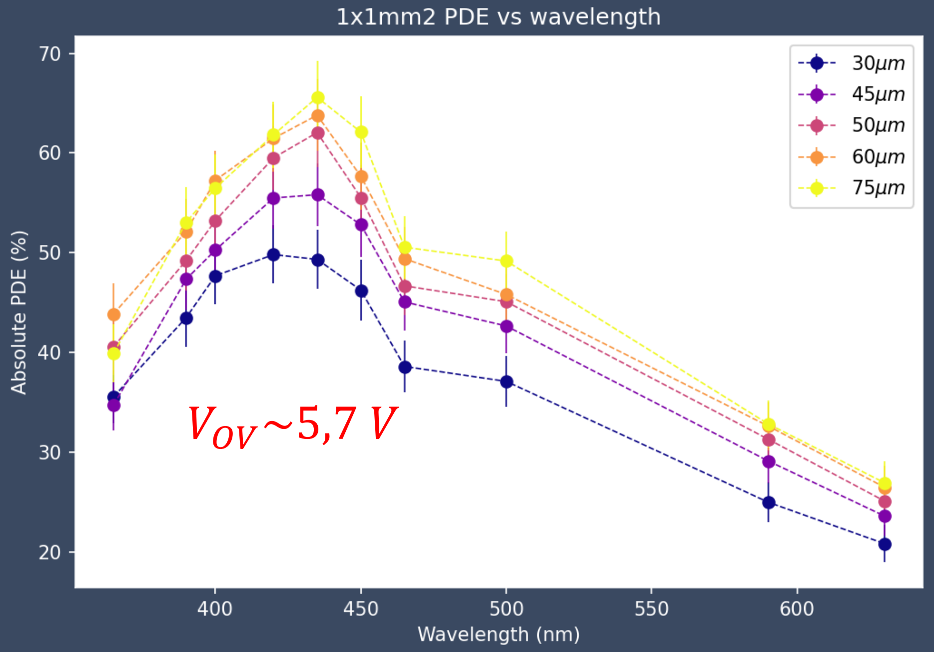
Tested SiPMs:

✓ 1x1 mm^2 FBK NUV-HD MT

with cell pitch: 30 μm, 45 μm, 50 μm, 60 μm, 75 μm

- PDE peaks at 435 nm, ranging from 50 % and 65 % depending on excess bias and cell pitch (60% at 8V for 1x1 mm^2 45 μm cell pitch SiPM)
- No significant difference in PDE with the NUV-HD technology (A.Gola *et al.* 2019)
- Same PDE of the 6x6 mm^2 SiPMs, since the PDE is a feature of the individual microcell (S. Merzi *et al.* 2023)





SiPMs in Astroparticle Physics: FBK NUV-HD MT (summary)

- **Low CT**; for the 6x6mm^2 SiPMs between 2 % and 5 % at 8V of excess bias, depending on the cell size. Delayed CT and Afterpulses probabilities estimated to be below 1%.
- Measurements on 6x6mm^2 taken without epoxy layer.
- Higher operational voltage than NUV-HD, more stability in terms of performances when reading thousands of channels
- Operating range extend resulting in increased photon-detection efficiency
- PDE retained while suppressing OCT!

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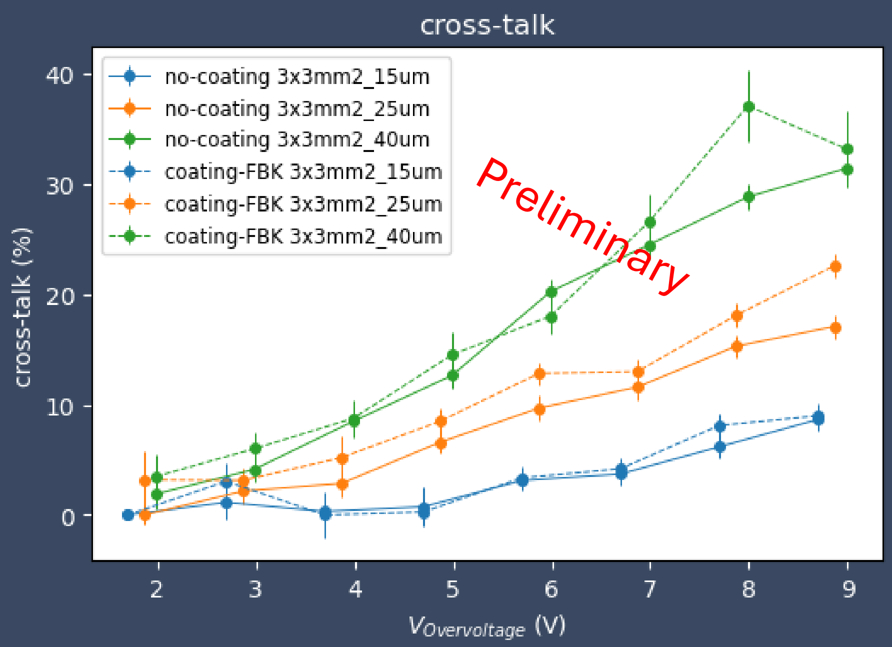
From FBK NUV-HD Rad Hard (RH) 3x3 mm^2 functional characterization:

- Optical Cross-Talk estimated from the compound Poisson distribution



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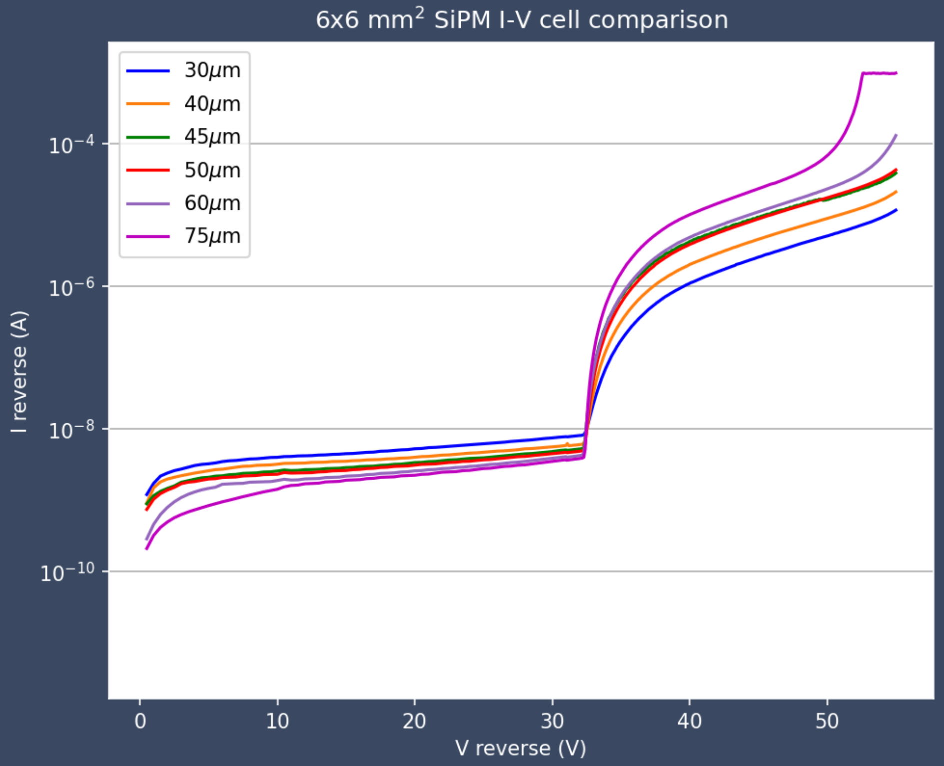

Conclusions

- SiPMs are growing their employment in ground-based Astroparticle physics experiments. Why?
  - ✓ Cost per channel
  - ✓ Photon Detection Efficiency in the Cherenkov photons peak (~350nm)
  - ✓ Tolerance against Night Sky Background, ~700 kHz/mm^2 expected vs 50-80 kHz/mm^2 DCR
- Major drawbacks:
  - ☒ Gain dependence on temperature
  - ☒ Optical Cross-Talk + Night Sky Background can cause false triggers due to accidental coincidences

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Metal-in-Trench technology employed in FBK NUV-HD-MT is succesfully reducing Optical Cross-Talk without affecting other characteristics.

THE END

Thanks for your attention!