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Radiation Damage Analysis for Irradiated SiPMs using Emission Microscopy

Projet de master en physique

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Overview

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- SiPM mechanism and infrared emission
- SiPMs: Hamamatsu and FBK
- EMMI Introduction
- IV scan
- Background subtraction
- Defect location of non-irradiated SiPMs
- Relationship between emission intensity and current
- Damage point analysis using FBK SiPM

SiPM Mechanism

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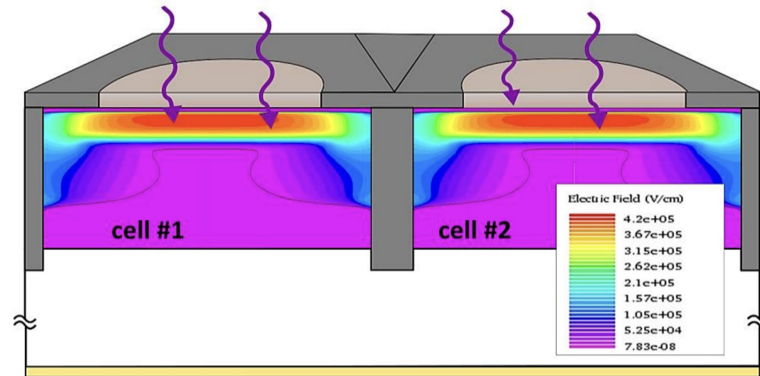
- Avalanches are produced in the multiplication region close to the surface
- The charge carriers produce infrared photons through Bremsstrahlung, which are visible through camera



SiPMs under investigation

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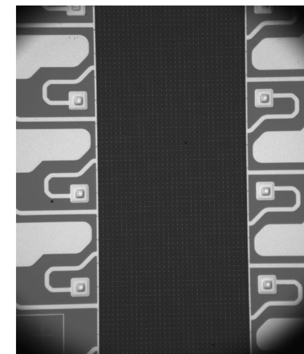
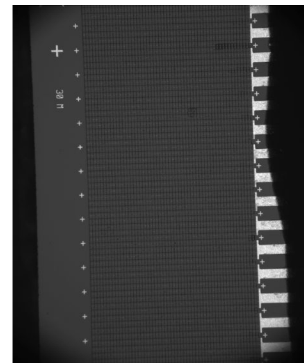
Producer	Name	Pixel Size	Fluence	Vbd (ch118)
Hamamatsu	H2024	50um	1e13 n_{eq}/cm^2	51.69 ± 0.02 V
	H2024	50um	3e12 n_{eq}/cm^2	50.97 ± 0.02 V
	H2024	50um	1e12 n_{eq}/cm^2	51.45 ± 0.07 V
	H2024	50um	3e11 n_{eq}/cm^2	51.31 ± 0.02 V
	H2024	50um	0 n_{eq}/cm^2	51.10 ± 0.11 V



Producer	Name	Pixel Size	Fluence	Vbd (ch118)
FBK	W3m	31um	1e13 n_{eq}/cm^2	31.07 ± 0.02 V
	W3m	31um	3e12 n_{eq}/cm^2	31.00 ± 0.02 V
	W3m	31um	1e12 n_{eq}/cm^2	31.11 ± 0.02 V
	W3m	31um	3e11 n_{eq}/cm^2	31.19 ± 0.02 V
	W1m	31um	0 n_{eq}/cm^2	30.94 ± 0.04 V



Emission Microscopy (EMMI)

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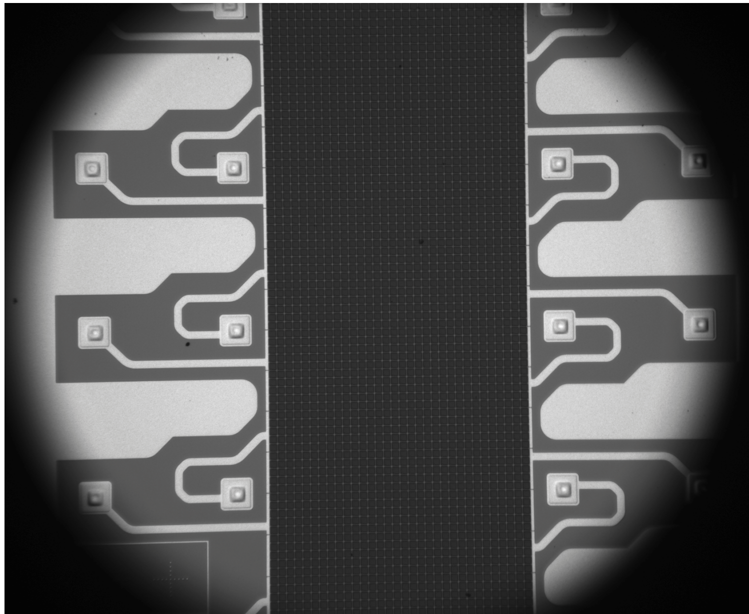
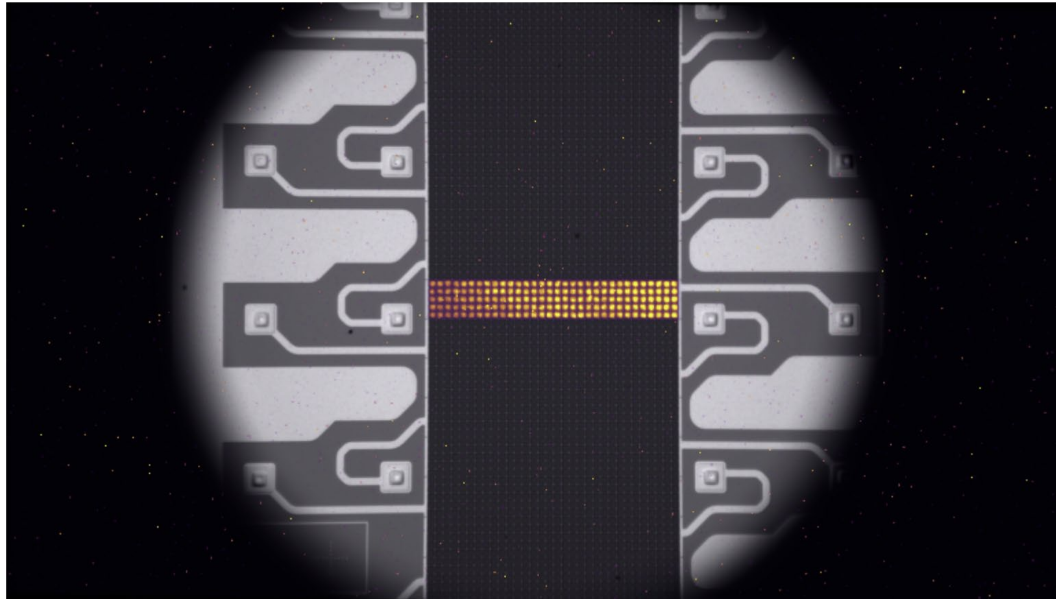
- Reference and emission images are taken using the camera through microscope



Emission Microscopy (EMMI)

- They are then combined to form the EMMI image

Superimposed Image
(Pure EMMI, Rotated by -0.80°)



IV Scan Results

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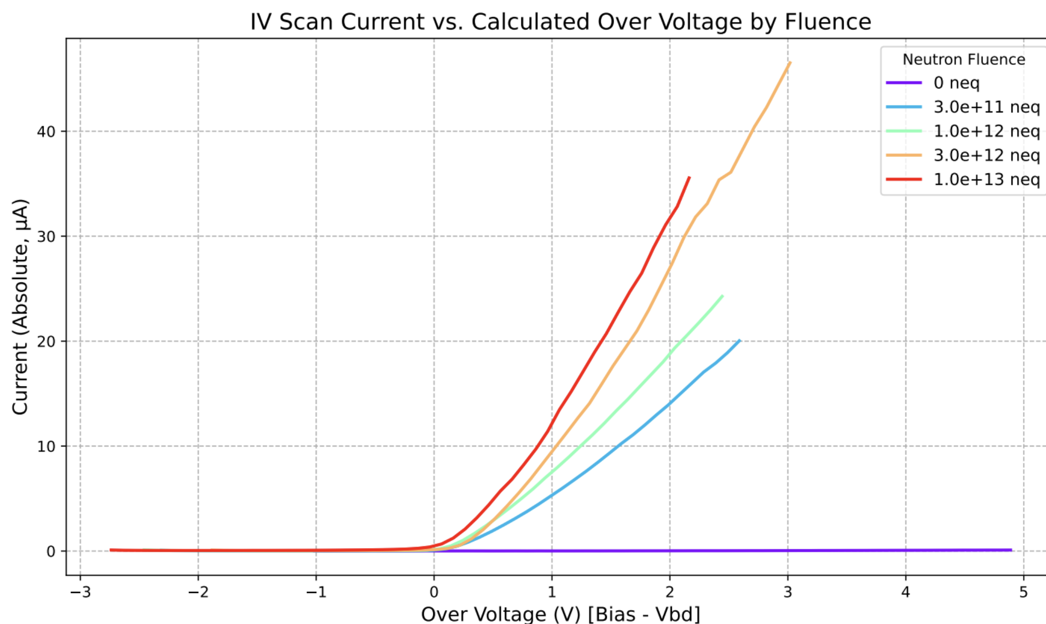
- IV scan result for Hamamatsu SiPMs, current scales with fluence



IV Scan Results

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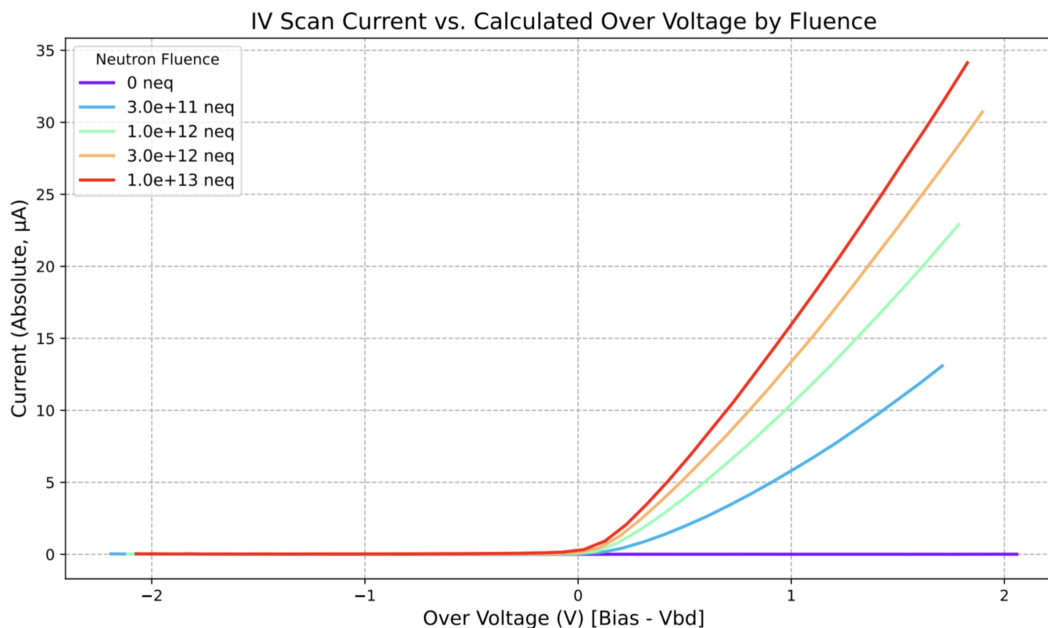
- IV scan result for FBK SiPMs, current scales with fluence



Camera Noise Subtraction

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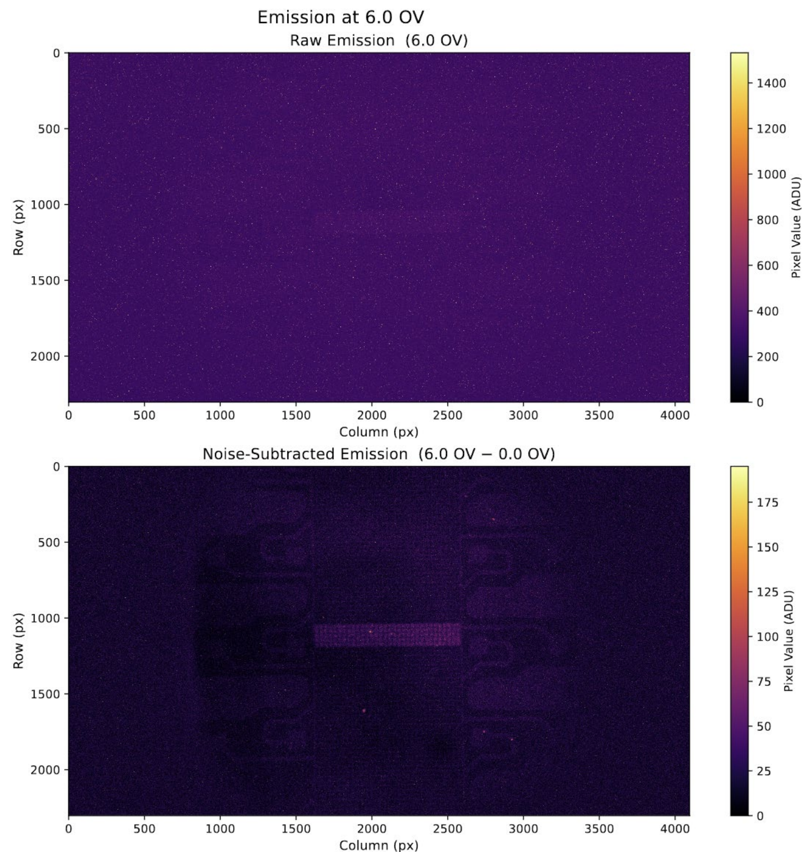
- For non-irradiated SiPM, emission intensity is very low. In this case, de-noise is important

- The dark image is taken also at 10min. It is then subtracted from the emission to remove the camera noise contribution.



Non-irradiated SiPM

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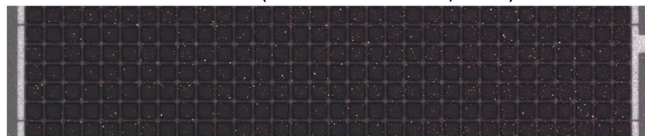
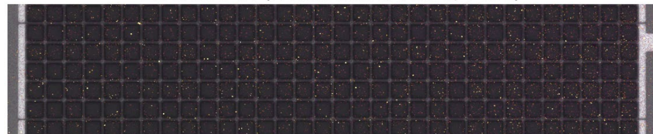
- EMMI for H2024_50um_0neq_ch118 at various OV:

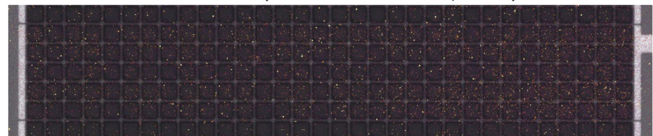
EMMI Image at 1.0 OV
Zoomed-In (Noise-Subtracted, Pure)



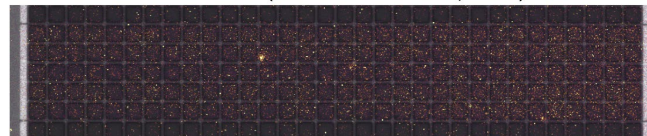
EMMI Image at 2.5 OV
Zoomed-In (Noise-Subtracted, Pure)



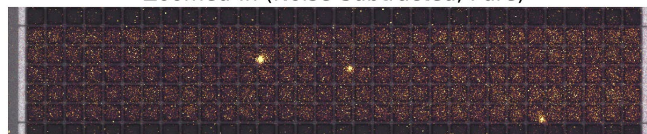
EMMI Image at 4.0 OV
Zoomed-In (Noise-Subtracted, Pure)



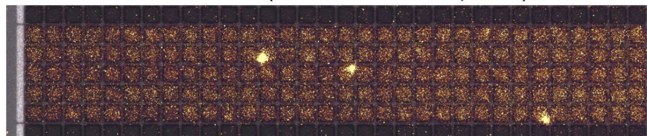
EMMI Image at 6.0 OV
Zoomed-In (Noise-Subtracted, Pure)



EMMI Image at 8.0 OV
Zoomed-In (Noise-Subtracted, Pure)



EMMI Image at 10.0 OV
Zoomed-In (Noise-Subtracted, Pure)



Non-irradiated SiPM

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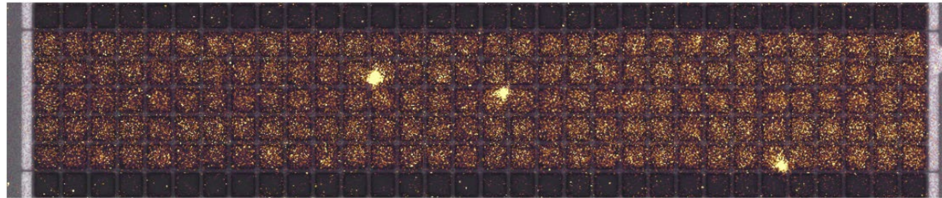
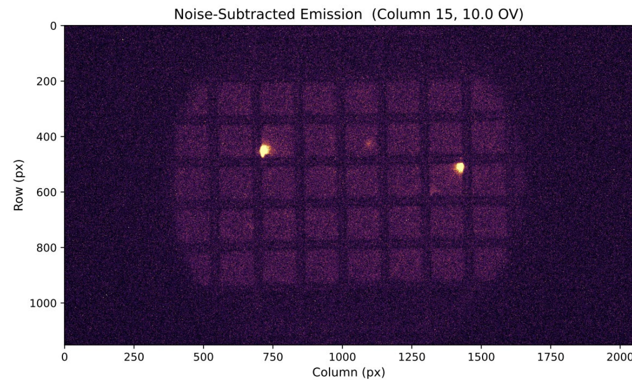
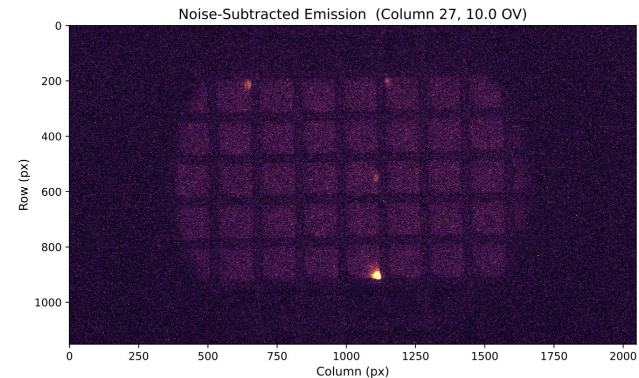
- EMMI for H2024_50um_0neq ch118 at 10.0 OV:

EMMI Image at 10.0 OV
Zoomed-In (Noise-Subtracted, Pure)

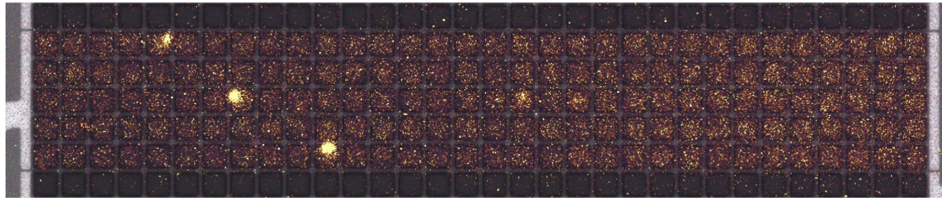


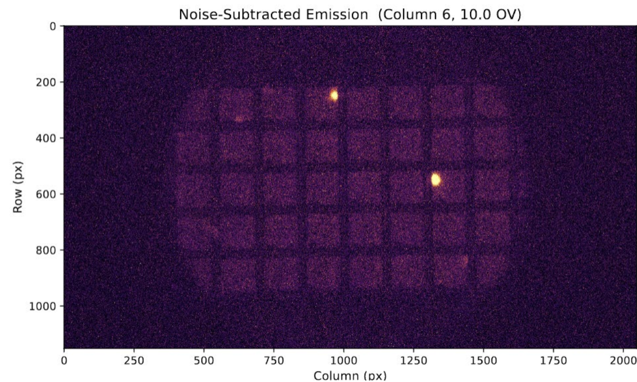


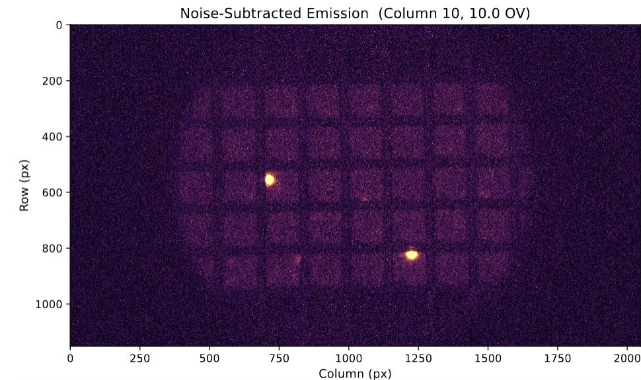


Non-irradiated SiPM

- EMMI for H2024_50um_0neq ch117 at 10.0 OV:

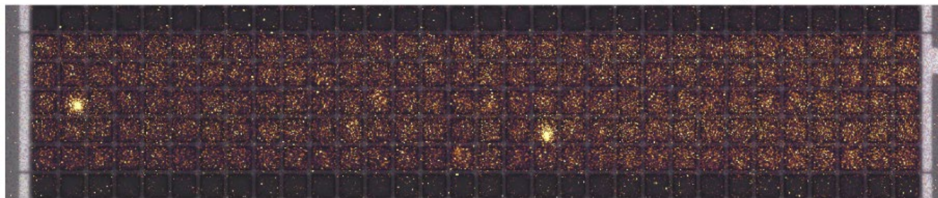


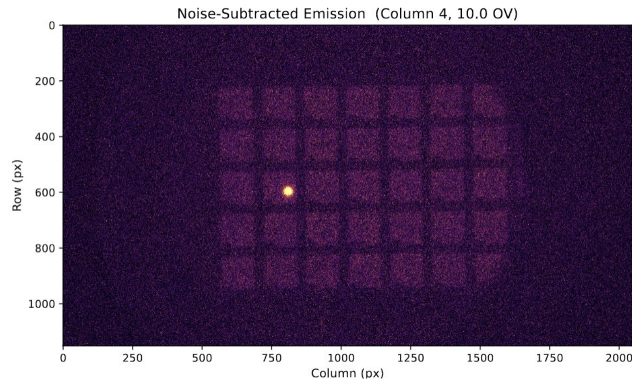


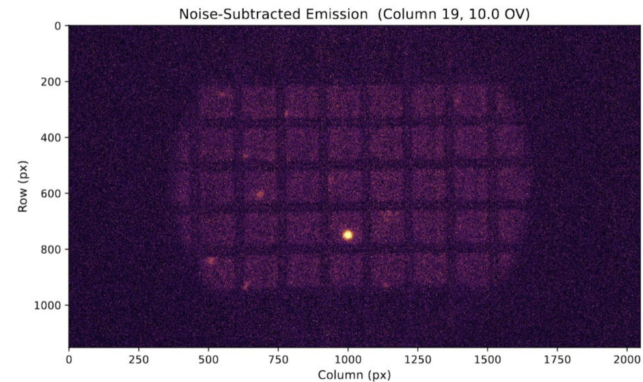


Non-irradiated SiPM

- EMMI for H2024_50um_0neq ch102 at 10.0 OV:







Non-irradiated SiPM

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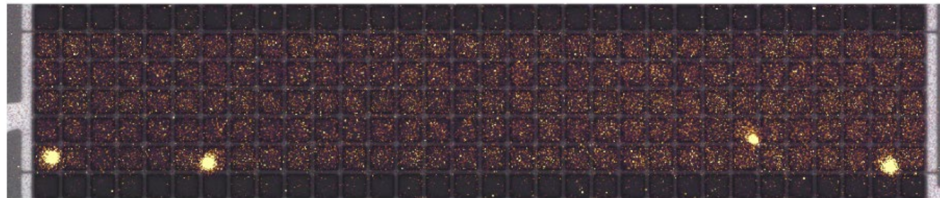
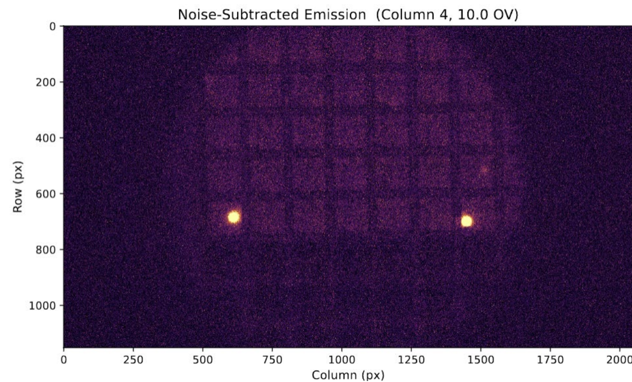
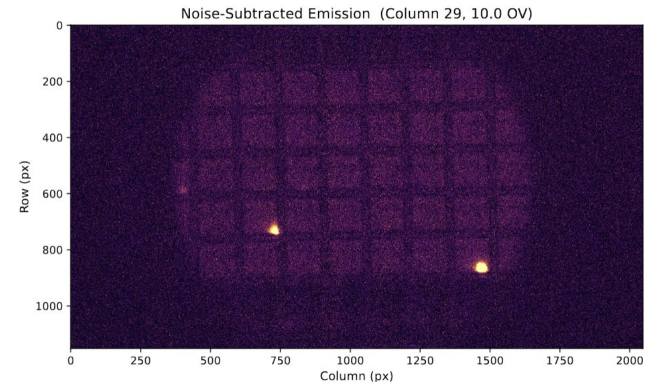
- EMMI for H2024_50um_0neq ch101 at 10.0 OV:







Non-irradiated SiPM

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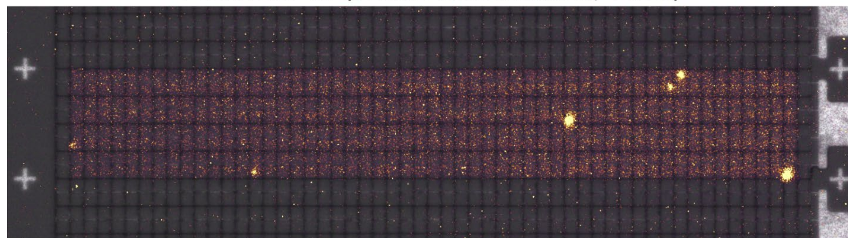
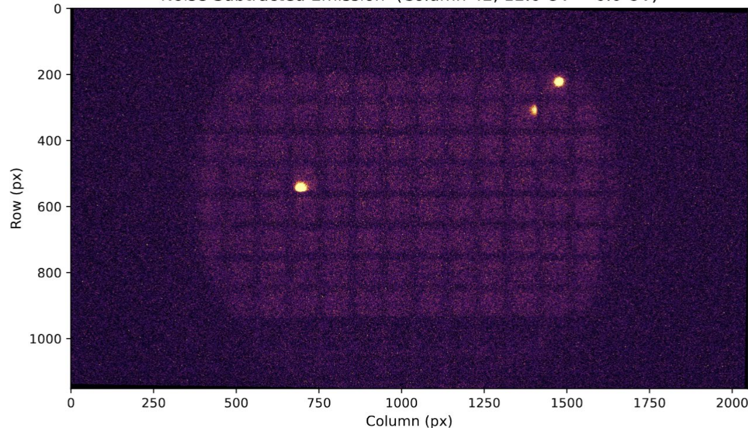
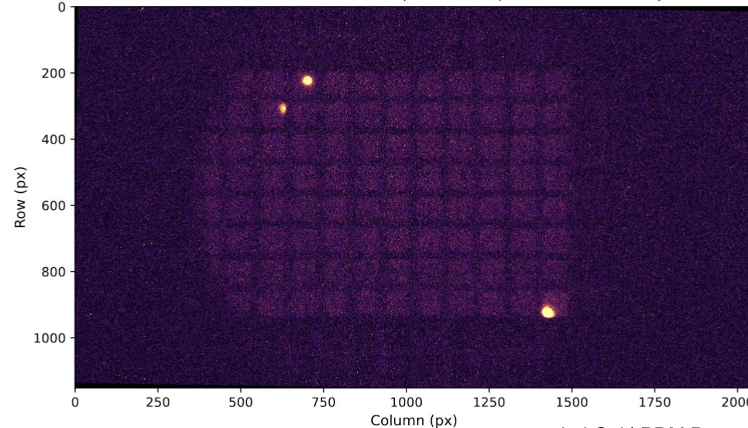
- EMMI for W1m_31um_0neq ch118 at 12.0 OV:







Non-irradiated SiPM

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- Similar behaviour is observed in other SiPM EMMI papers

Characterisation of SiPM Photon Emission in the Dark
https://www.mdpi.com/1424-8220/21/17/5947

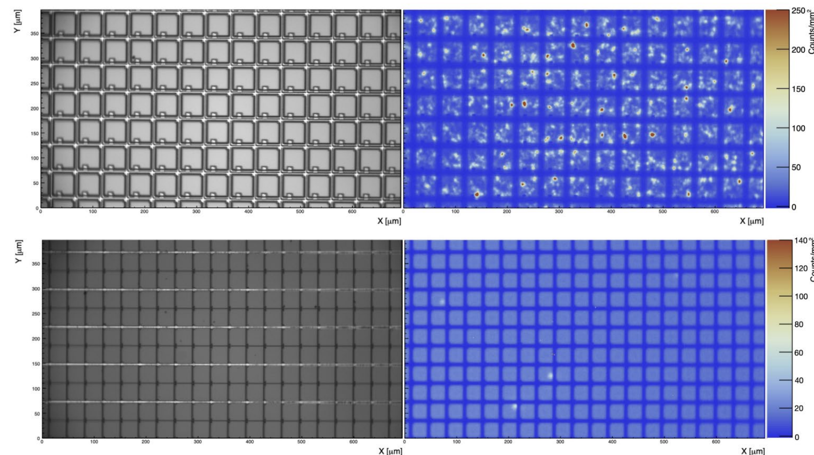

Figure 3. Top row: Emission microscopy image (EMMI) of the HPK VUV4 biased at 11.2 ± 1.0 V of over voltage. Bottom row: EMMI of FBK VUV-HD3 biased at 13 ± 1 V of over voltage. Both EMMIs were taken with the same camera exposure time and objective lens: LMPLFLN20X ($20\times$ magnification).

Spatially resolved dark count rate of SiPMs
https://link.springer.com/article/10.1140/epjc/s10052-018-6454-0

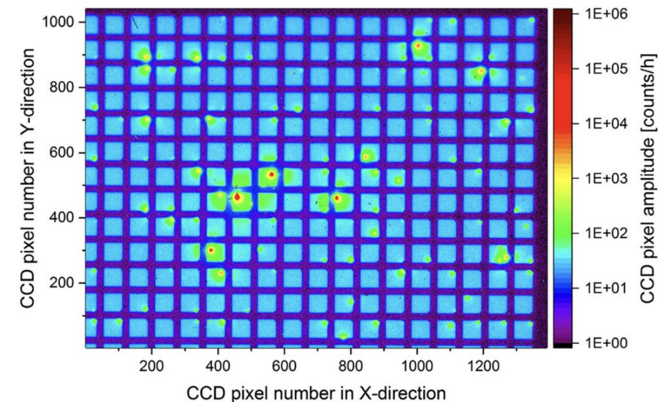

Fig. 1 Light emission image of the PM3350T STD at $t_{exp} = 4$ h and $\Delta V = 5.4$ V. Active areas of single micro-cells (blue) and hotspots within the micro-cells (red) are clearly visible. One CCD pixel corresponds to $0.42\ \mu\text{m}^2$ of the SiPM area

Non-irradiated SiPM

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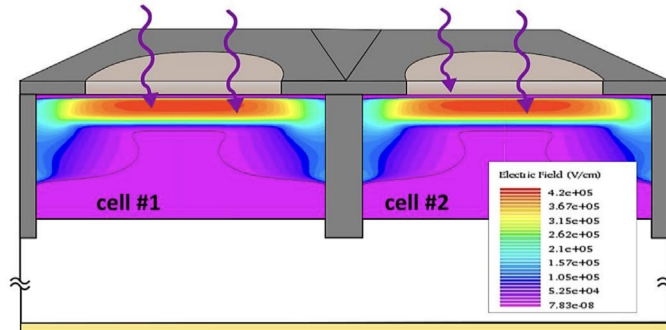
- But non of them give a good explanation in why this is the case

- Guesses:
    1. During the etching of the trenches, damage is caused to the silicon crystal lattice at the trench walls, leaving crystal defects
    2. At high OV, trenches are no longer effective in isolating the electric fields, creating extremely high field regions
    3. The sharp cutoff at trench walls introduce curved and crowded field lines, creating high local fields



Irradiated SiPMs

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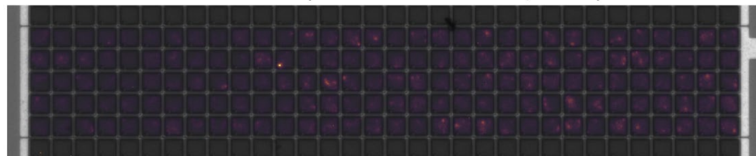
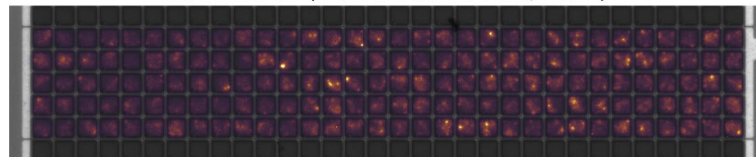
- EMMI for H2024_50um_1e12neq ch118 at various OV:

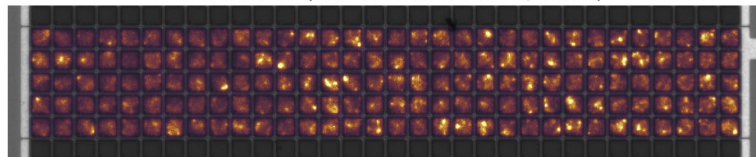
EMMI Image at 1.0 OV
Zoomed-In (Noise-Subtracted, Pure)



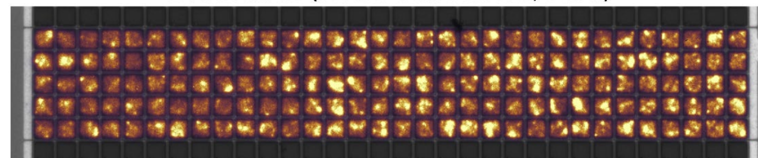
EMMI Image at 1.5 OV
Zoomed-In (Noise-Subtracted, Pure)



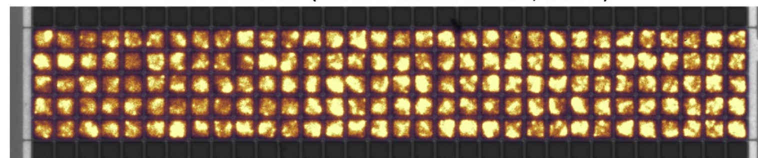
EMMI Image at 2.0 OV
Zoomed-In (Noise-Subtracted, Pure)

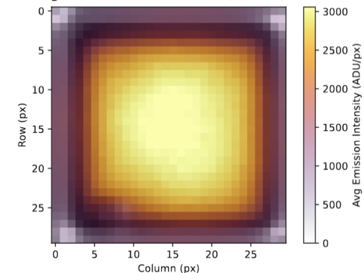


EMMI Image at 2.5 OV
Zoomed-In (Noise-Subtracted, Pure)



EMMI Image at 3.0 OV
Zoomed-In (Noise-Subtracted, Pure)





Irradiated SiPMs

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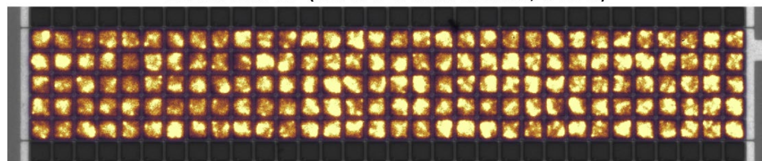
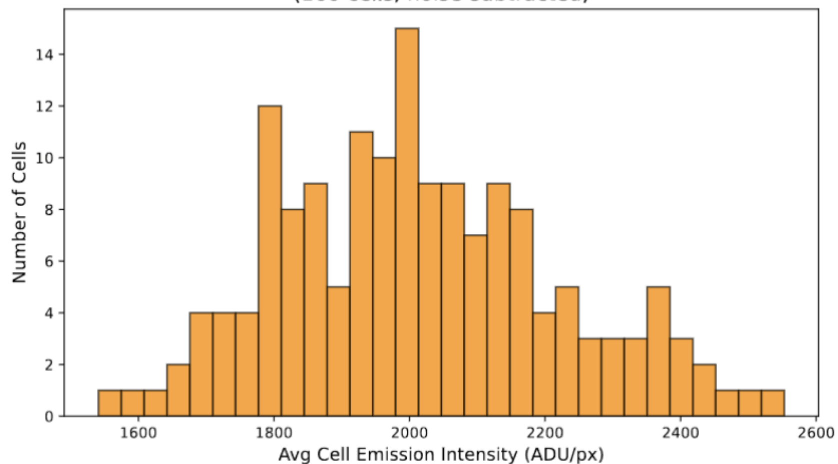
- For 3.0 OV, the cell intensity is normally distributed





Irradiated SiPMs

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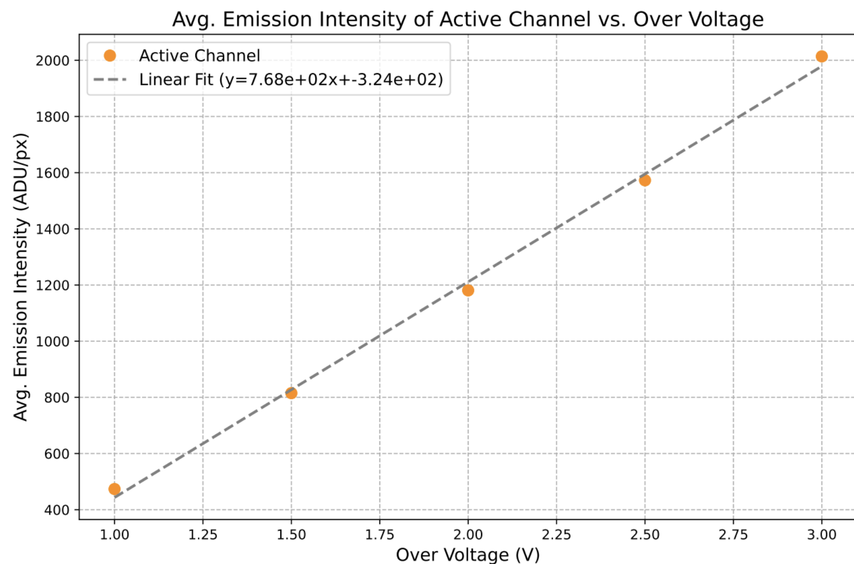
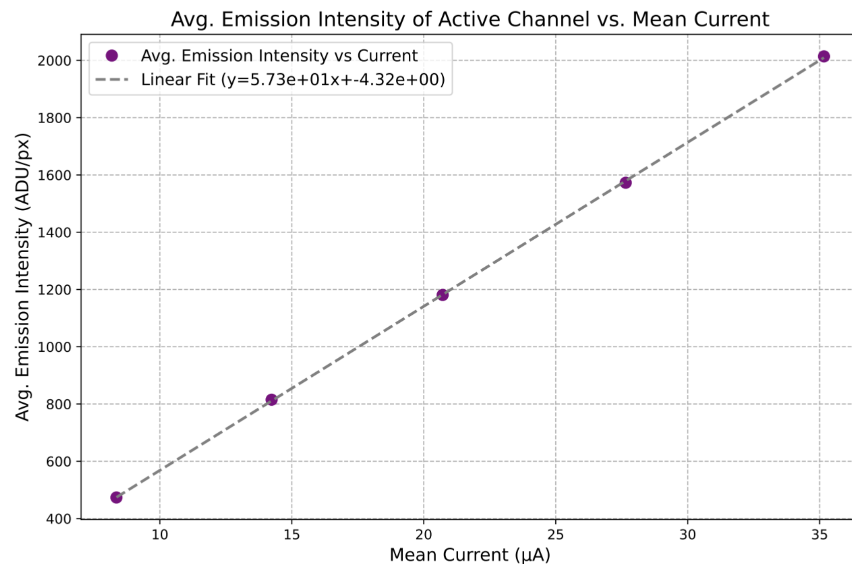
- For H2024_50um_1e12neq, averaged intensity in the active channel scales linearly with the current





Irradiated SiPMs

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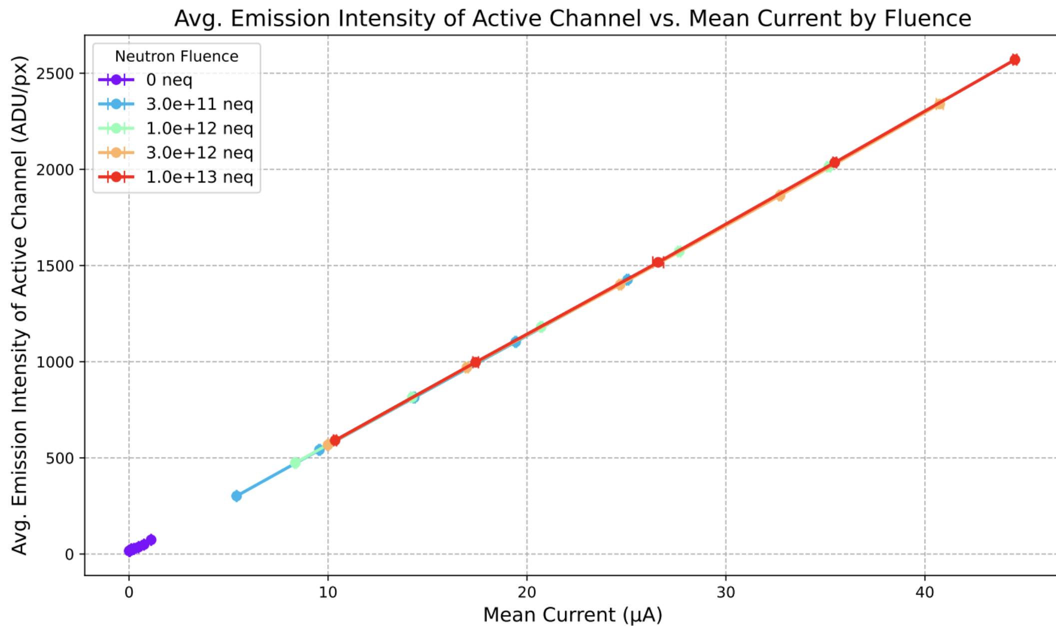
- For H2024_50um, across different fluences, the intensity vs current all sit on the same linear relationship -> DCR / dark current is proportional to emission intensity



Damage Point Analysis

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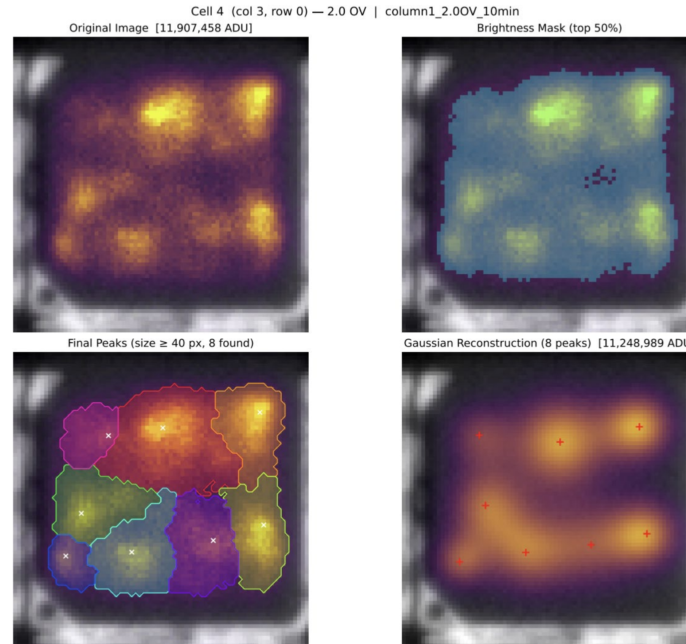
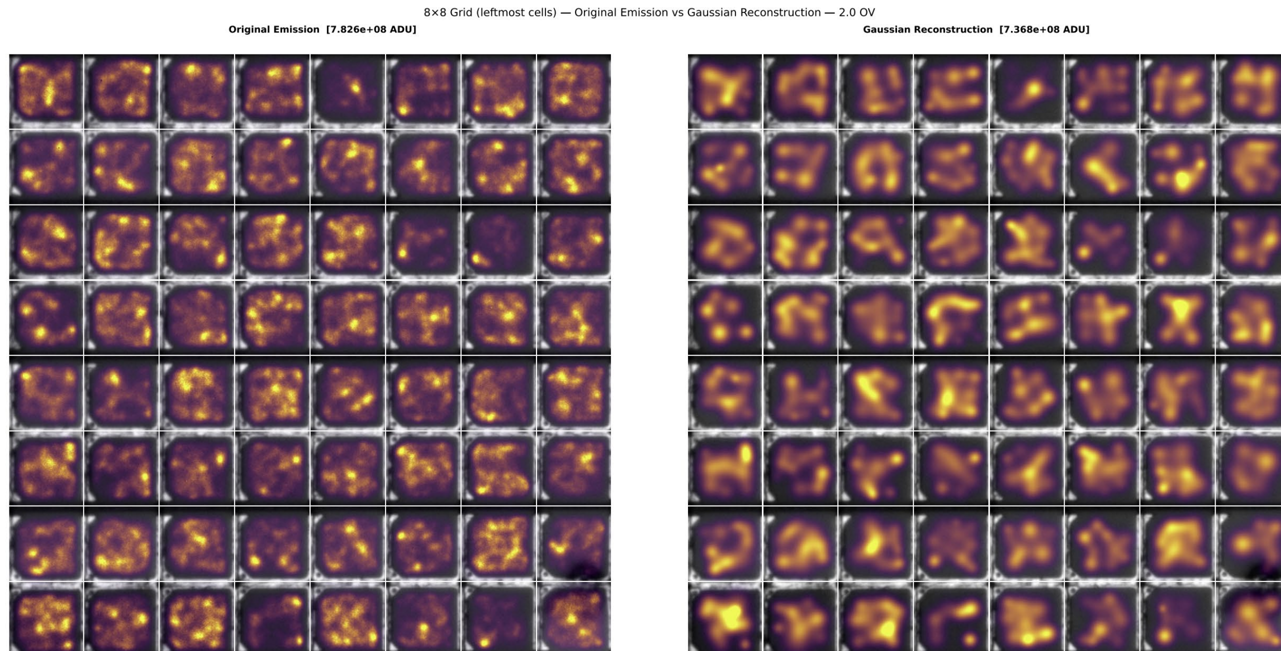
- Using peak-finding and 2D Gaussian reconstruction methods to extract amplitude, sigma, and position information of the damage points



Damage Point Analysis

- Overall aligning well



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Thank you!