

Characterization of irradiated SiPM for the TOP detector at the Belle II experiment

Padova meeting
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Done:

- Irradiated SiPM modules in Padova
- Gain as function of bias voltage
- Gain as function of overvoltage
- Time resolution for first photon peak (Markov and simple) for SiPMs with recognized spectra
- Time resolution for all photon peaks using SiPMs with unrecognized spectra

To Do:

- Add fitted spectra (one bias voltage ~ 1.0 per temperature per SiPM)
- Check results and provide better fits if needed
- Update table with fitted breakdown voltages with uncertainties
- Time resolution for all photon peaks (Markov and simple) for SiPMs with recognized spectra?
- Time resolution for others than first photon peak (Markov and simple) for SiPMs with recognized spectra?

Tests with irradiated modules in Padova



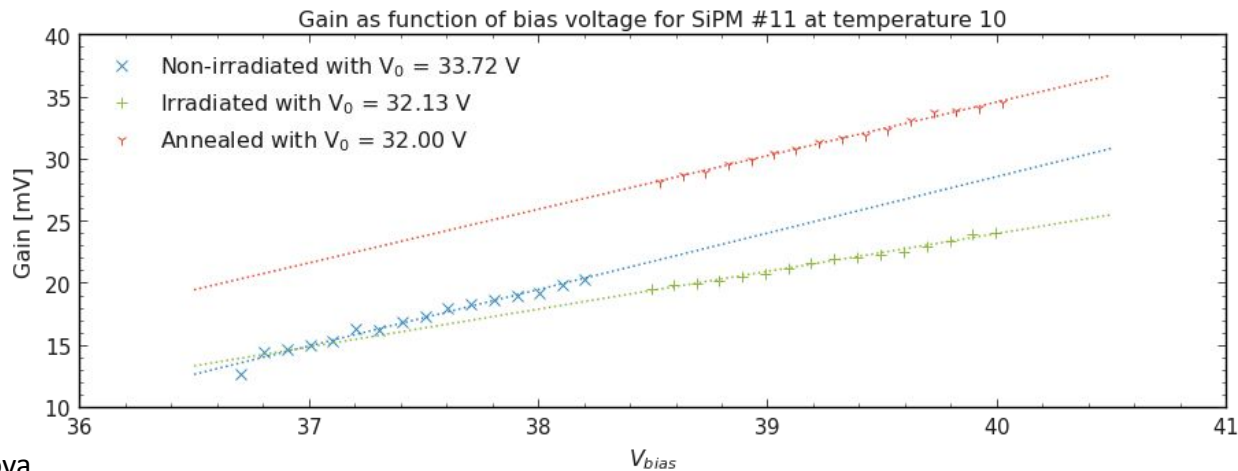
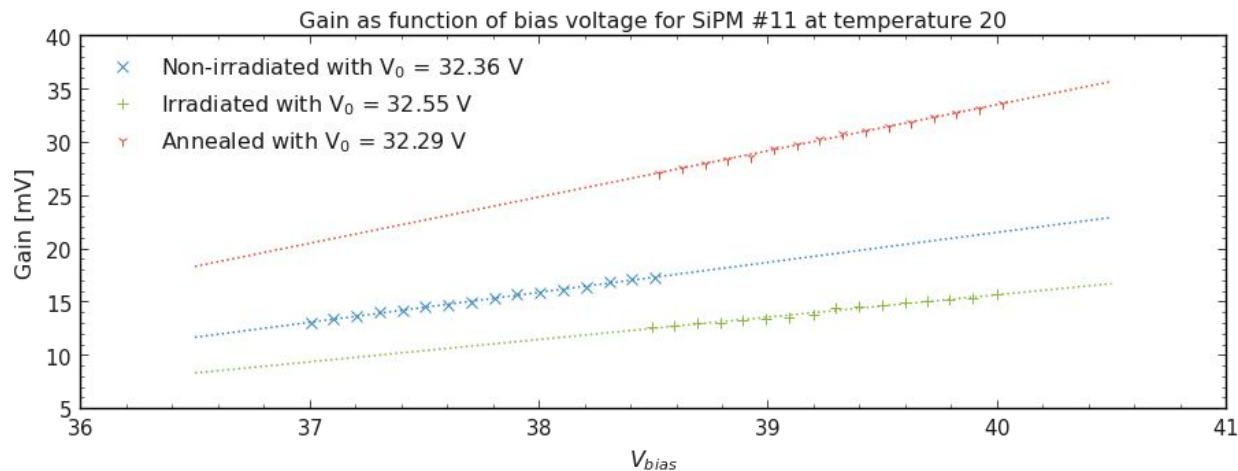
- In Belle II, MCP-PMTs with extended lifetime have been installed and they have limited lifetime depending on accumulated charge.
- We are trying to understand if they eventually can be replaced with SiPMs.
- We irradiated 24 SiPMs modules with different neutron fluxes and tested by laser.
- Eight of them are processed to study their response.
- Collected data are read from modules and analyzed.

Index	Producer	Dimension [mm × mm]	Pitch [μ m]	Distance [cm]	Neutron 1 MeV eg/cm ² fluence	Charge [mC]	Time [h]
8	FBK	3 × 3	15	18.36	1.0 · 10 ¹⁰	2.86	5.88
9	FBK	3 × 3	15	18.24	5.0 · 10 ⁹	1.41	2.90
10	FBK	3 × 3	15	33.24	1.0 · 10 ⁹	0.94	1.93
11	FBK	1 × 1	15	15.86	2.0 · 10 ¹⁰	4.26	8.77
12	FBK	1 × 1	15	30.86	1.0 · 10 ¹⁰	8.07	16.61
13	FBK	1 × 1	15	15.74	5.0 · 10 ⁹	1.05	2.16
14	FBK	1 × 1	15	30.74	1.0 · 10 ⁹	0.80	1.65
15	Hamamatsu	3 × 3	50	33.46	1.0 · 10 ⁹	0.95	1.95

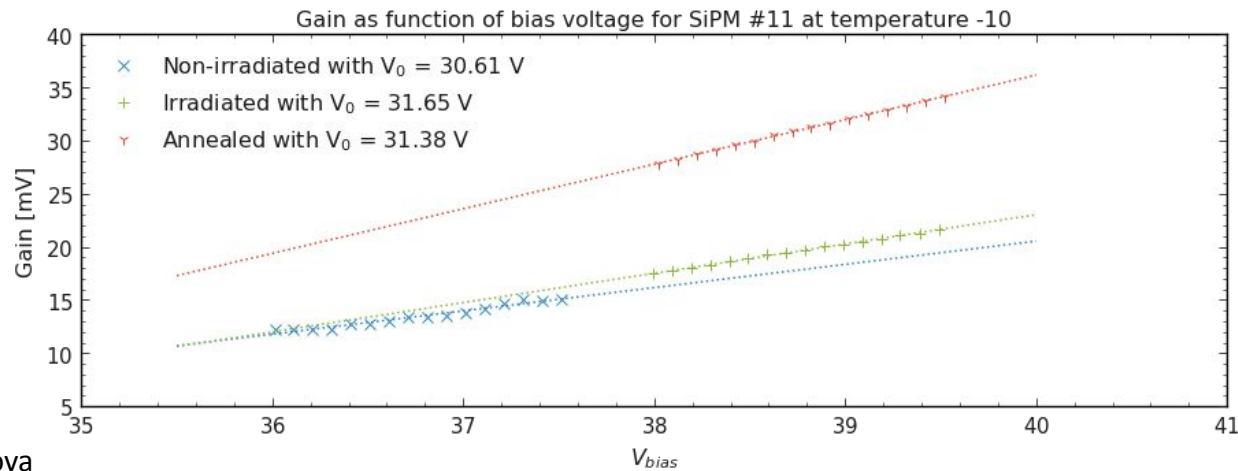
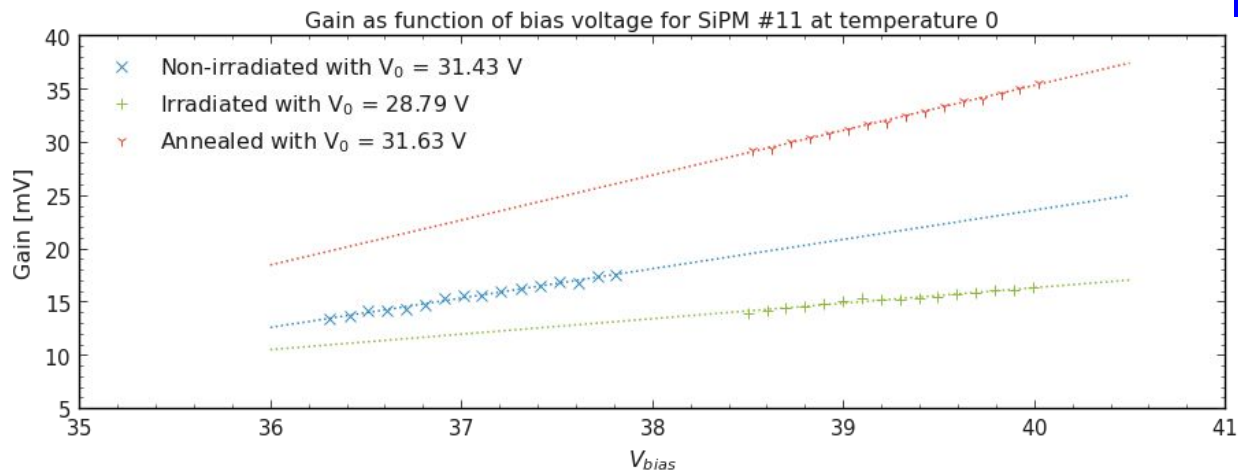
SIMP #11

Gain as function of bias voltage for SiPM #11

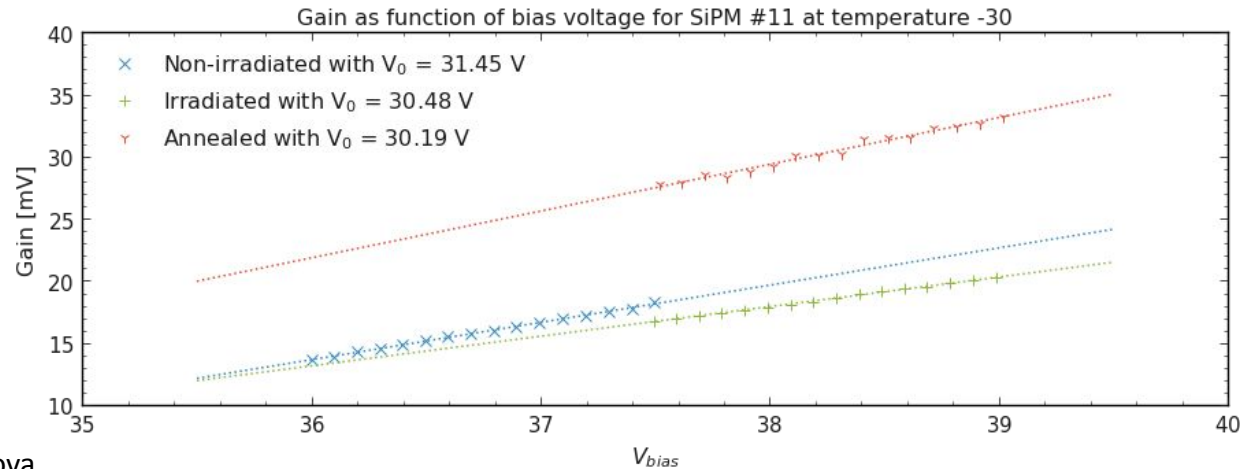
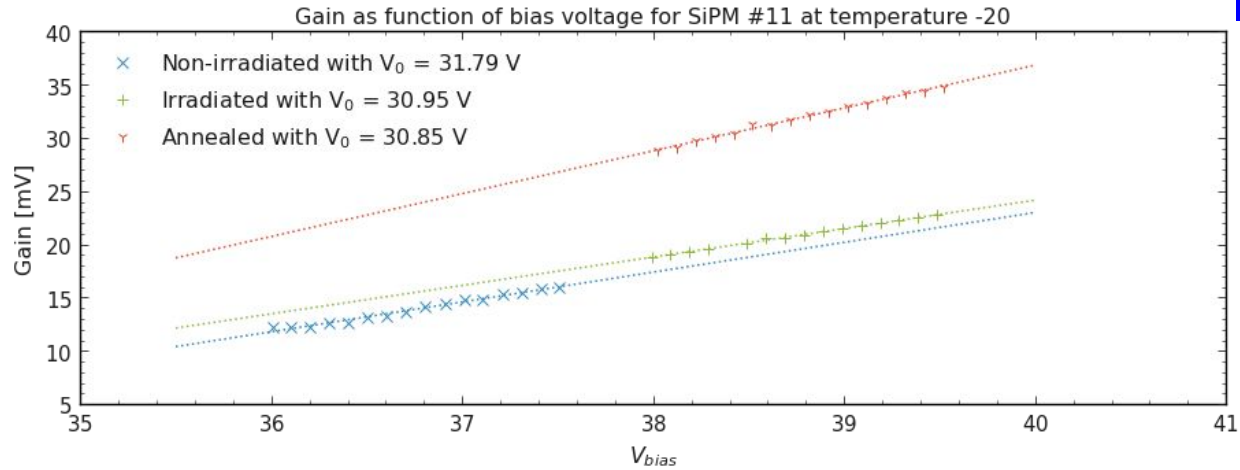
Gain as function of bias voltage



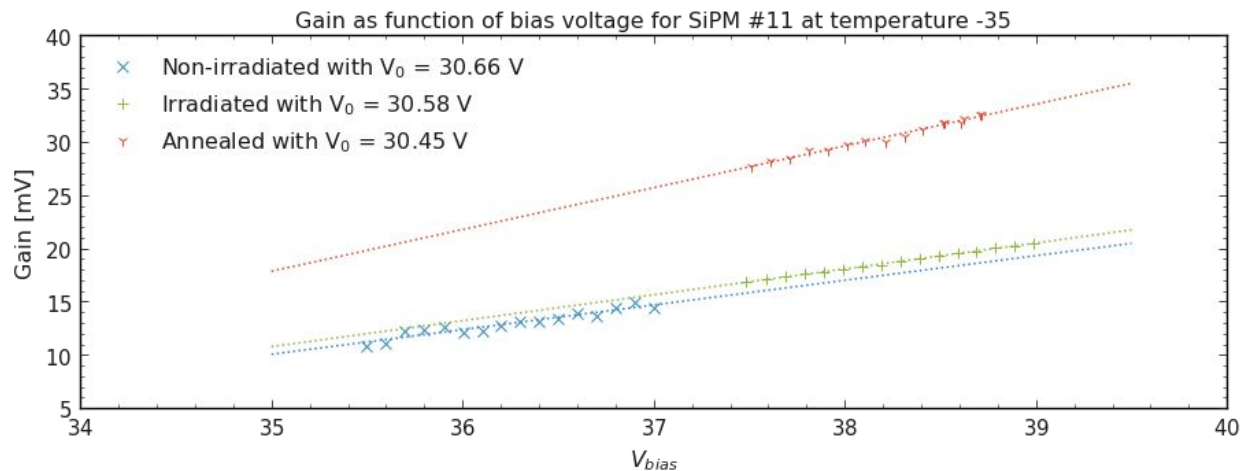
Gain as function of bias voltage



Gain as function of bias voltage

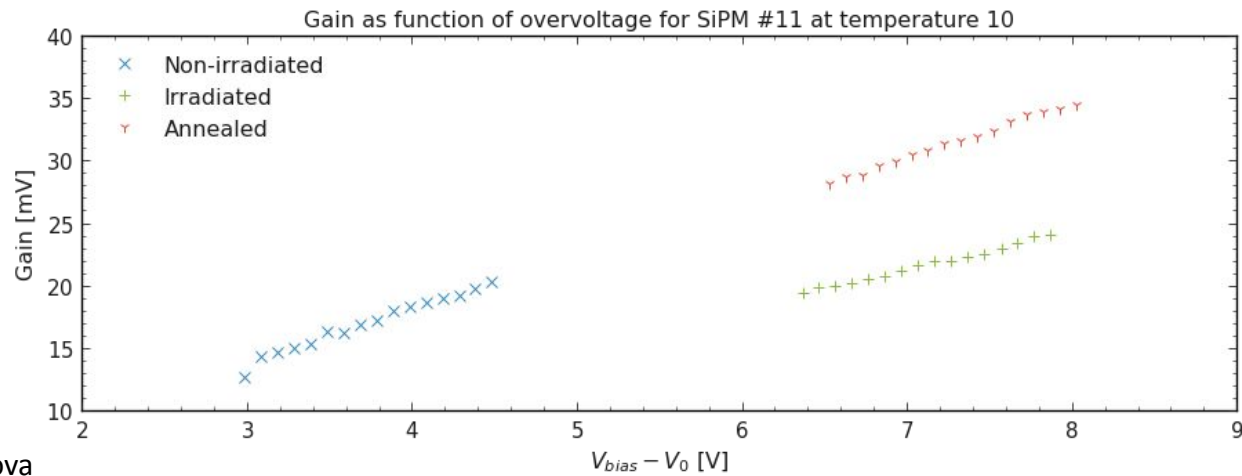
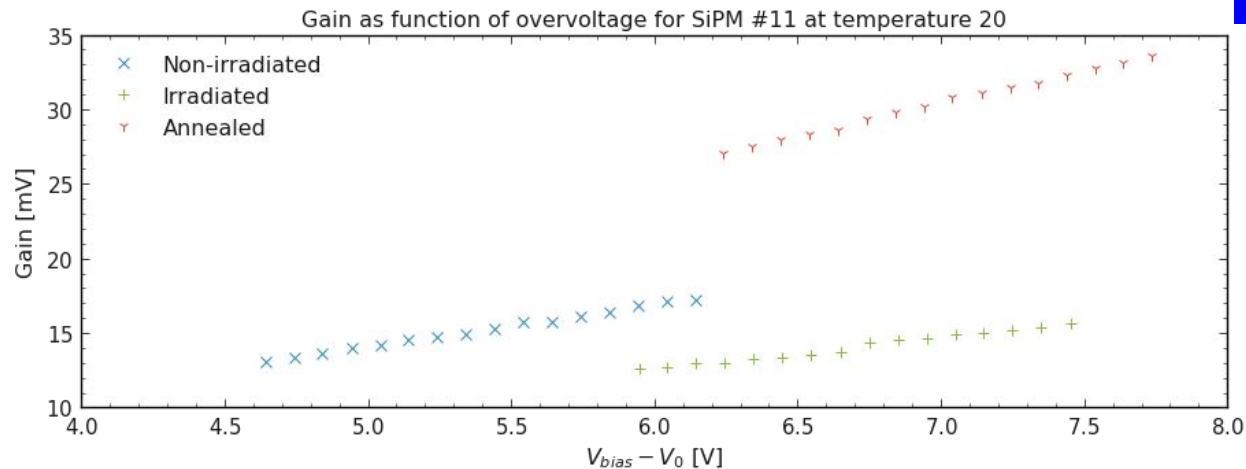


Gain as function of bias voltage

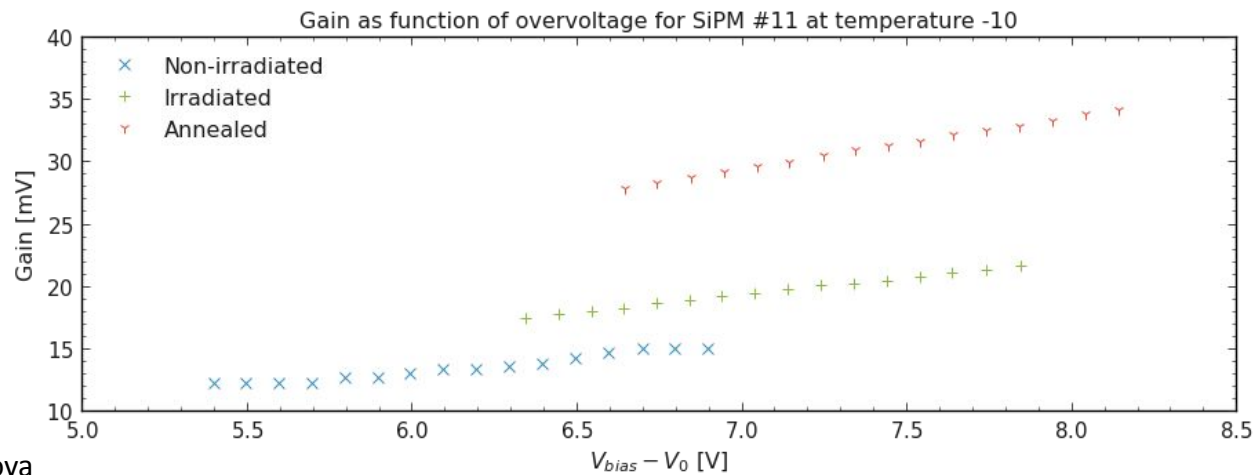
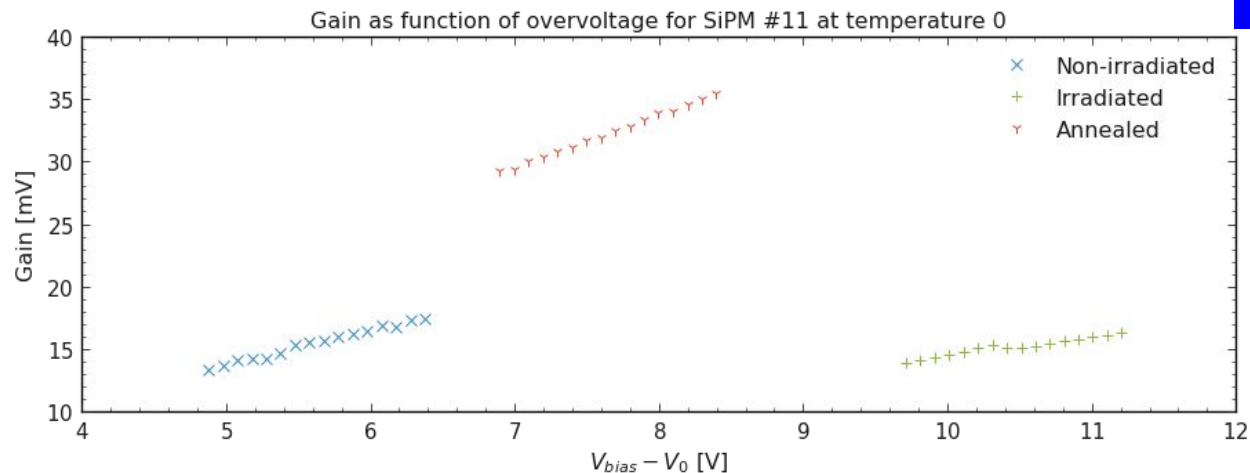


Gain as function of overvoltage for SiPM #11

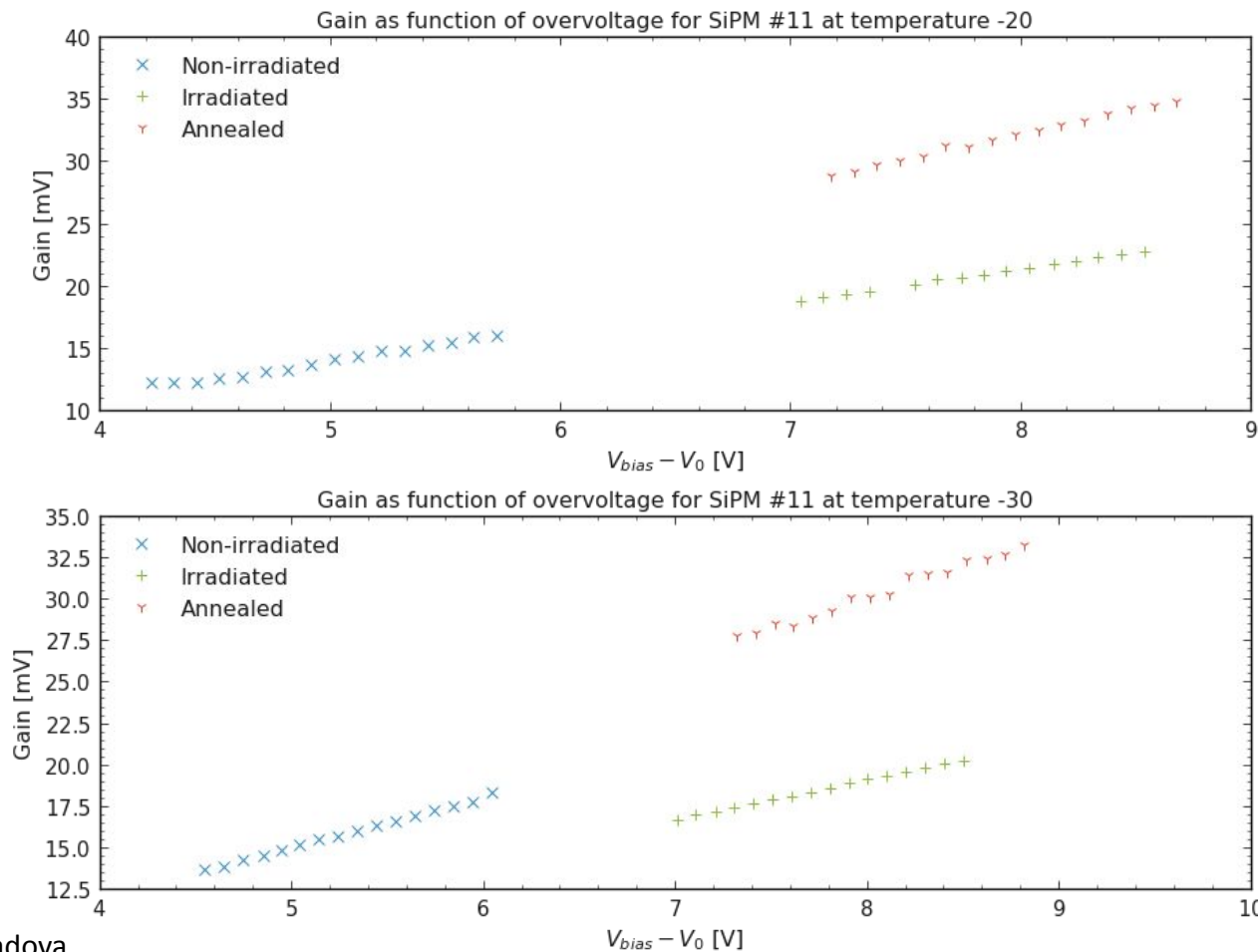
Gain as function of overvoltage



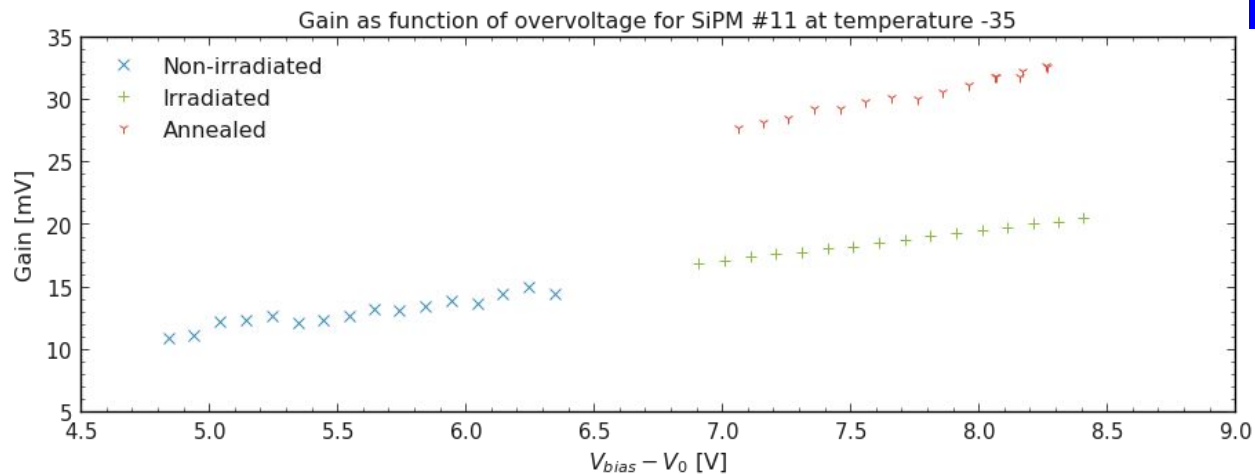
Gain as function of overvoltage



Gain as function of overvoltage



Gain as function of overvoltage

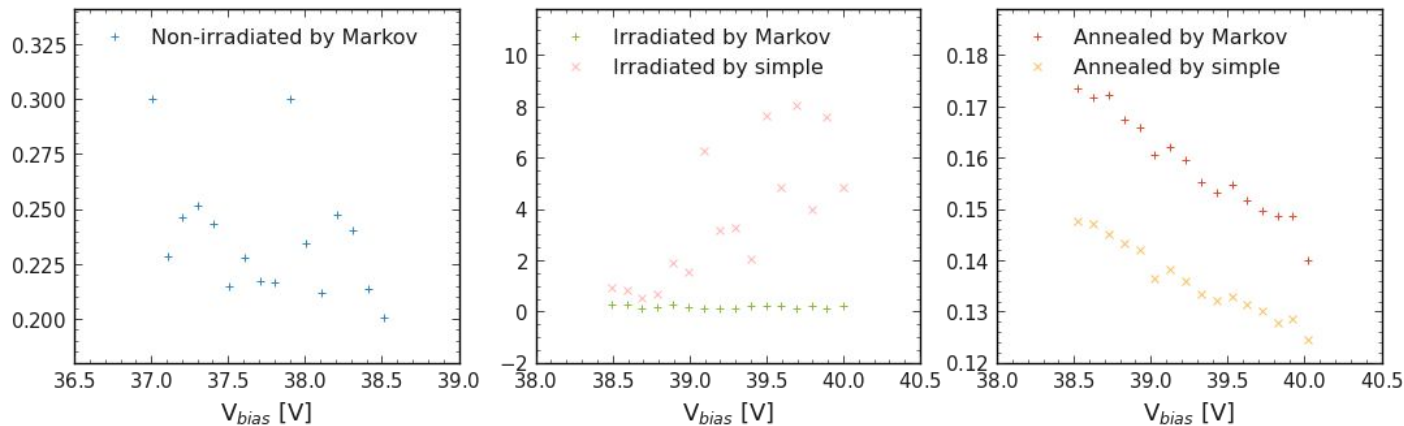


Time resolution for first photon peak for SiPM #11

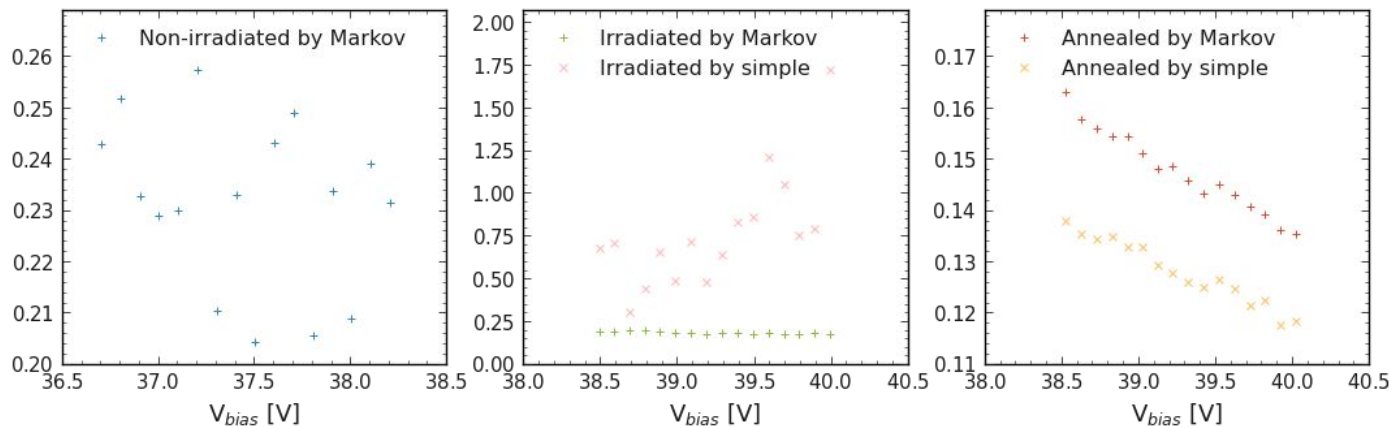
Time resolution for first photon peak



Time resolution of first peak for SiPM #11 at 20°



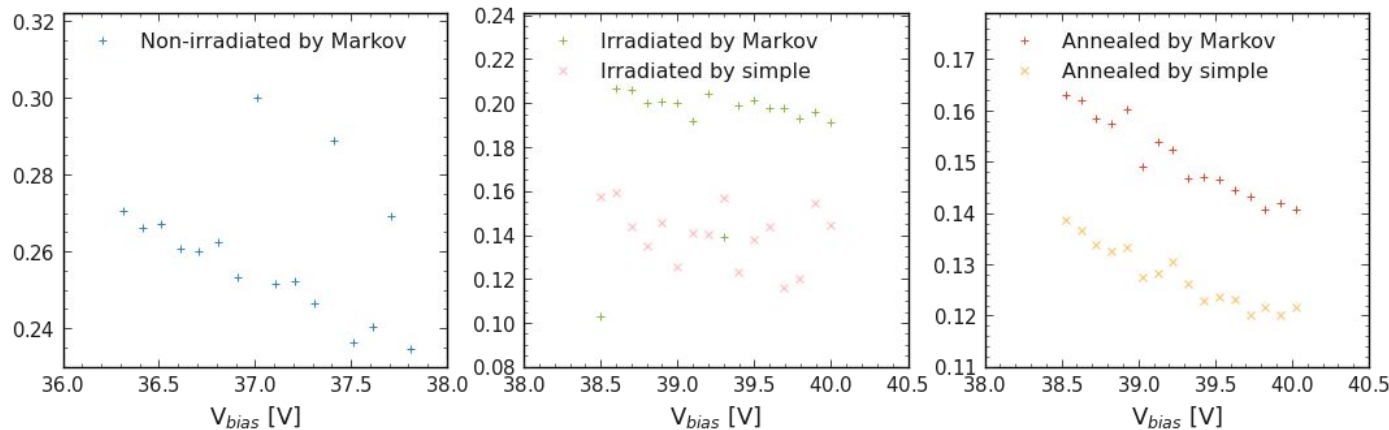
Time resolution of first peak for SiPM #11 at 10°



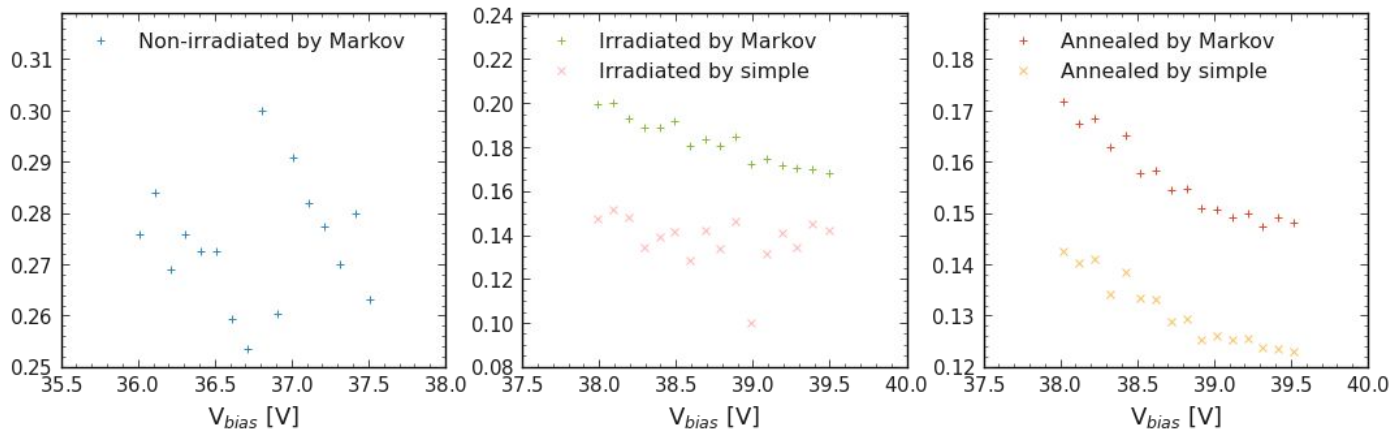
Time resolution for first photon peak



Time resolution of first peak for SiPM #11 at 0°



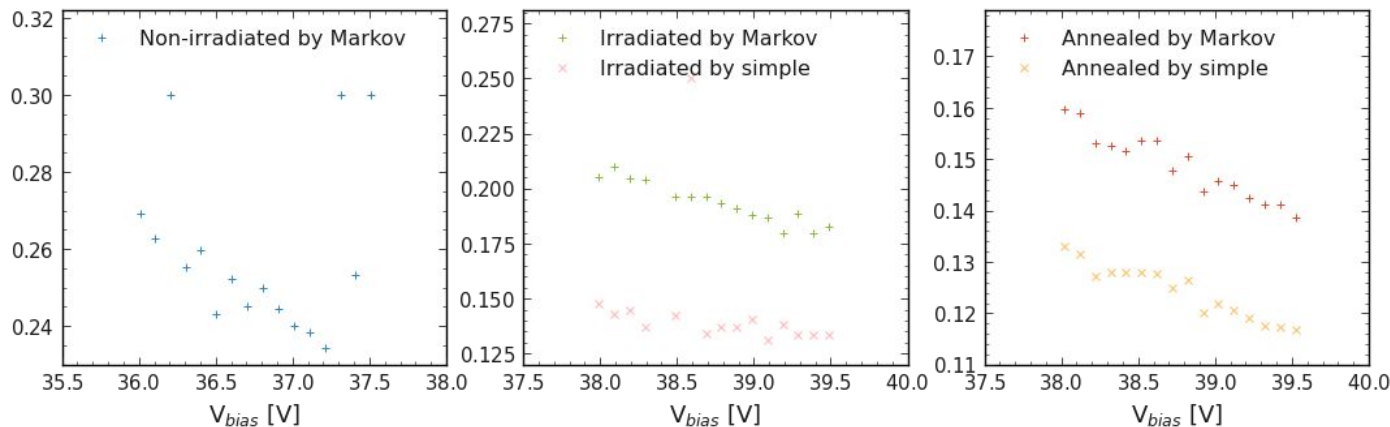
Time resolution of first peak for SiPM #11 at -10°



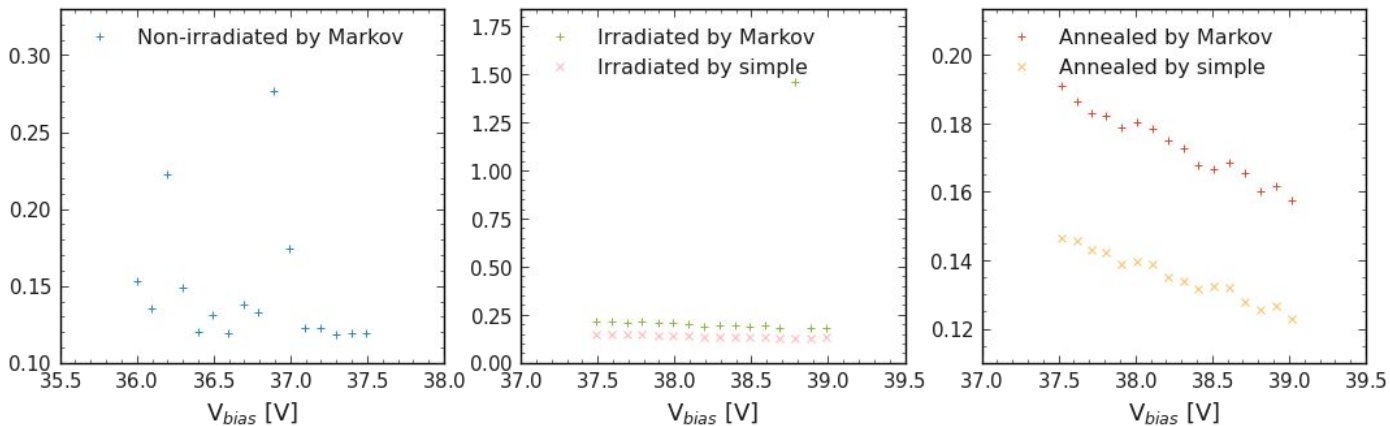
Time resolution for first photon peak



Time resolution of first peak for SiPM #11 at -20°



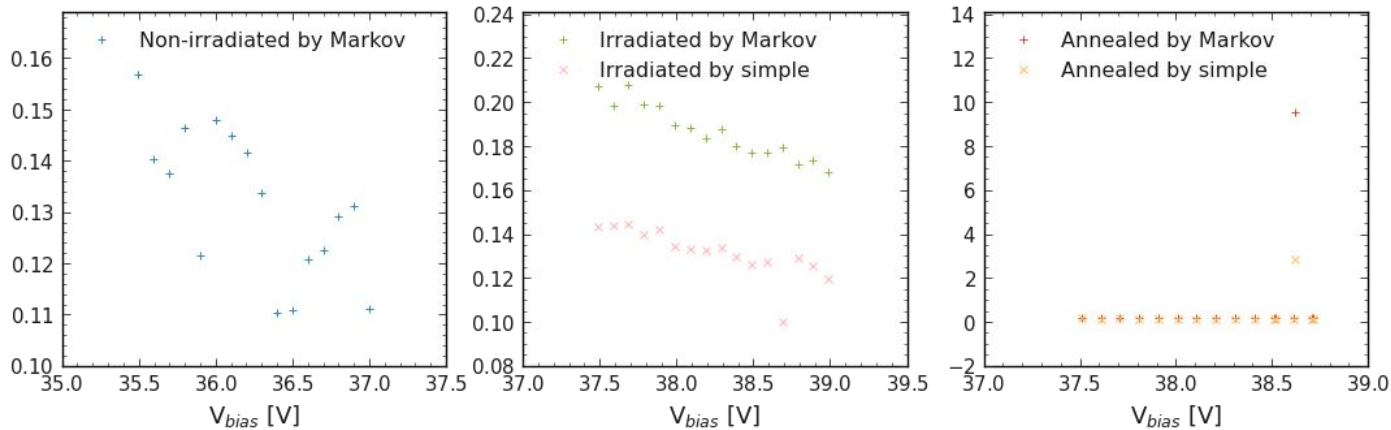
Time resolution of first peak for SiPM #11 at -30°



Time resolution for first photon peak



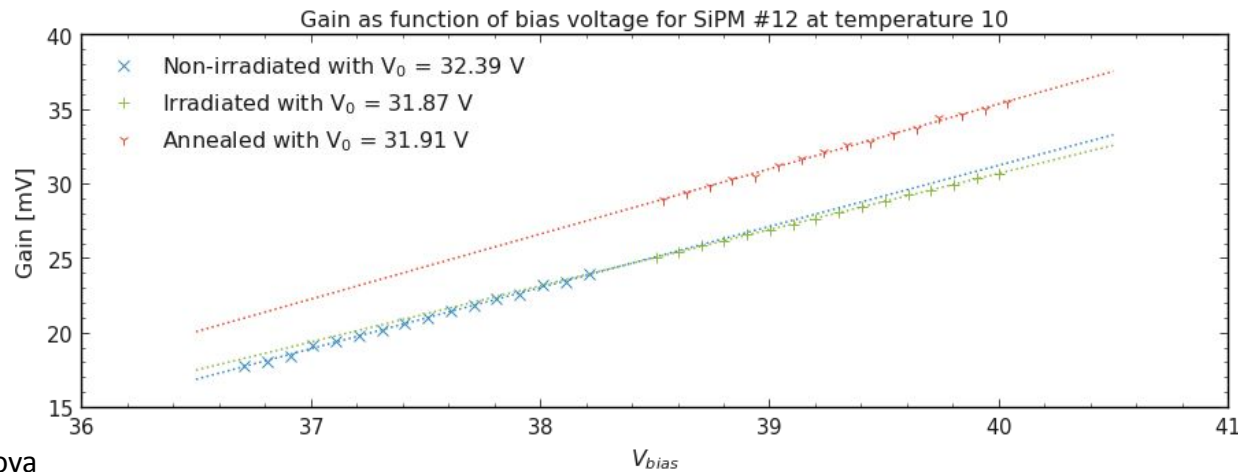
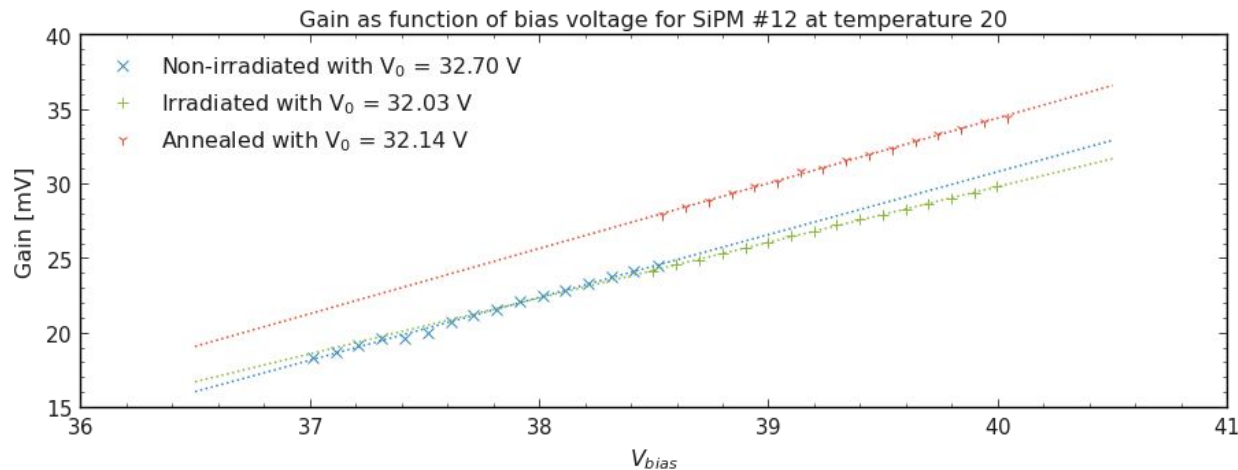
Time resolution of first peak for SiPM #11 at -35°



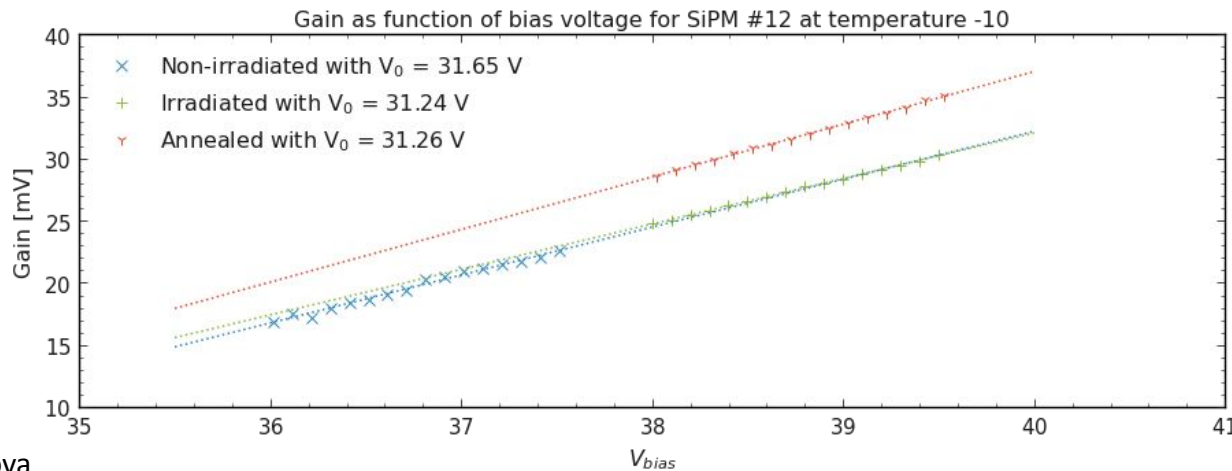
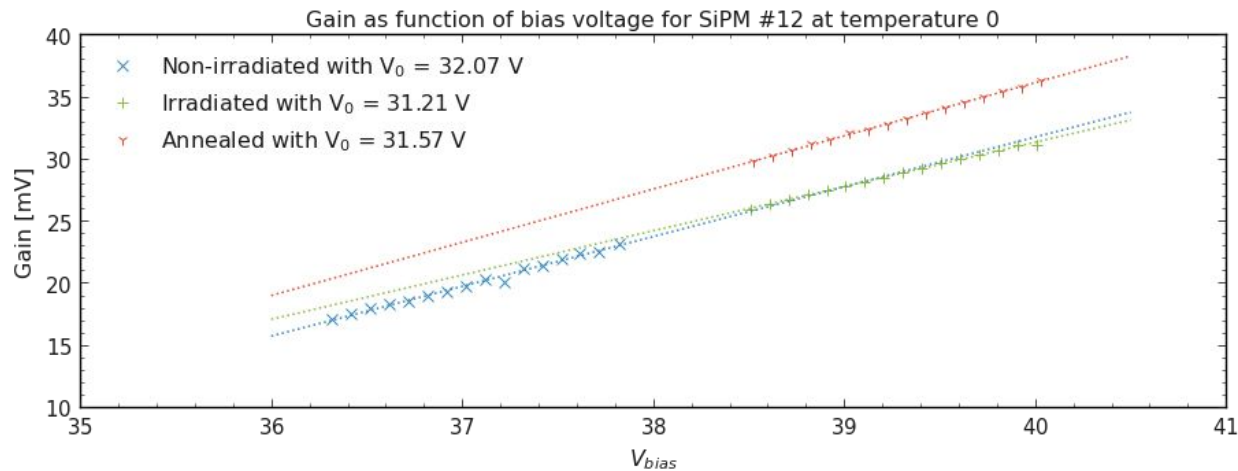
SiMP #12

Gain as function of bias voltage for SiPM #12

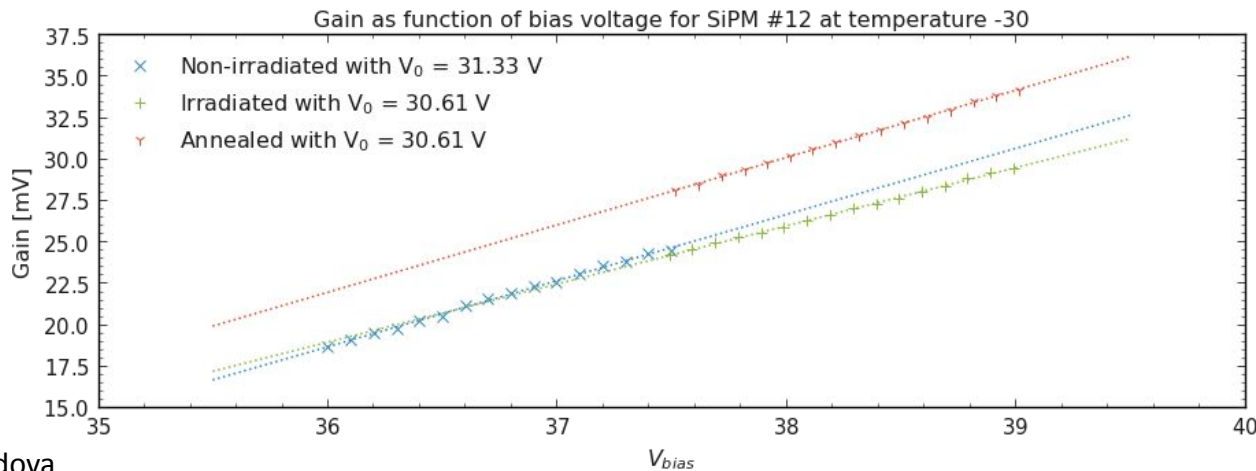
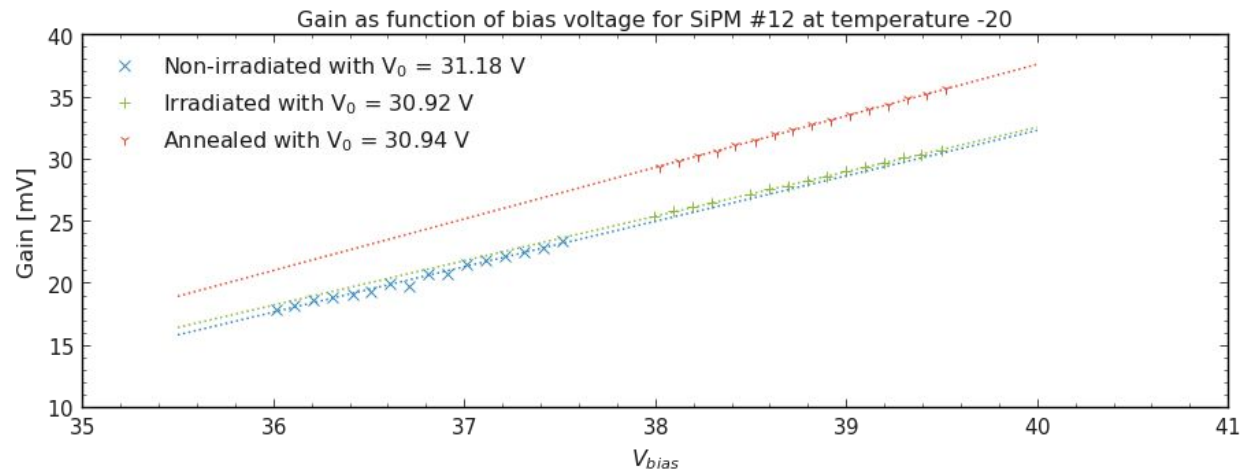
Gain as function of bias voltage



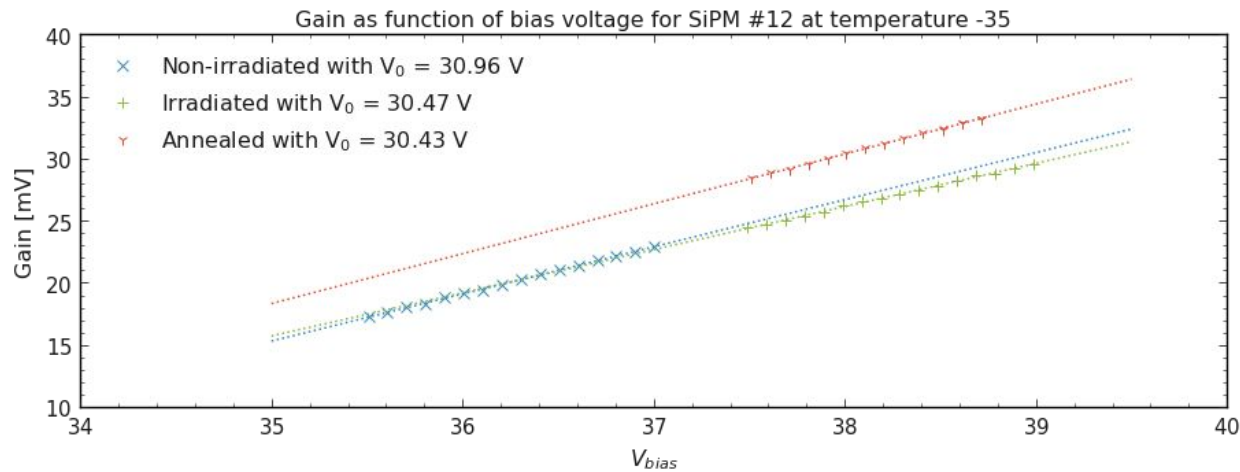
Gain as function of bias voltage



Gain as function of bias voltage

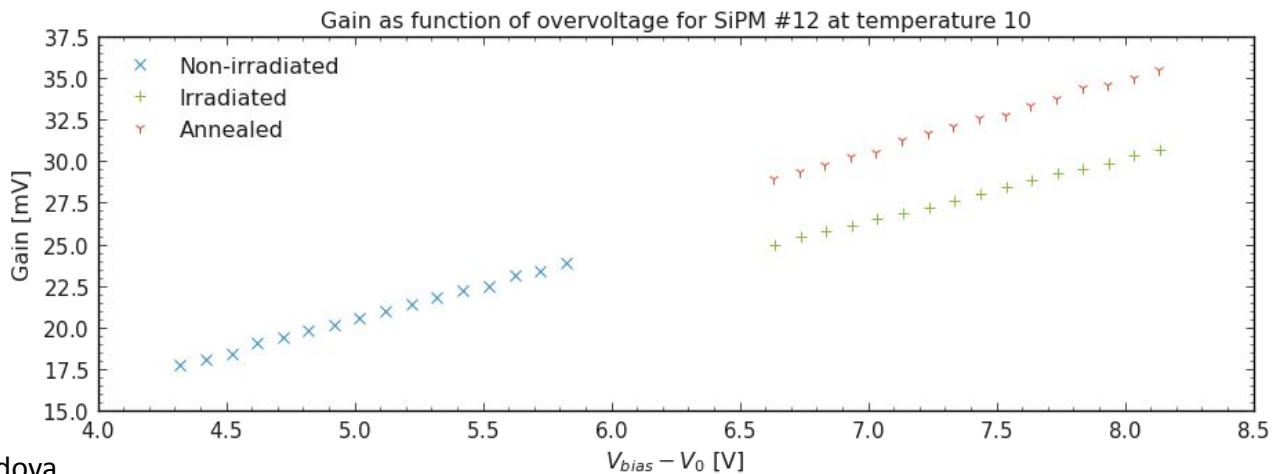
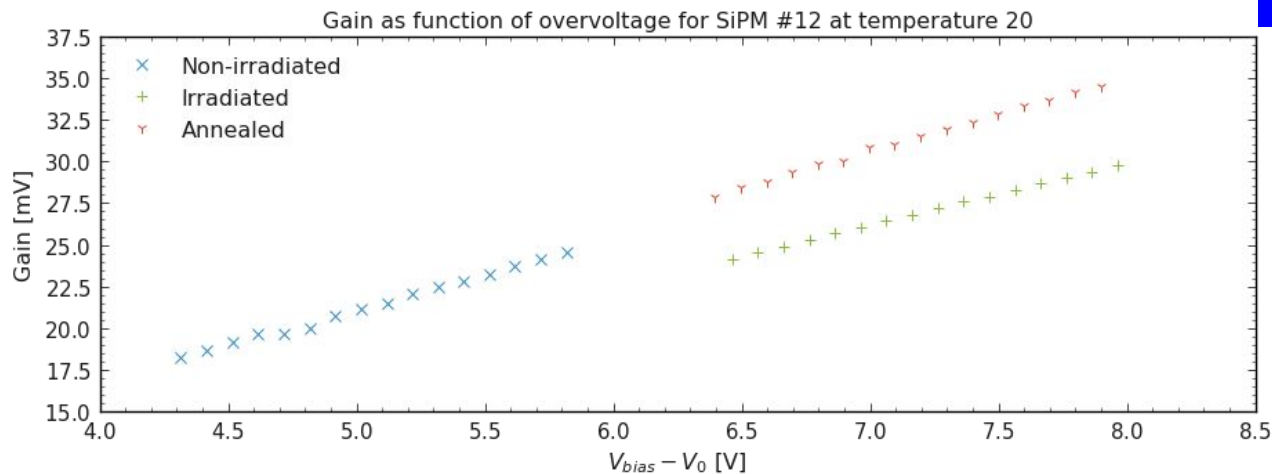


Gain as function of bias voltage

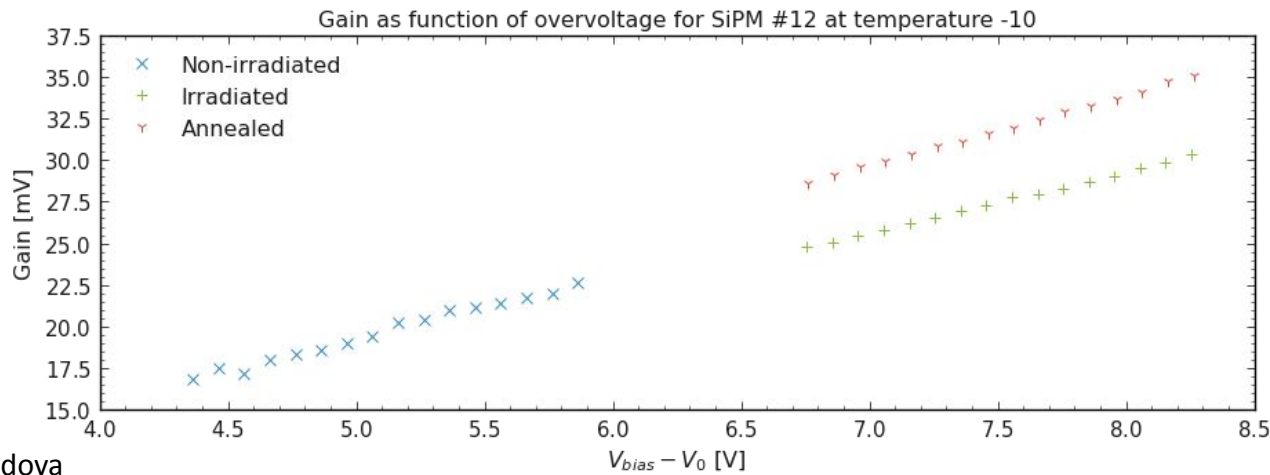
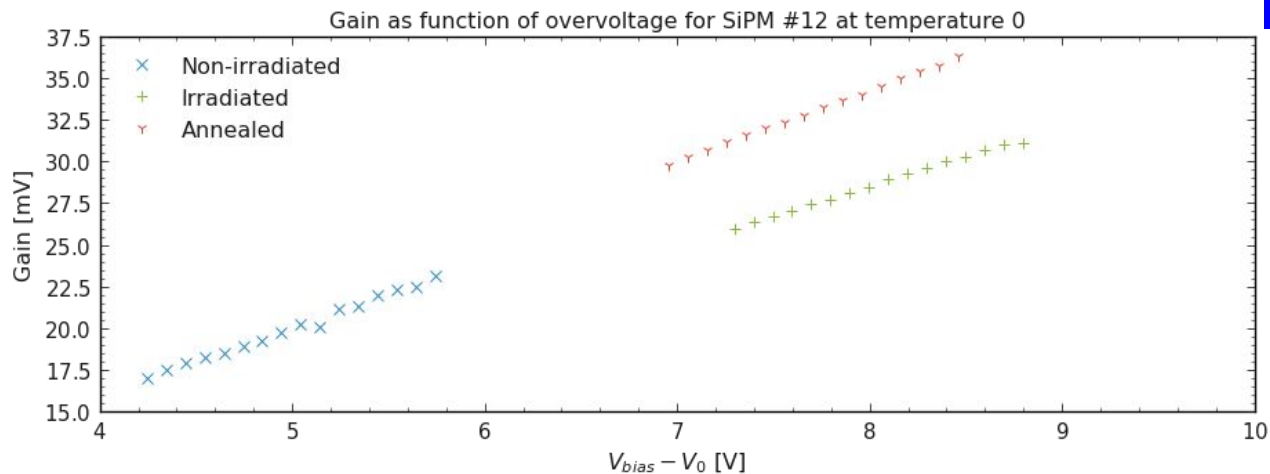


Gain as function of overvoltage for SiPM #12

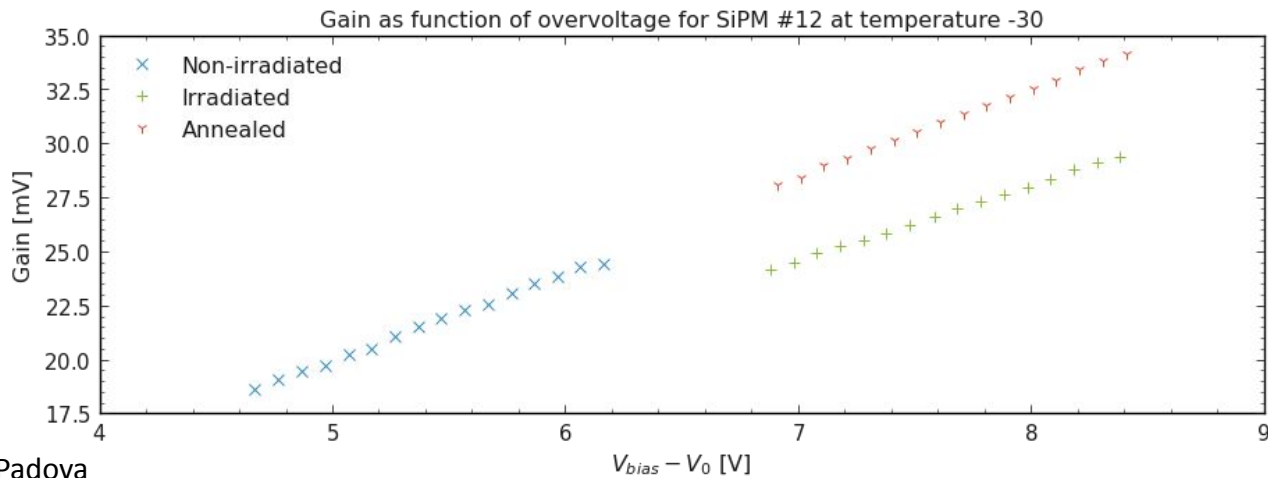
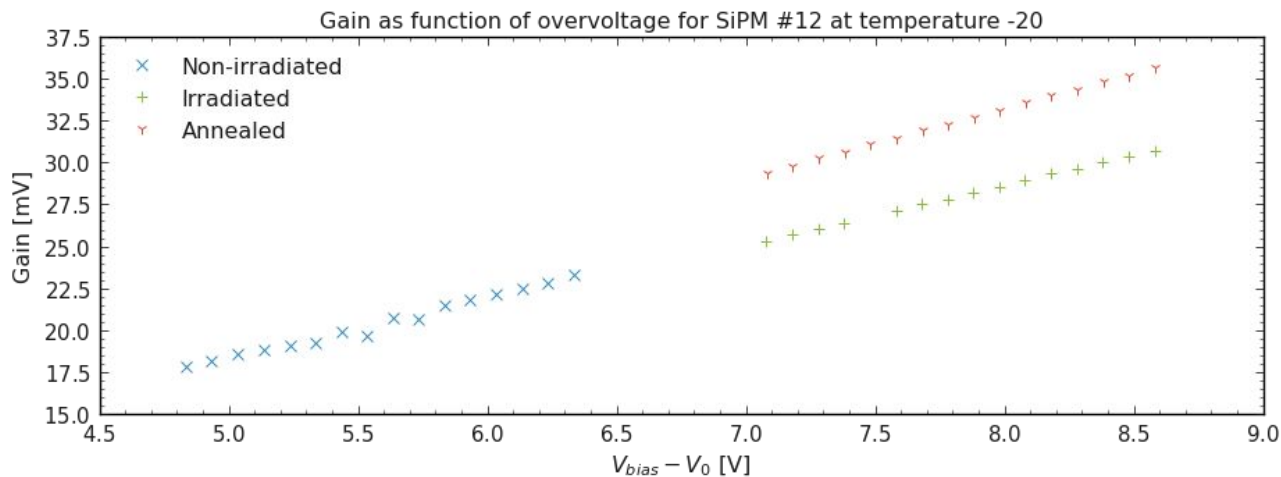
Gain as function of overvoltage



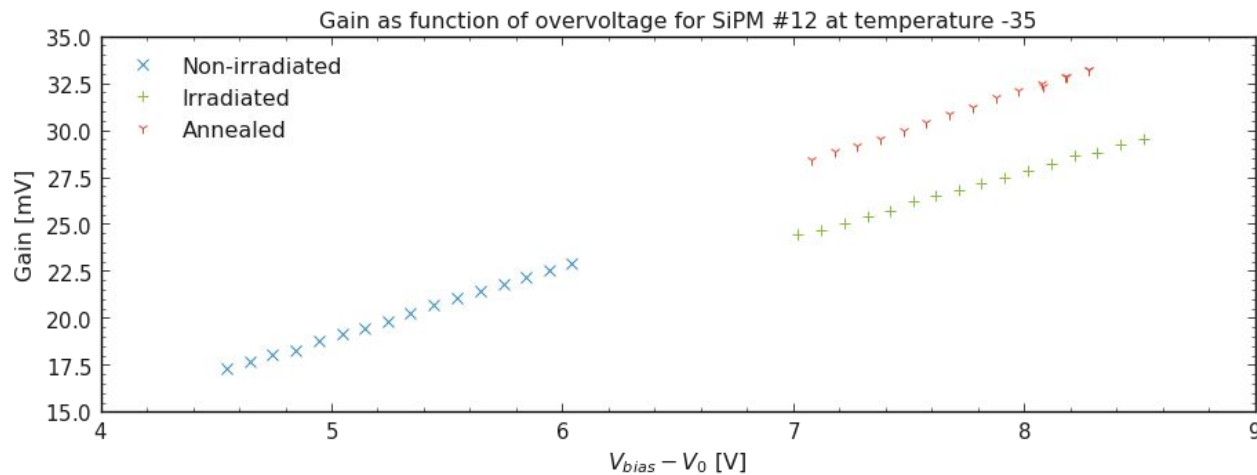
Gain as function of overvoltage



Gain as function of overvoltage



Gain as function of overvoltage

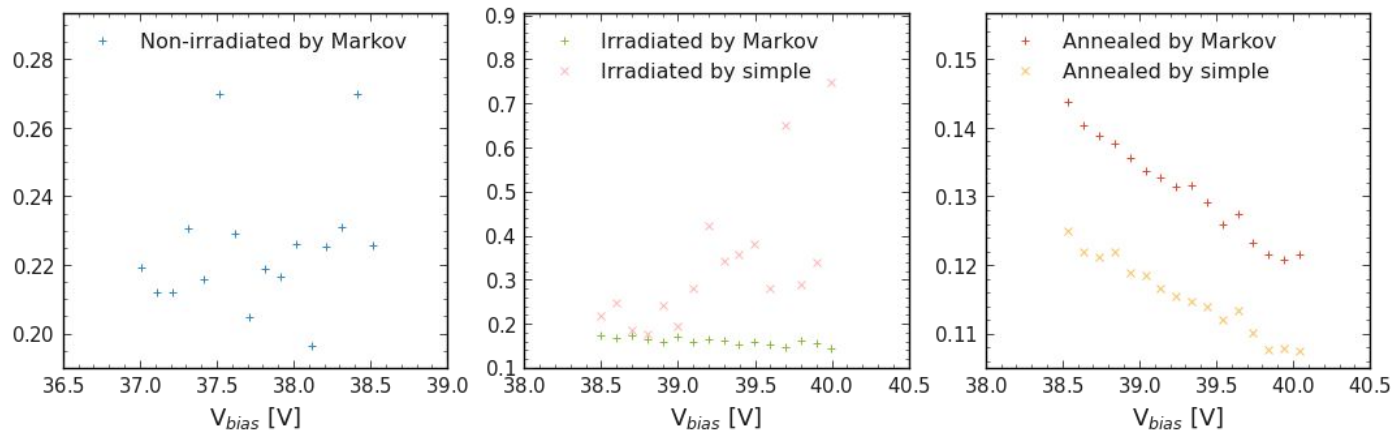


Time resolution for first photon peak for SiPM #12

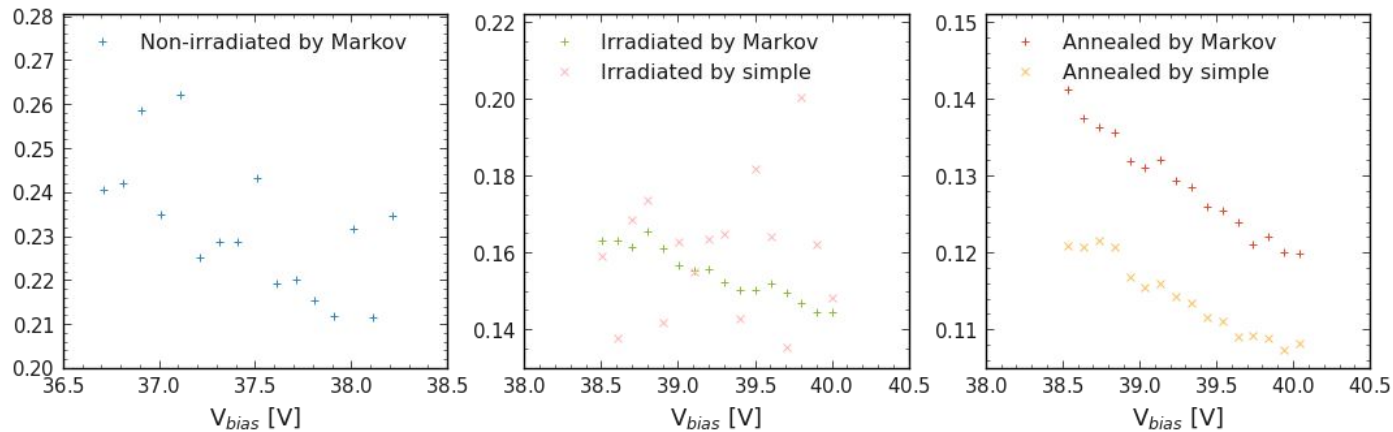
Time resolution for first photon peak



Time resolution of first peak for SiPM #12 at 20°



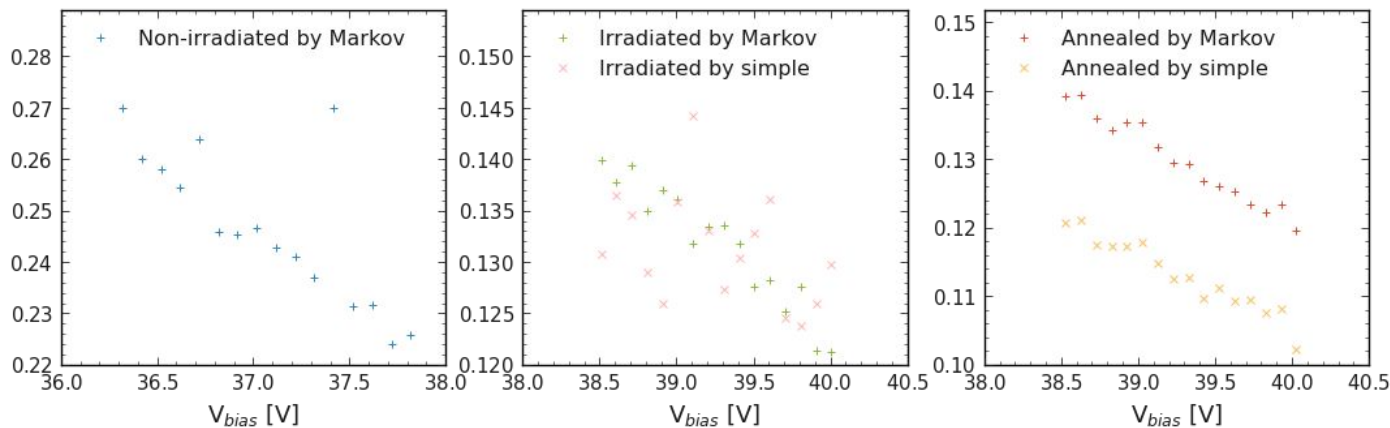
Time resolution of first peak for SiPM #12 at 10°



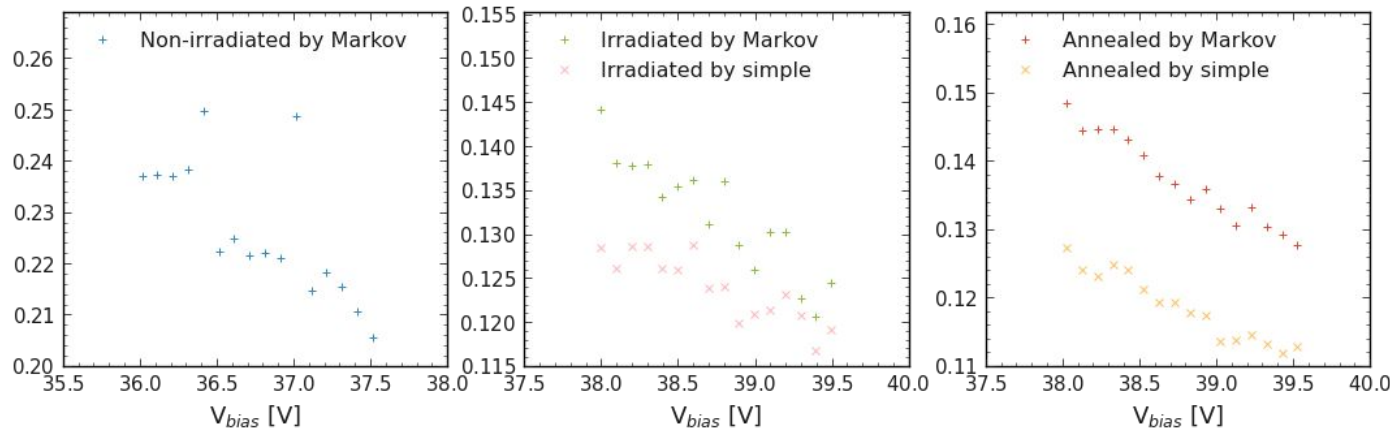
Time resolution for first photon peak



Time resolution of first peak for SiPM #12 at 0°



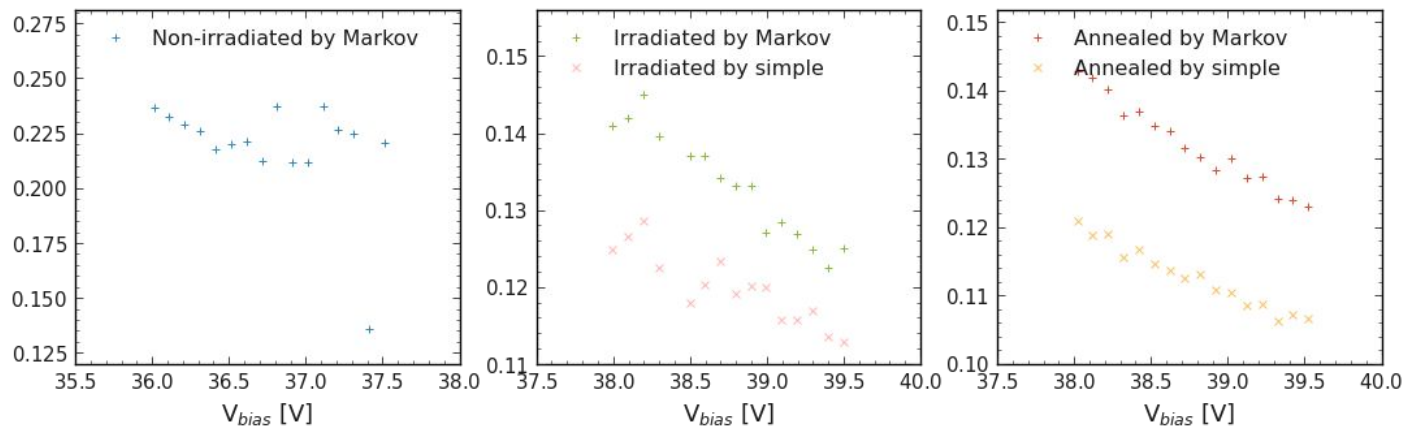
Time resolution of first peak for SiPM #12 at -10°



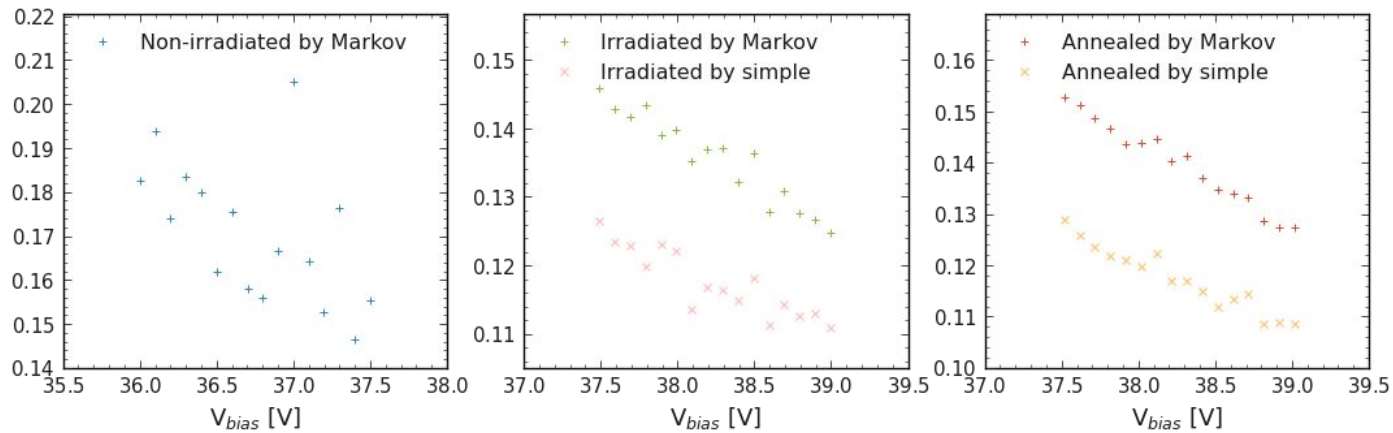
Time resolution for first photon peak



Time resolution of first peak for SiPM #12 at -20°



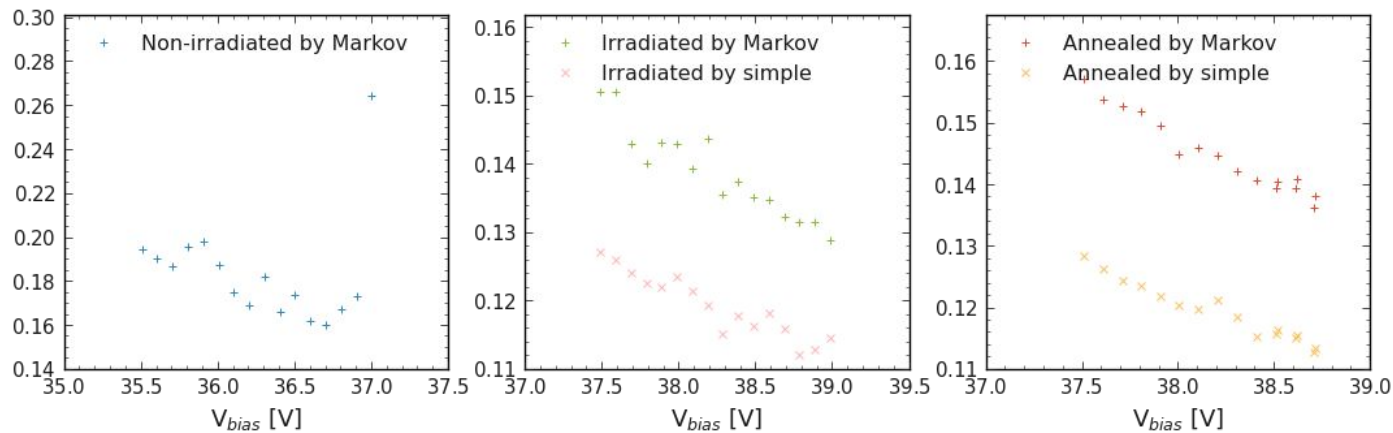
Time resolution of first peak for SiPM #12 at -30°



Time resolution for first photon peak



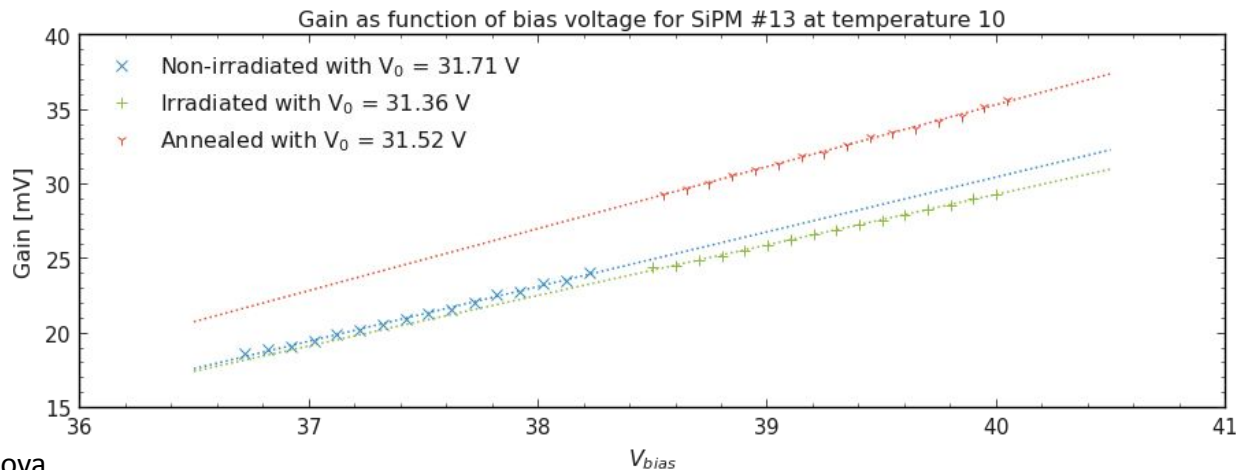
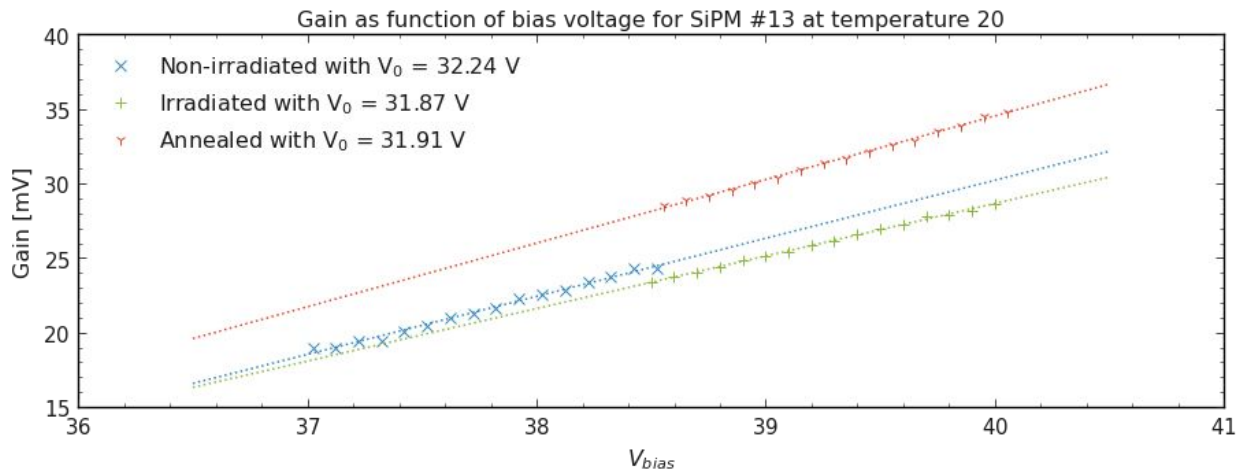
Time resolution of first peak for SiPM #12 at -35°



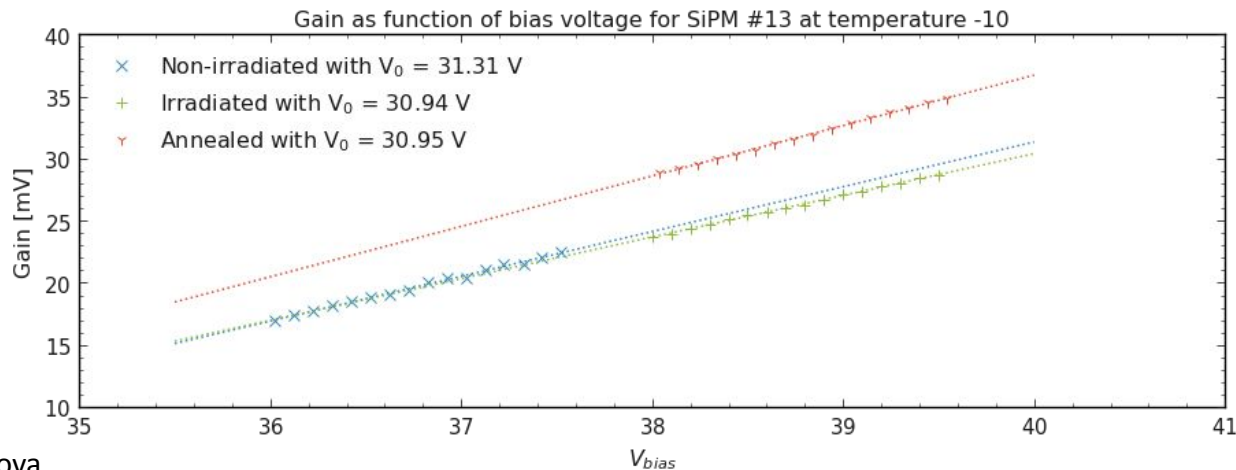
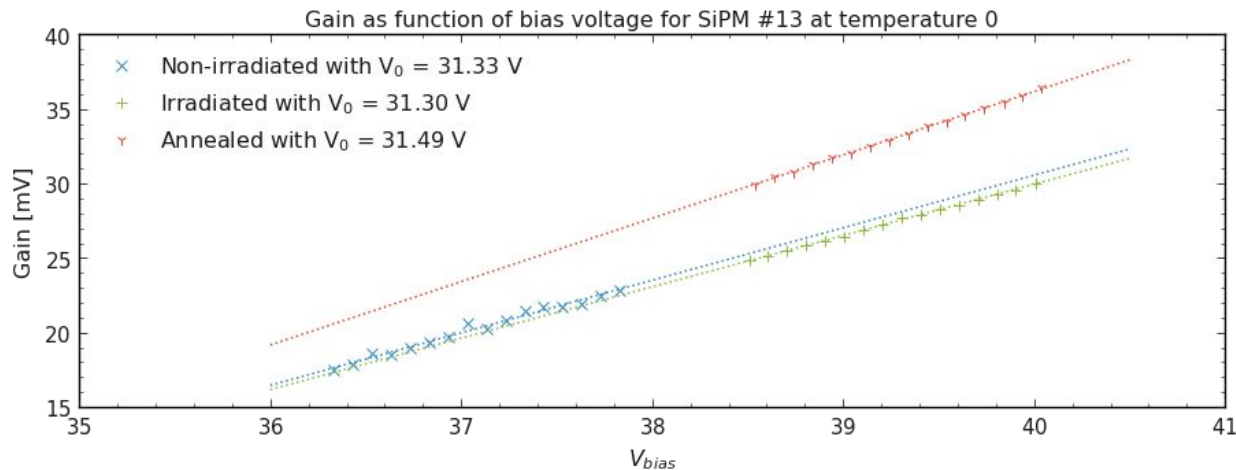
SiMP #13

Gain as function of bias voltage for SiPM #13

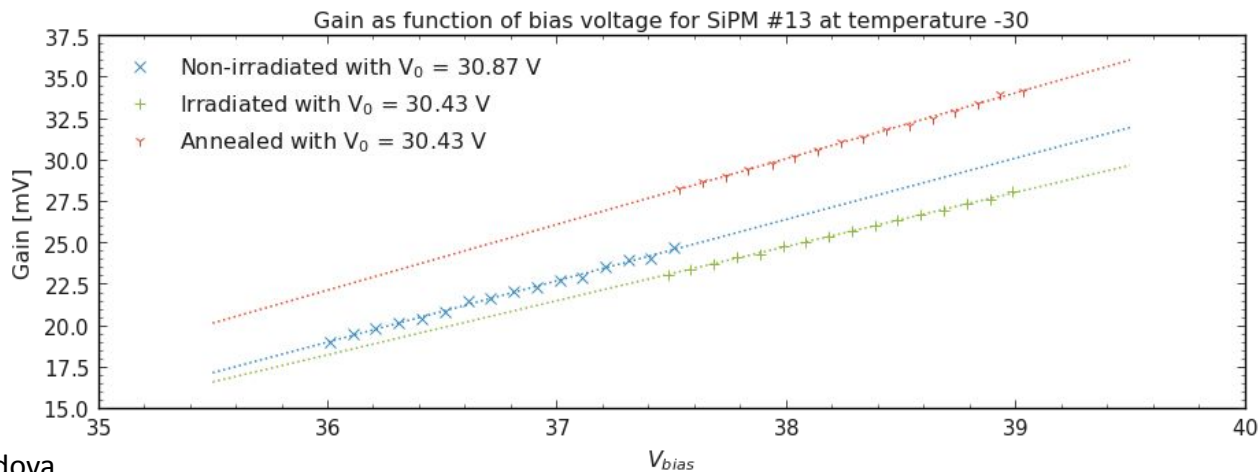
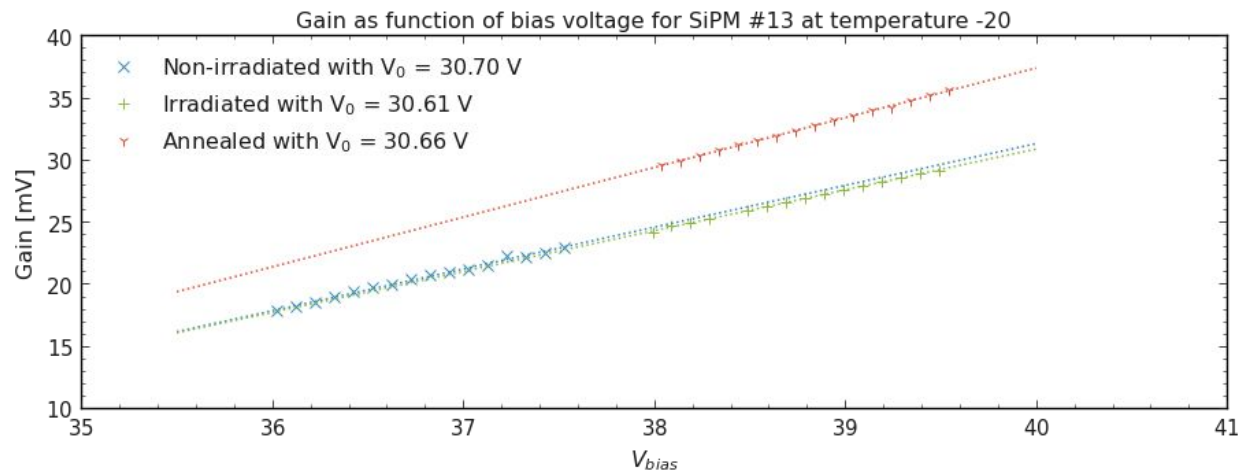
Gain as function of bias voltage



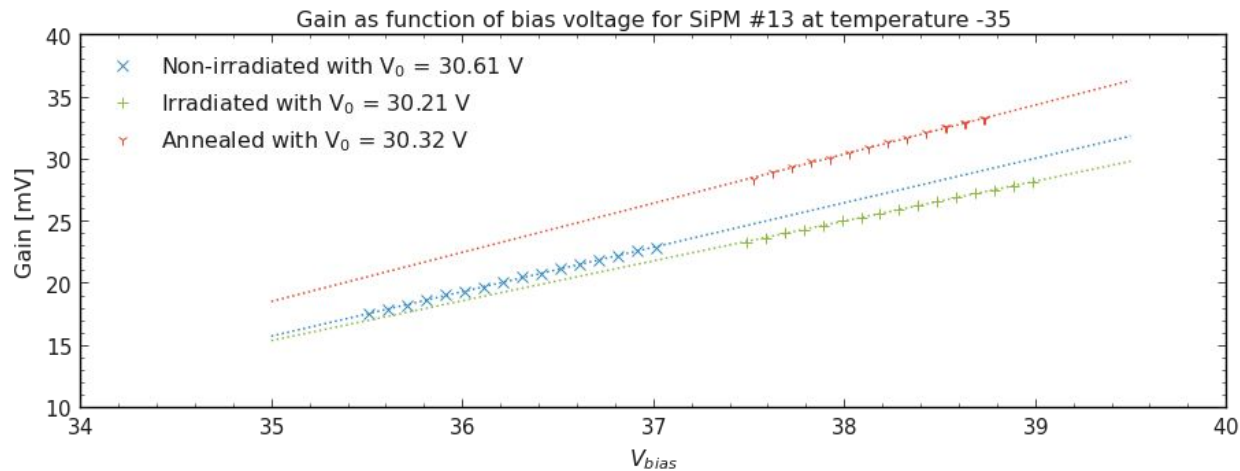
Gain as function of bias voltage



Gain as function of bias voltage

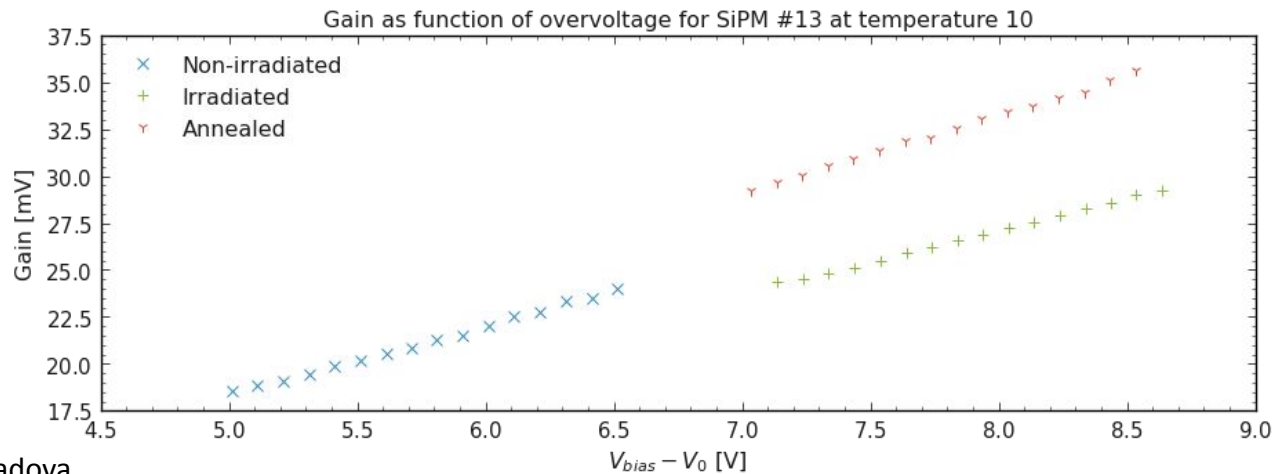
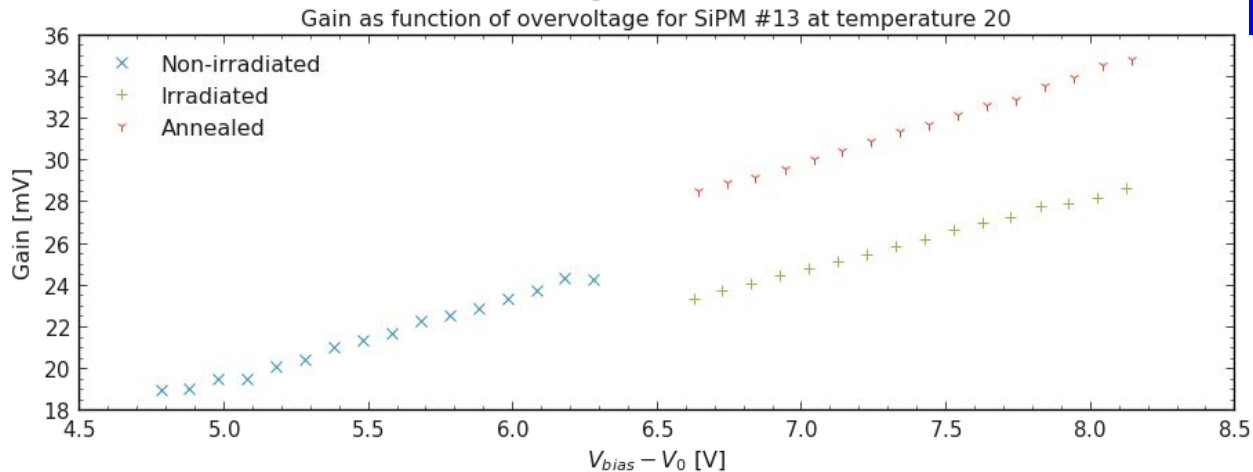


Gain as function of bias voltage

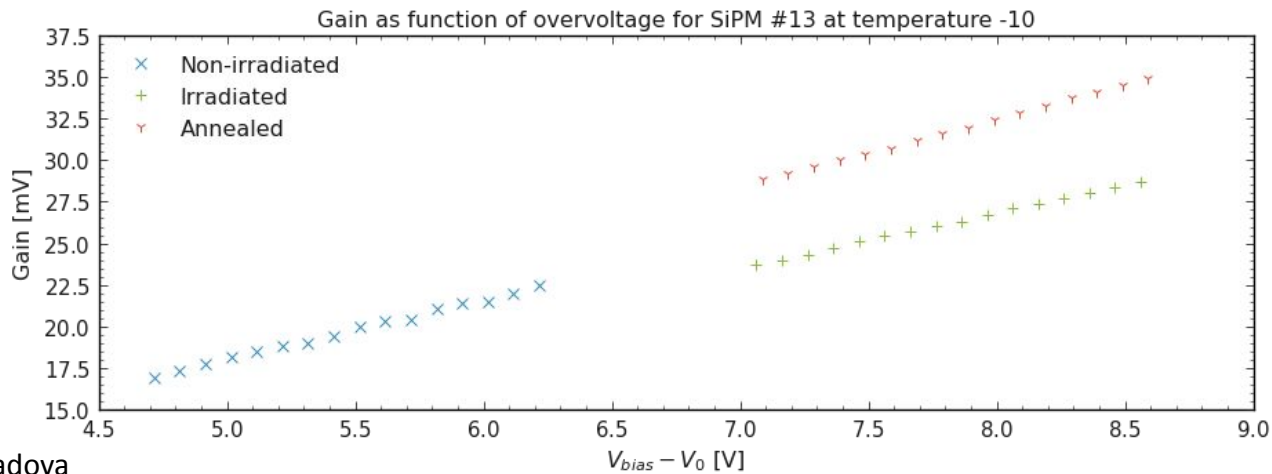
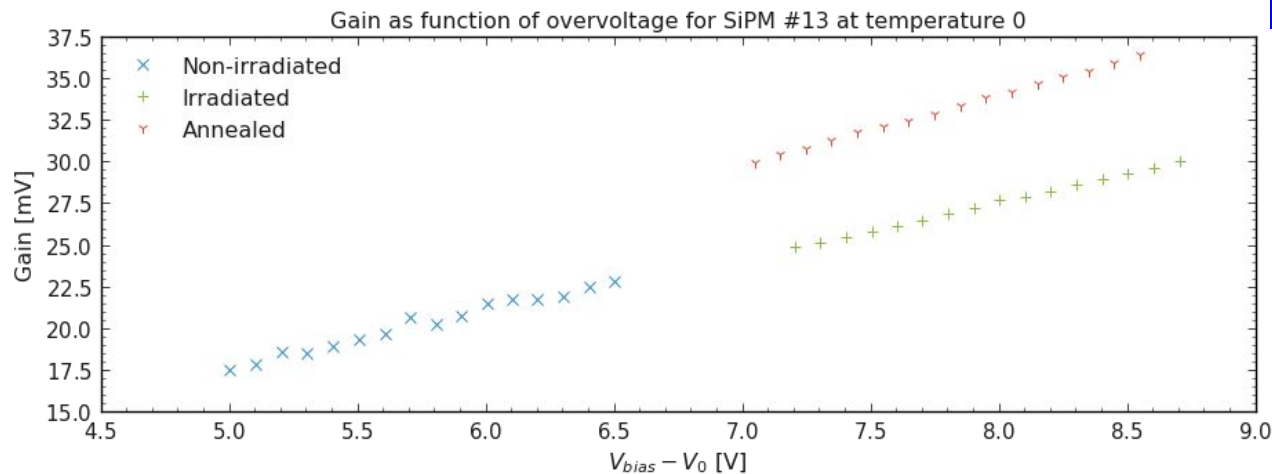


Gain as function of overvoltage for SiPM #13

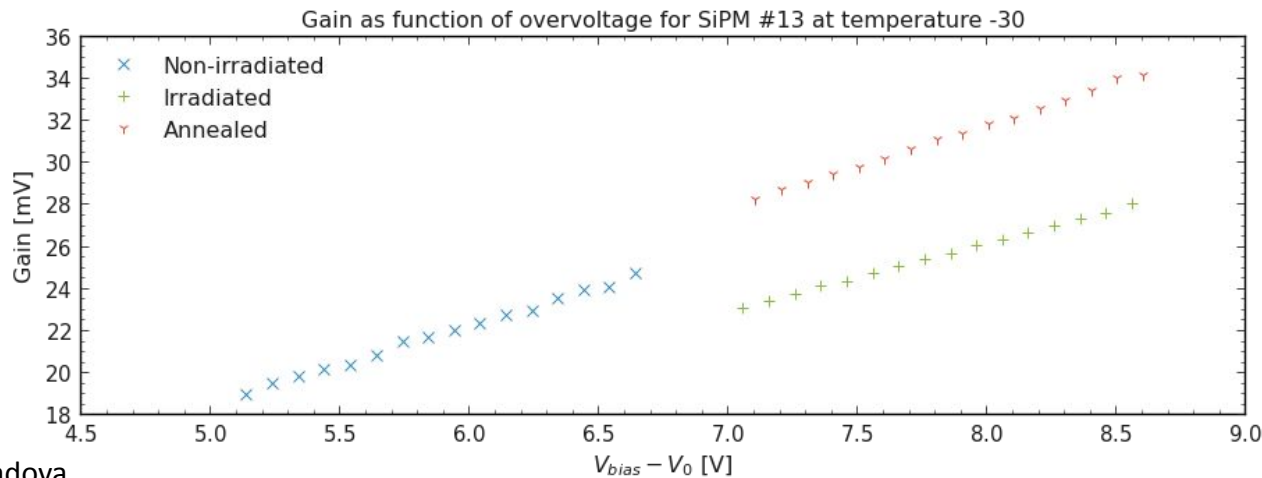
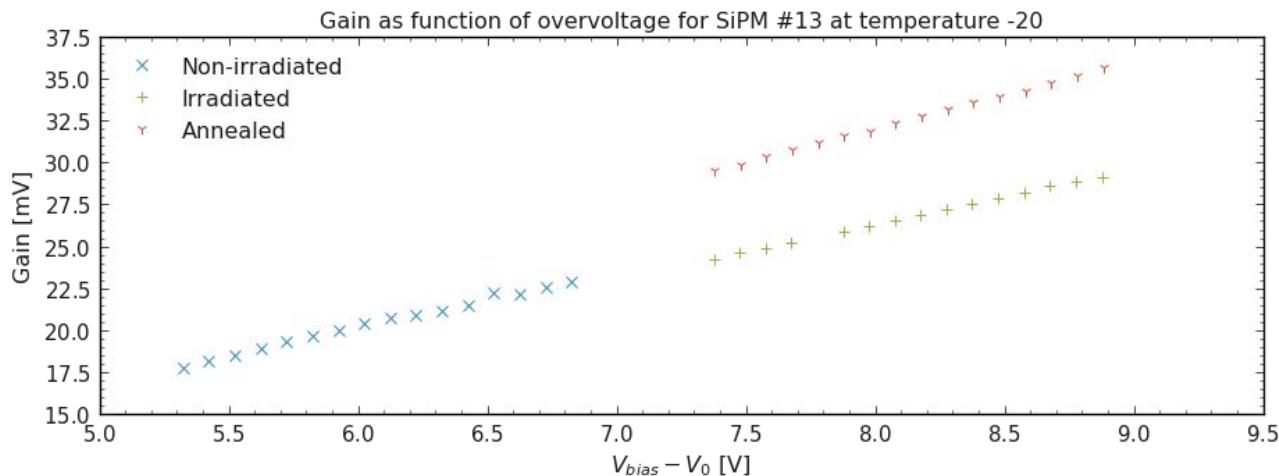
Gain as function of overvoltage



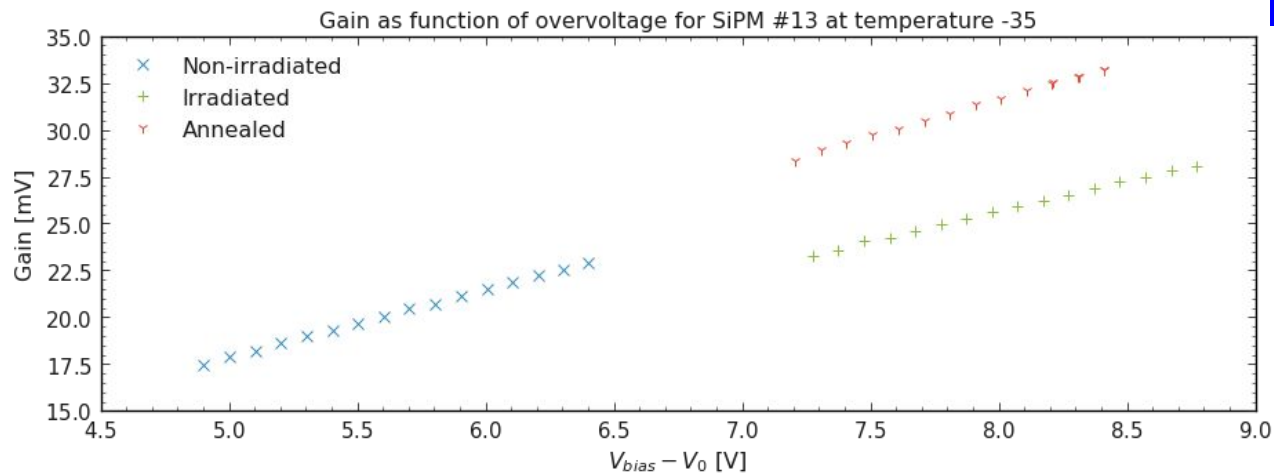
Gain as function of overvoltage



Gain as function of overvoltage



Gain as function of overvoltage

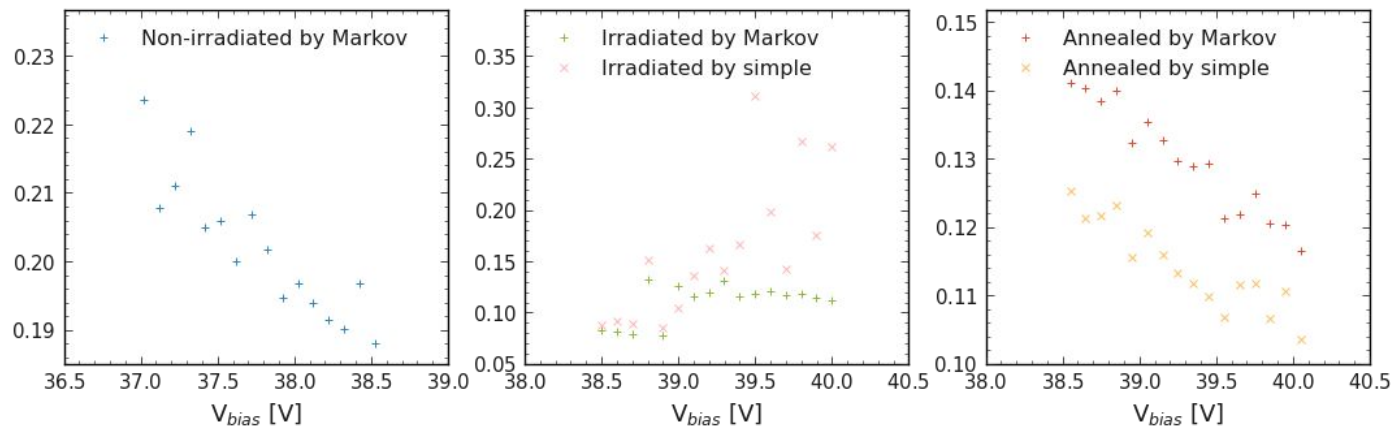


Time resolution for first photon peak for SiPM #13

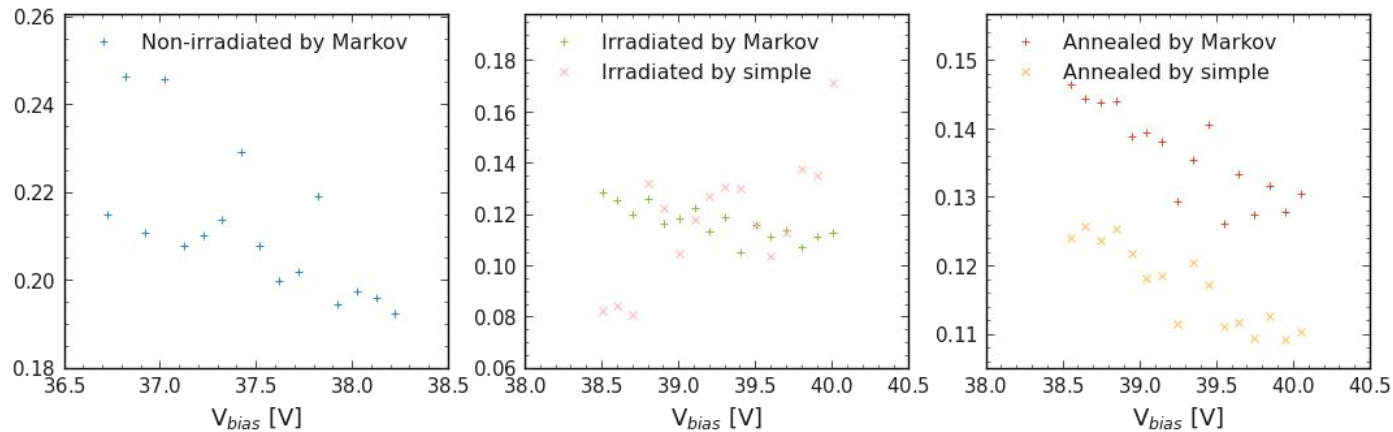
Time resolution for first photon peak



Time resolution of first peak for SiPM #13 at 20°



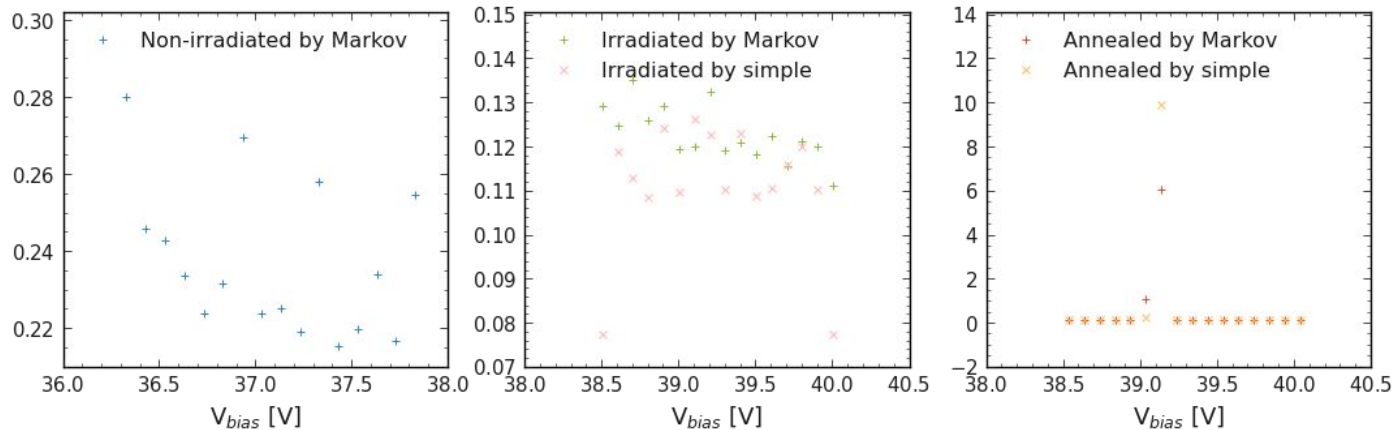
Time resolution of first peak for SiPM #13 at 10°



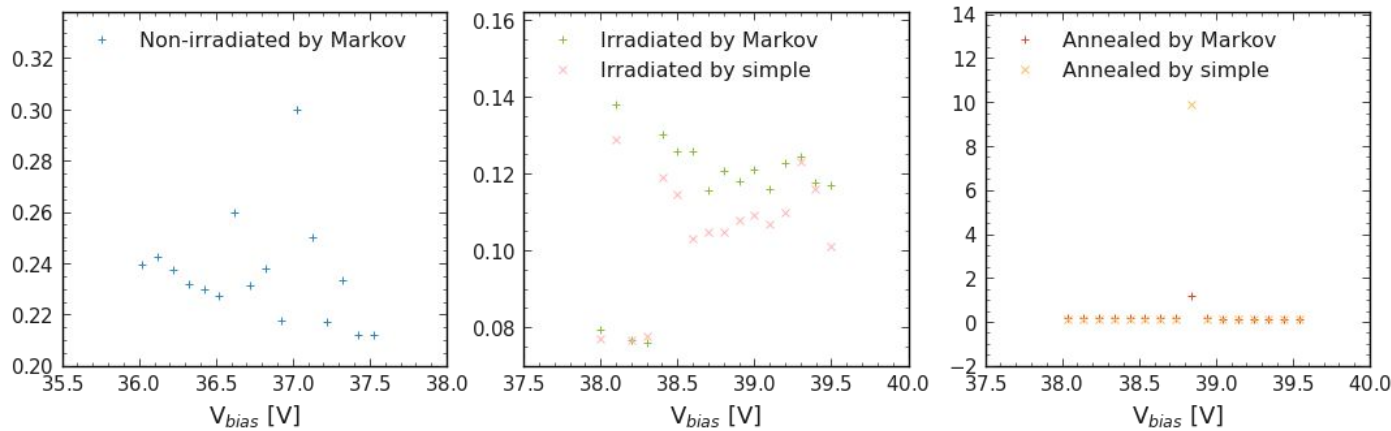
Time resolution for first photon peak



Time resolution of first peak for SiPM #13 at 0°



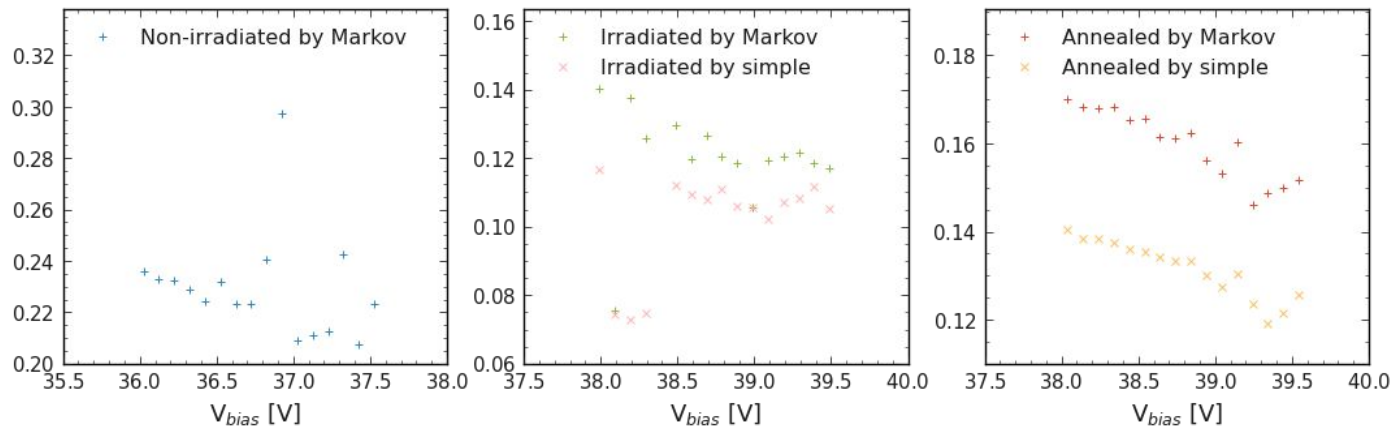
Time resolution of first peak for SiPM #13 at -10°



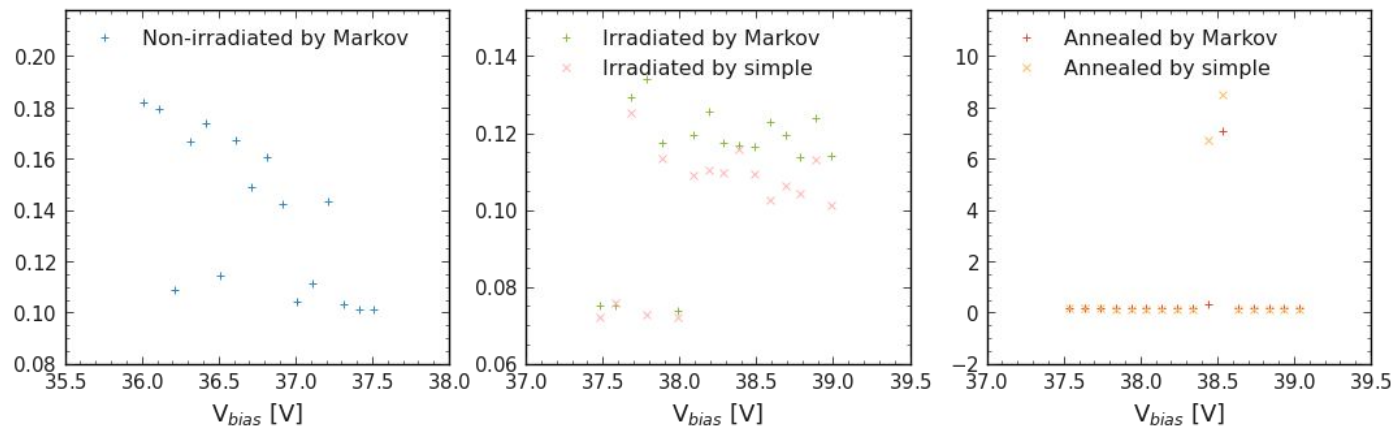
Time resolution for first photon peak



Time resolution of first peak for SiPM #13 at -20°



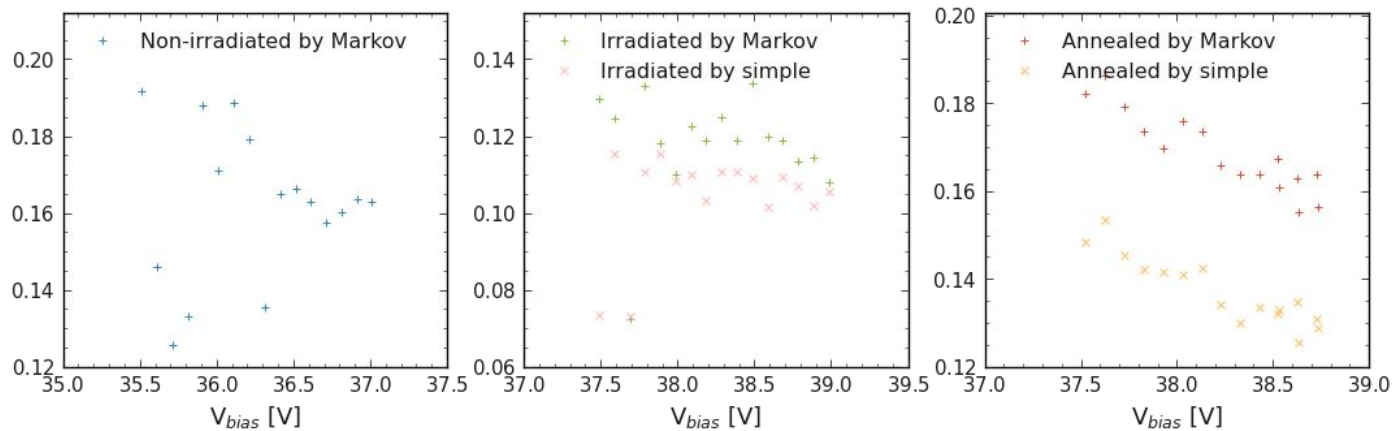
Time resolution of first peak for SiPM #13 at -30°



Time resolution for first photon peak



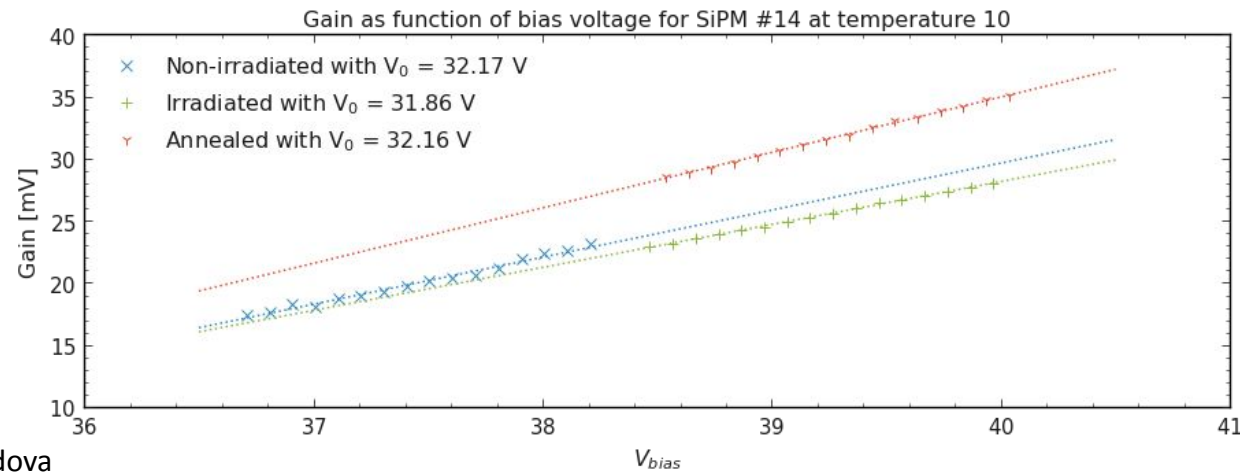
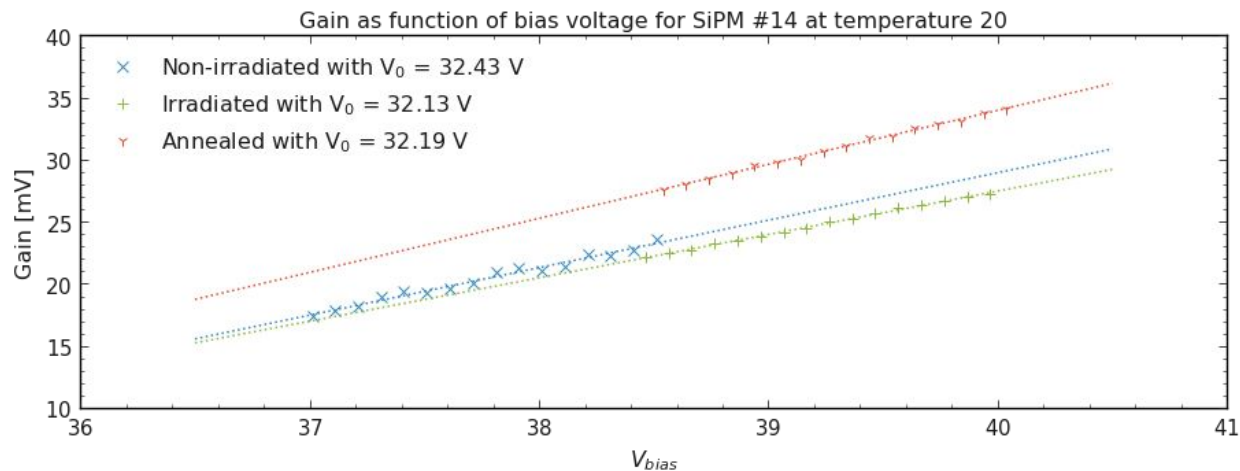
Time resolution of first peak for SiPM #13 at -35°



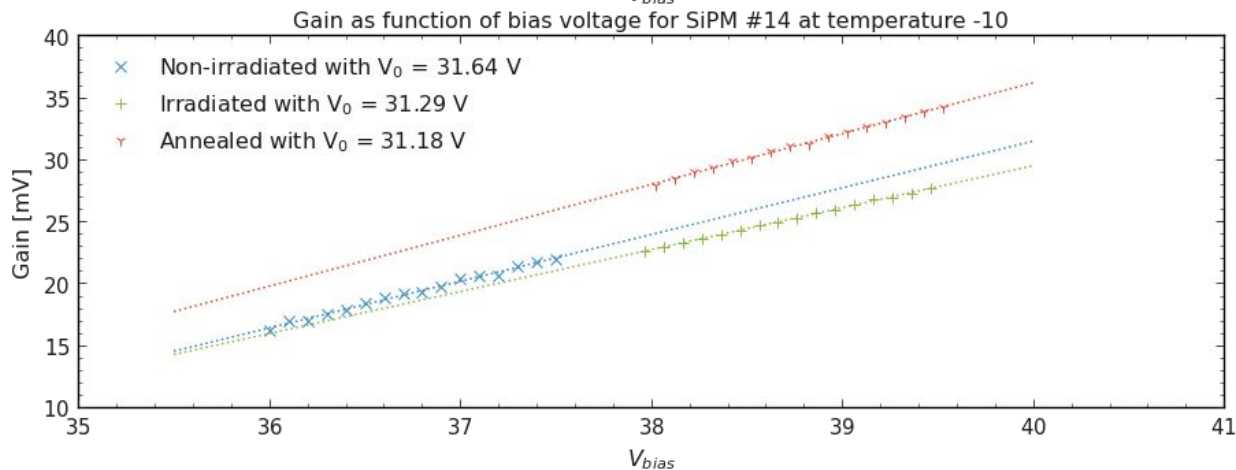
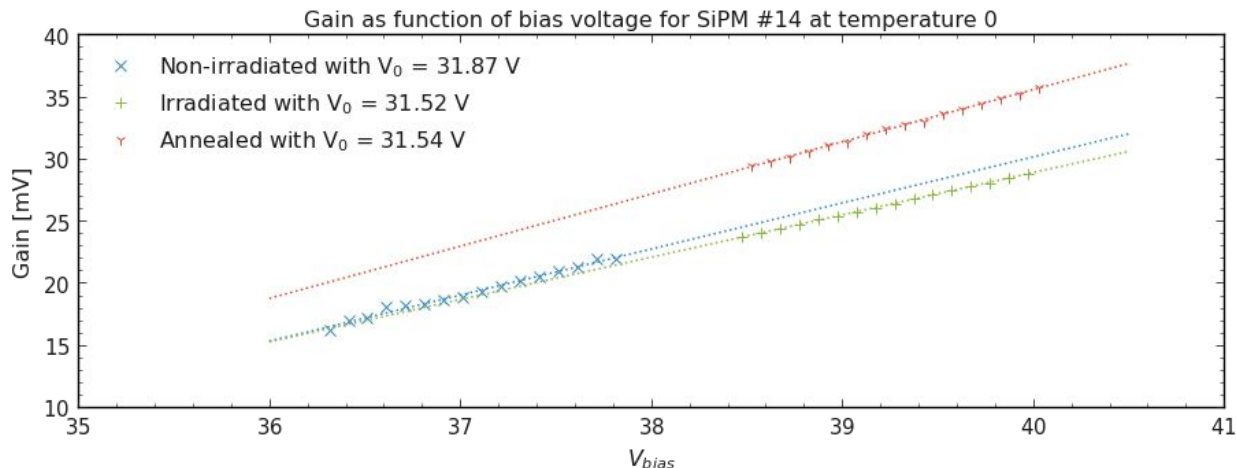
SIMP #14

Gain as function of bias voltage for SiPM #14

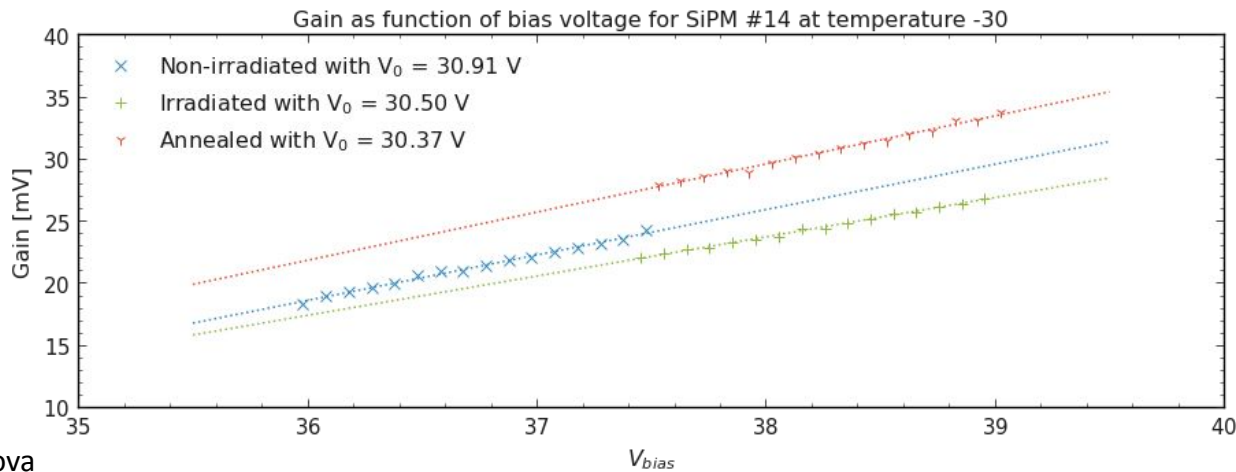
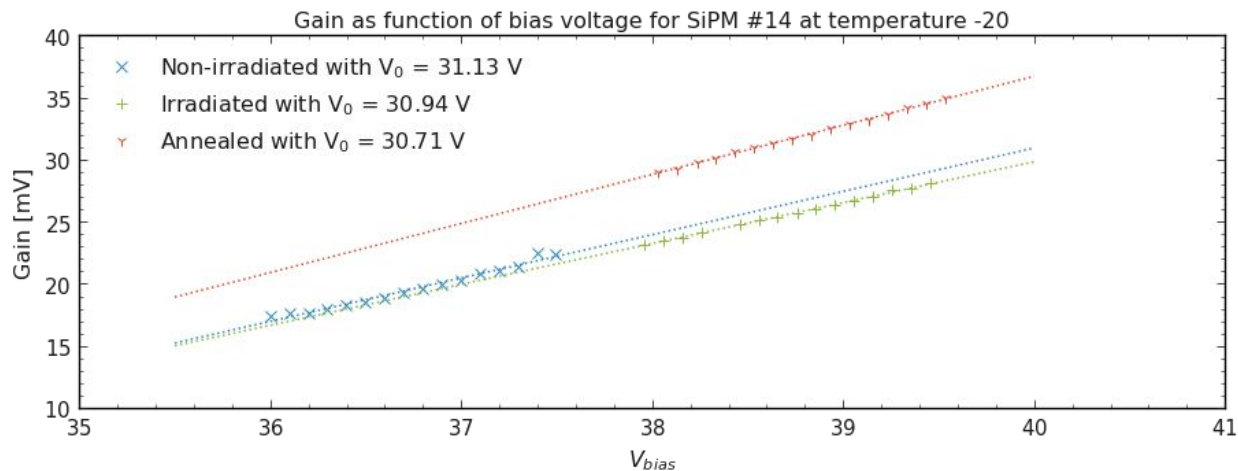
Gain as function of bias voltage



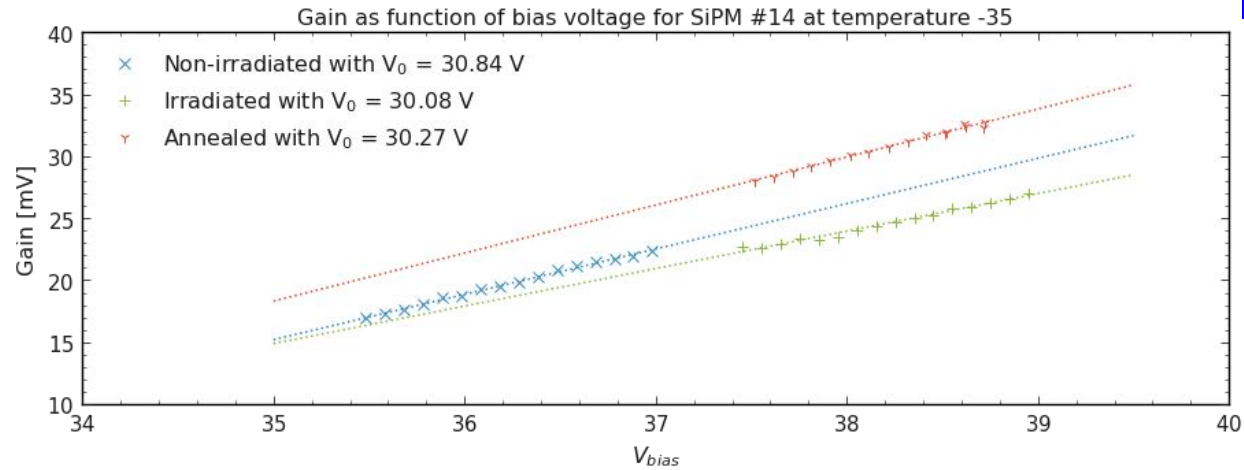
Gain as function of bias voltage



Gain as function of bias voltage



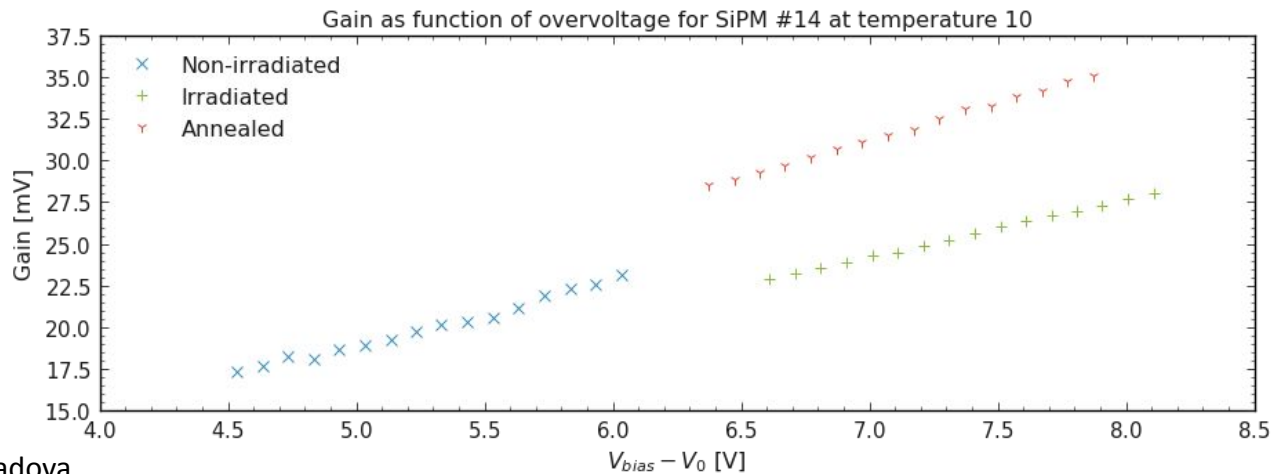
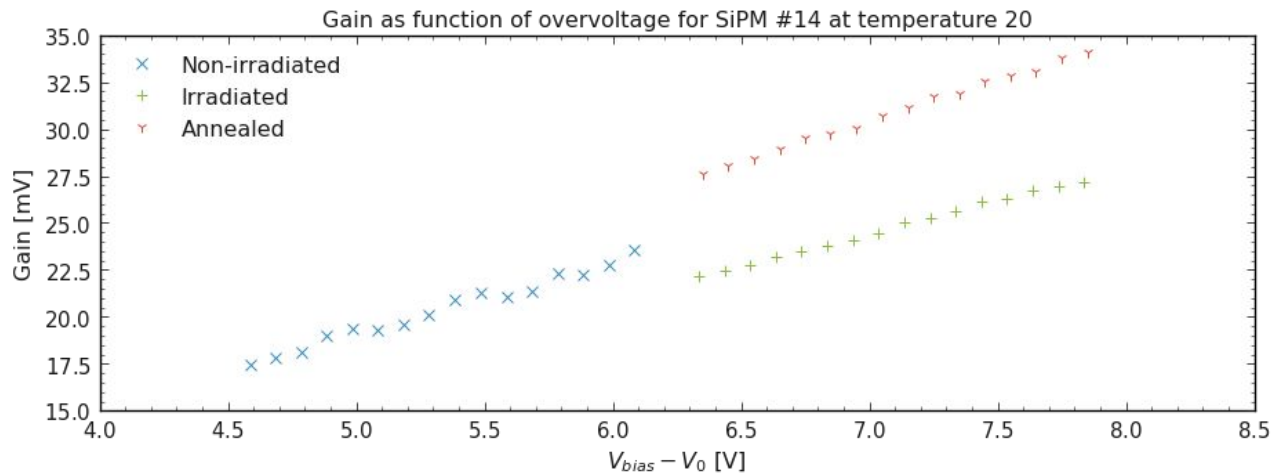
Gain as function of bias voltage



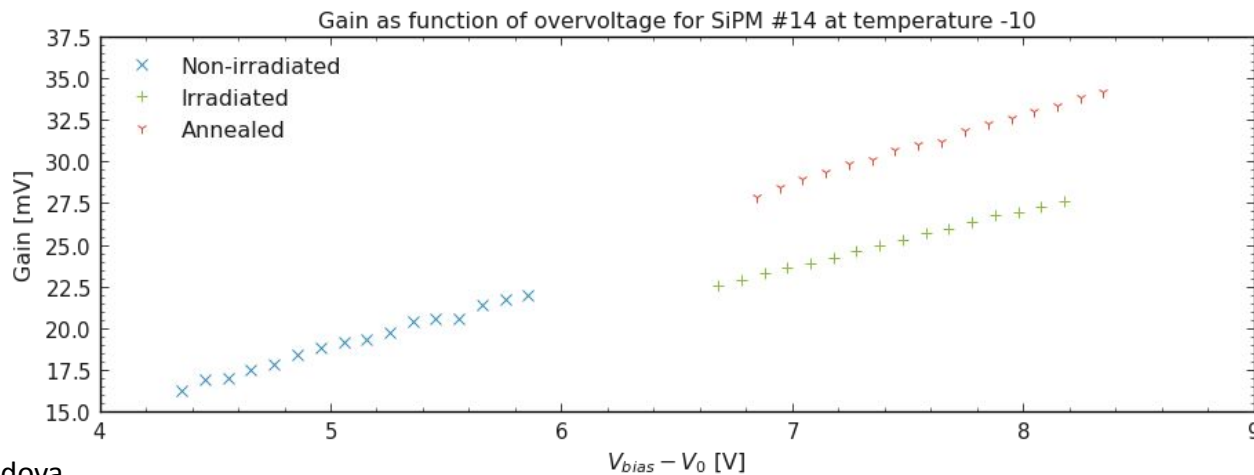
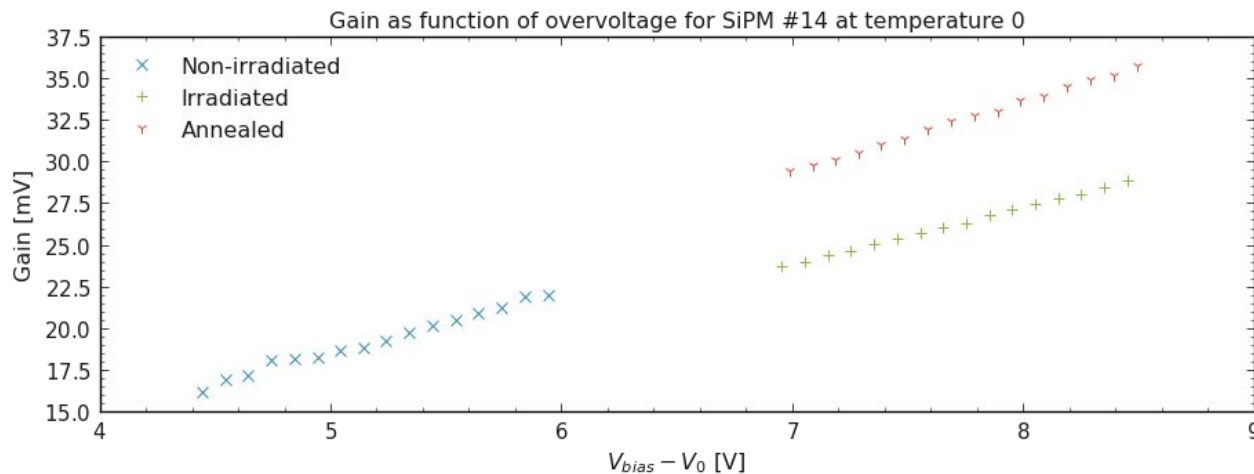


Gain as function of overvoltage for SiPM #14

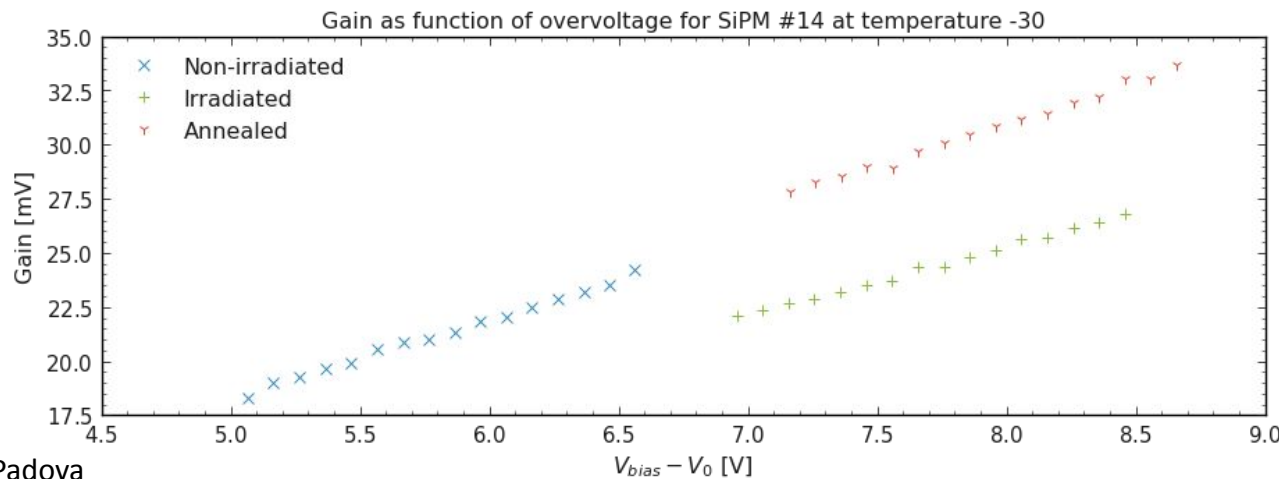
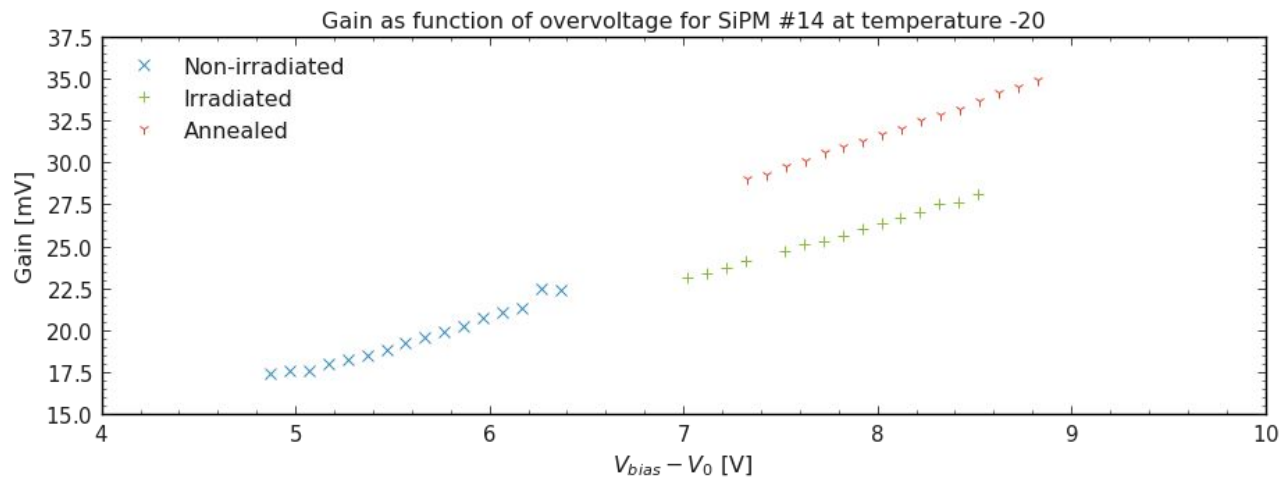
Gain as function of overvoltage



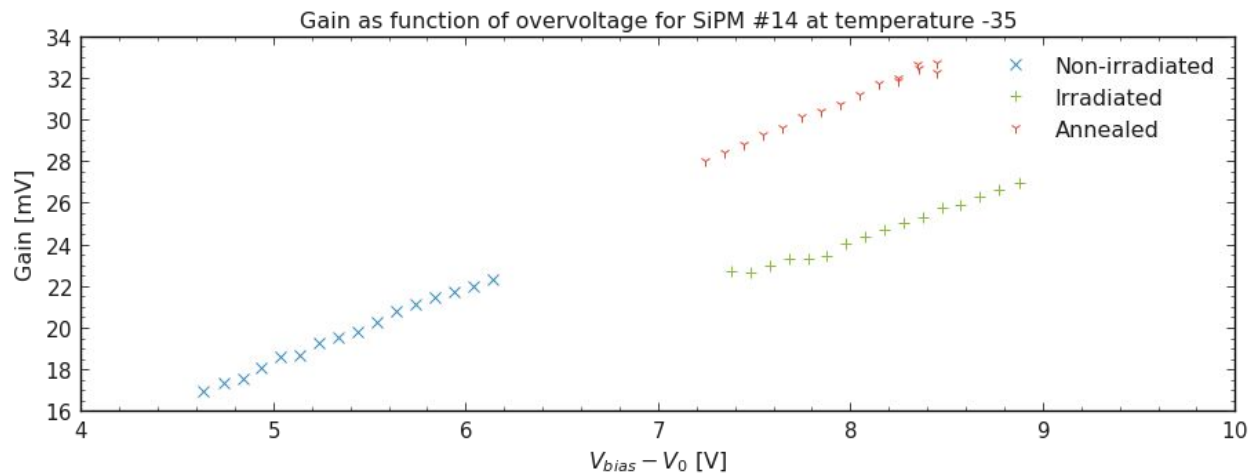
Gain as function of overvoltage



Gain as function of overvoltage



Gain as function of overvoltage

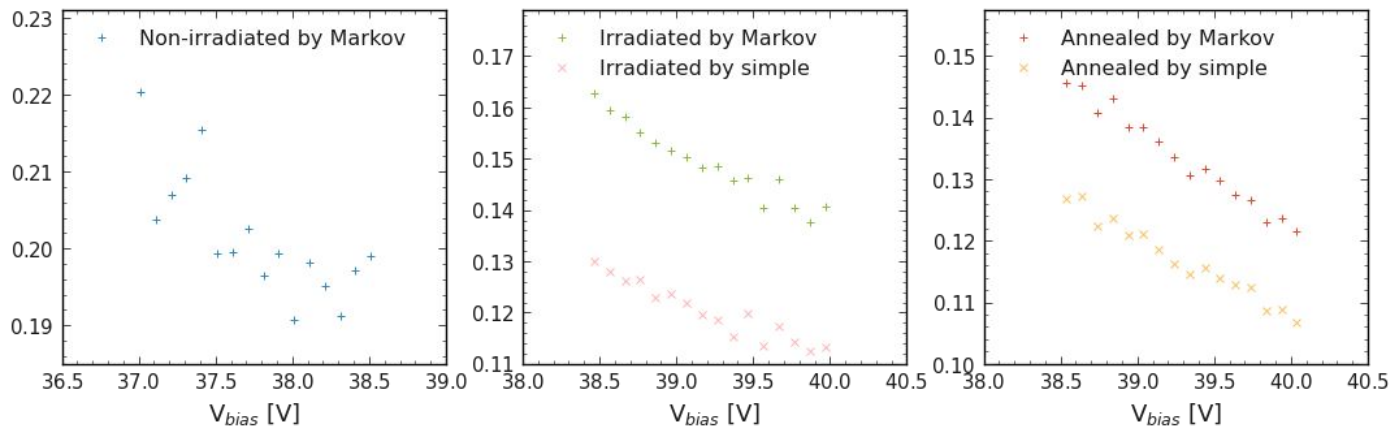


Time resolution for first photon peak for SiPM #14

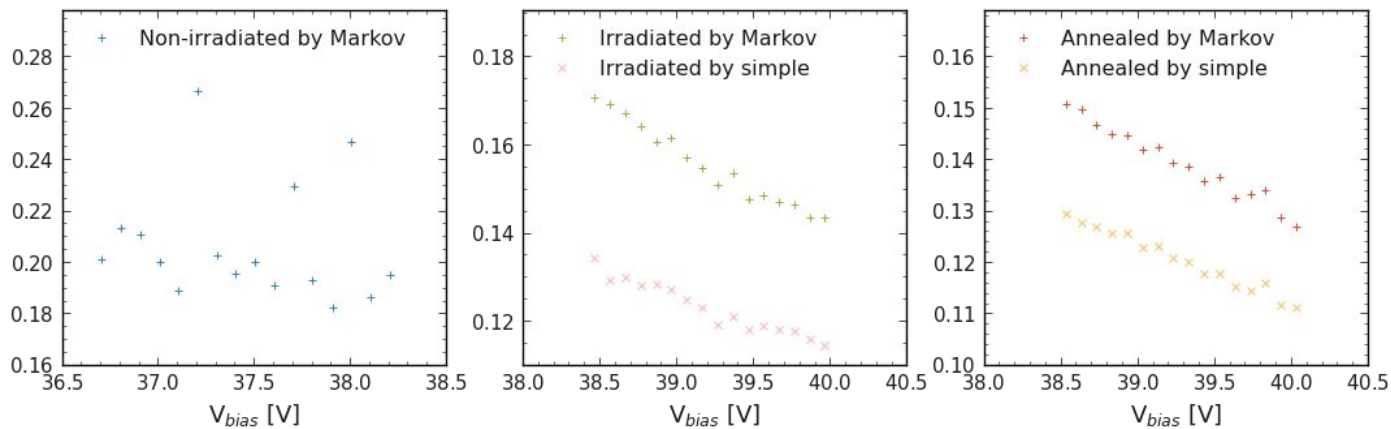
Time resolution for first photon peak



Time resolution of first peak for SiPM #14 at 20°



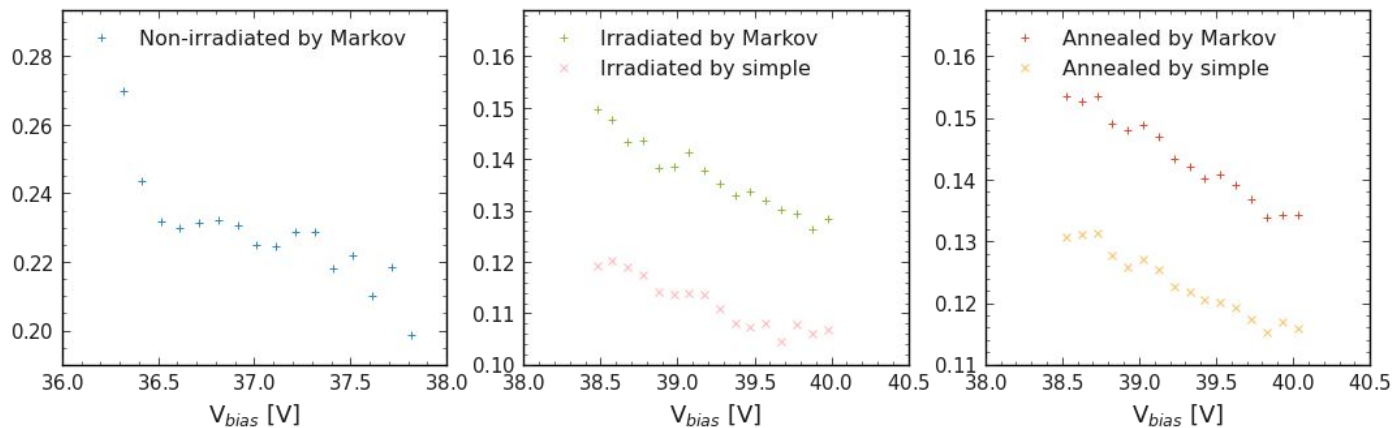
Time resolution of first peak for SiPM #14 at 10°



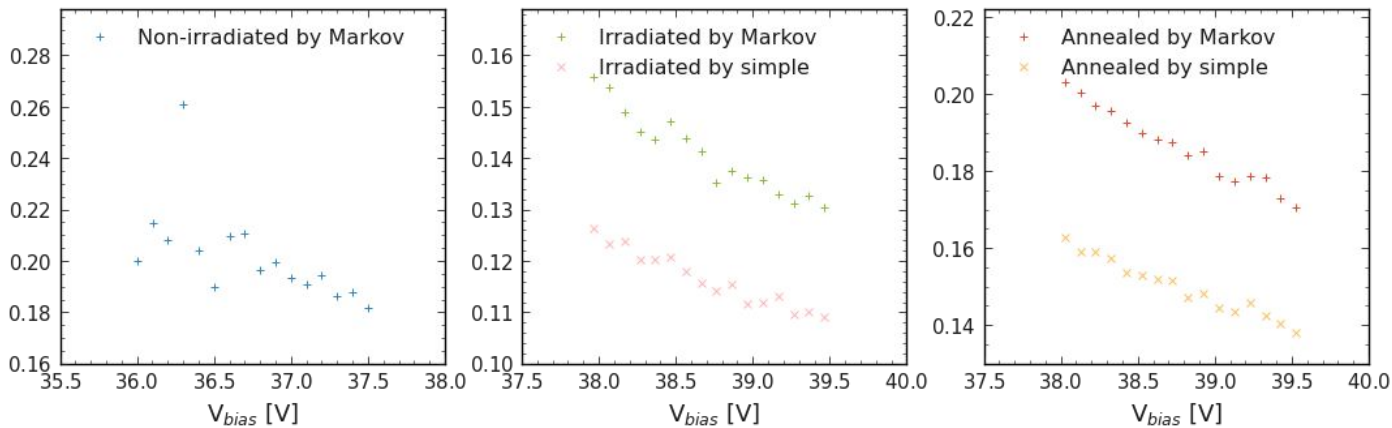
Time resolution for first photon peak



Time resolution of first peak for SiPM #14 at 0°



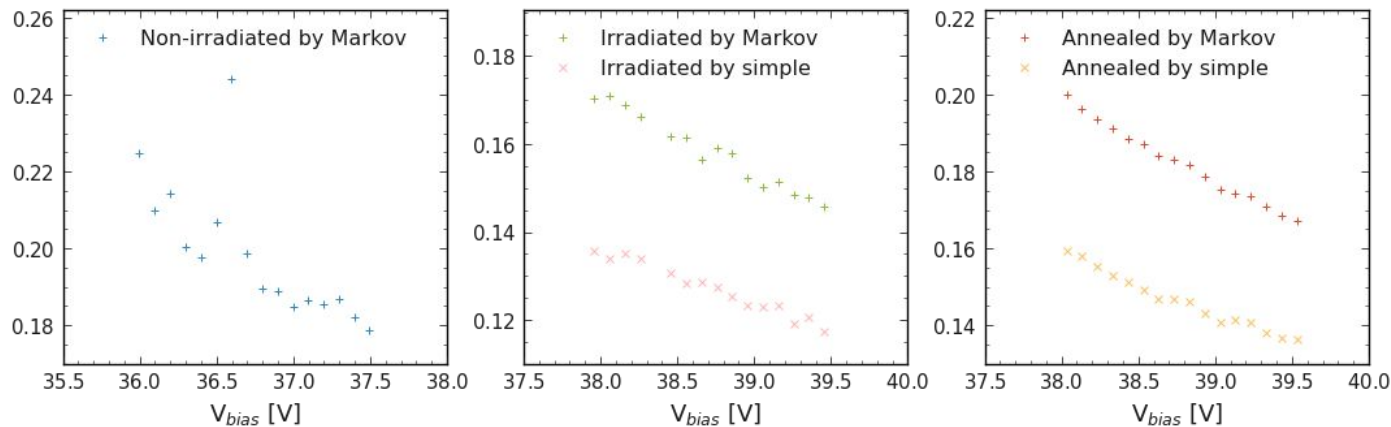
Time resolution of first peak for SiPM #14 at -10°



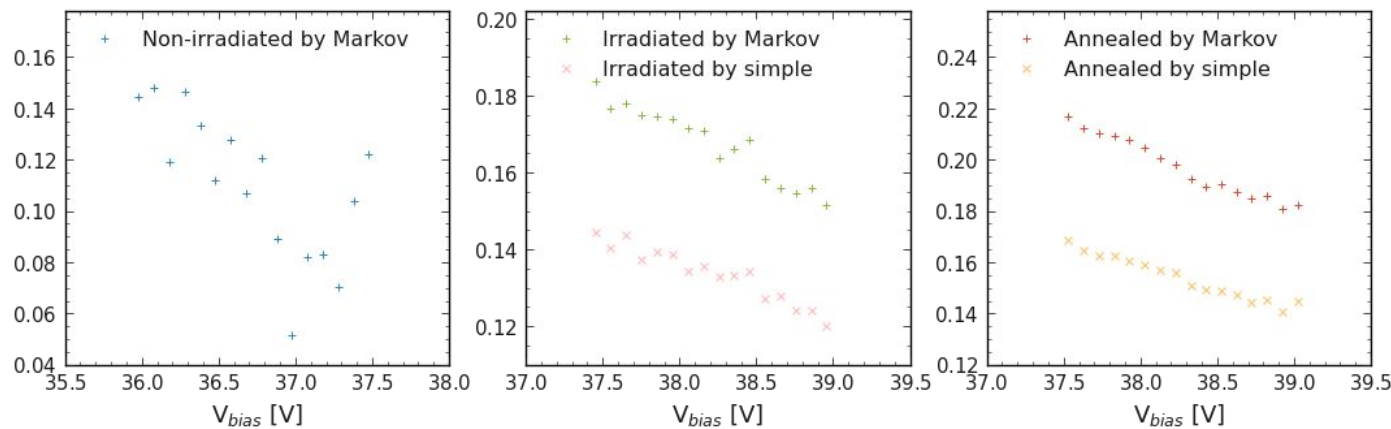
Time resolution for first photon peak



Time resolution of first peak for SiPM #14 at -20°



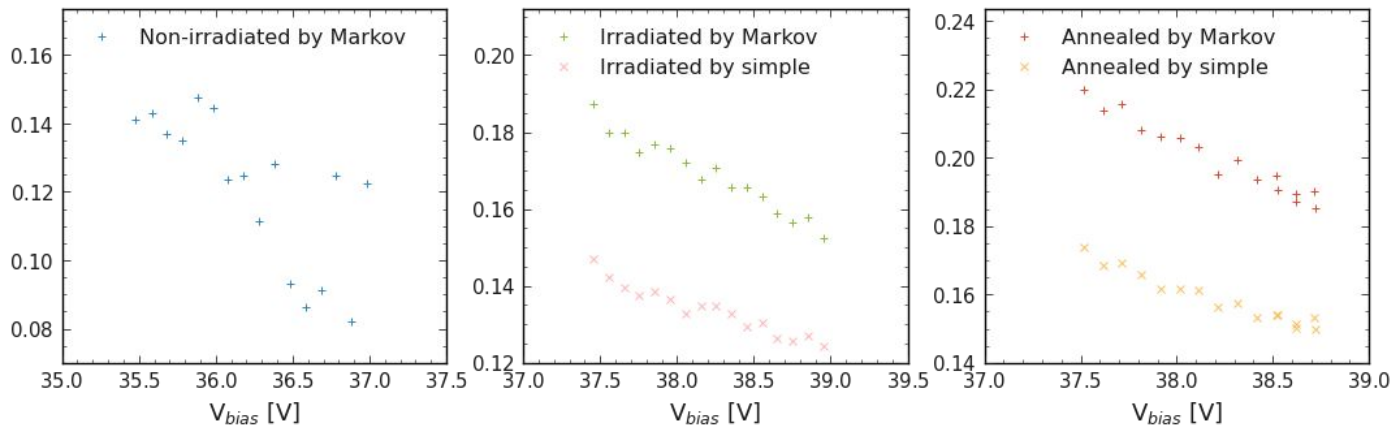
Time resolution of first peak for SiPM #14 at -30°



Time resolution for first photon peak



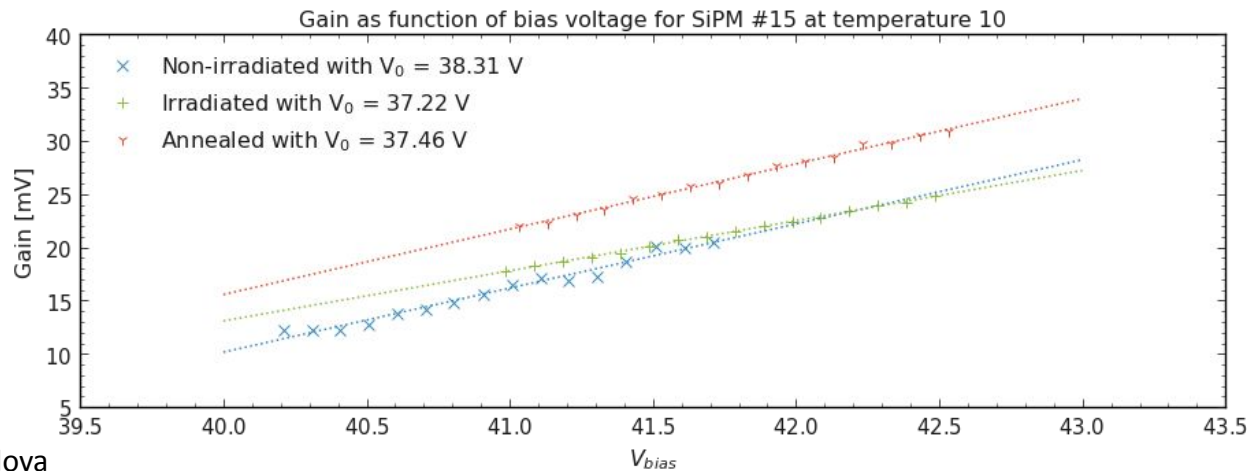
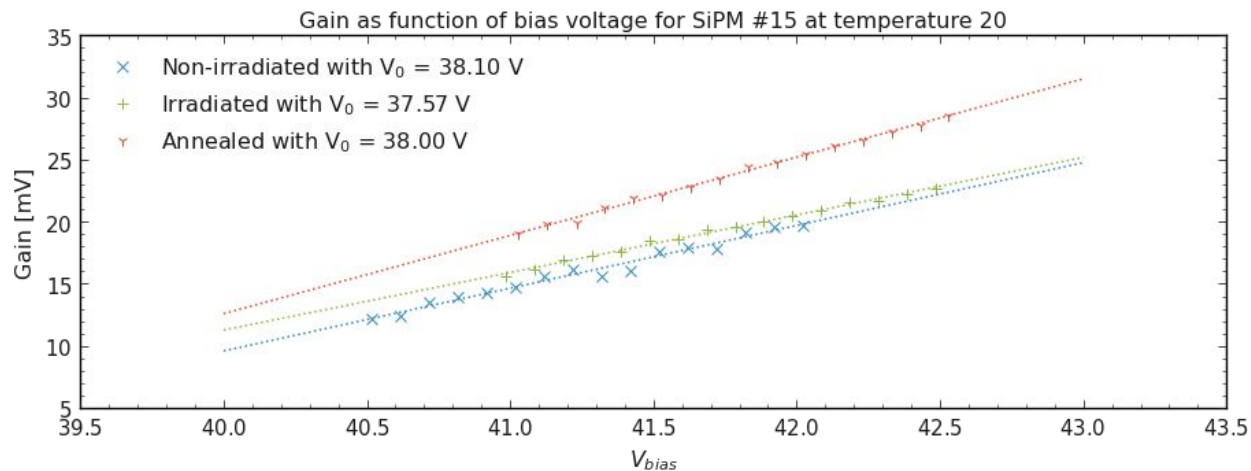
Time resolution of first peak for SiPM #14 at -35°



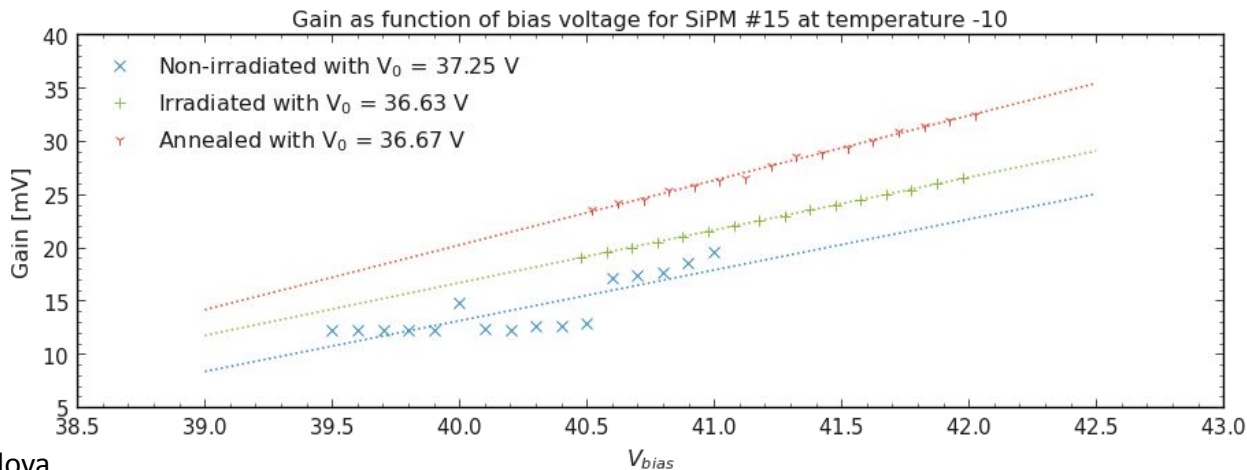
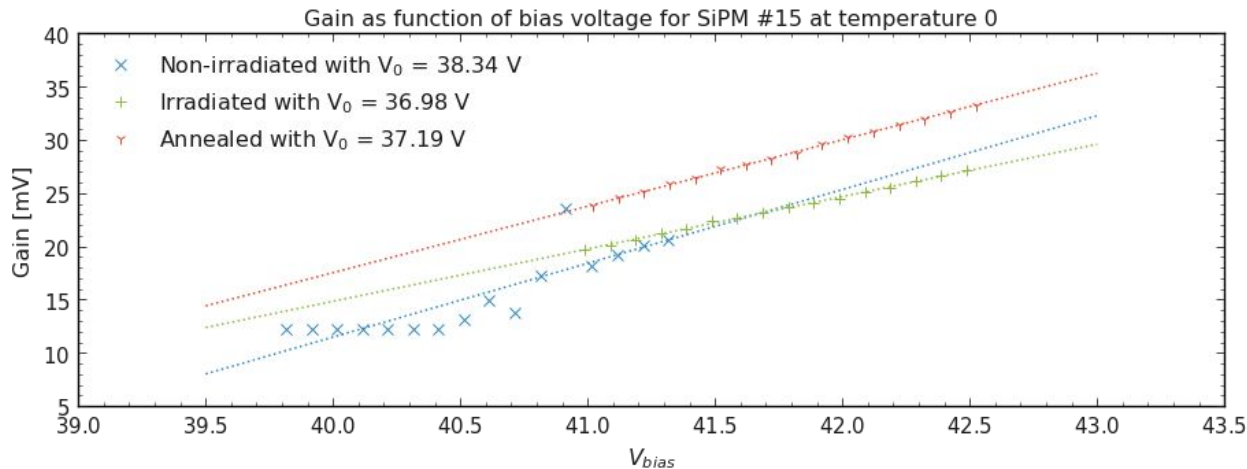
SIMP #15

Gain as function of bias voltage for SiPM #15

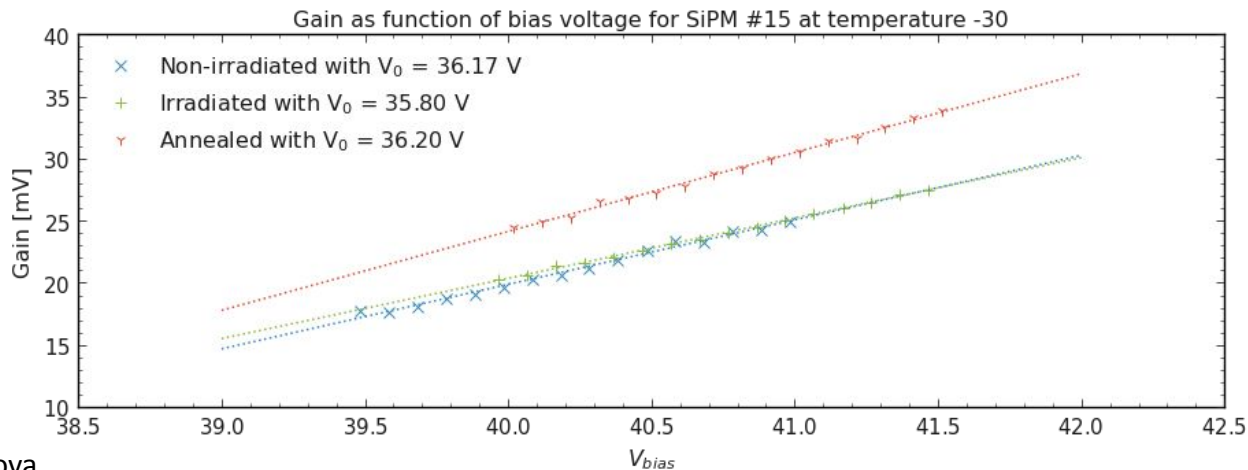
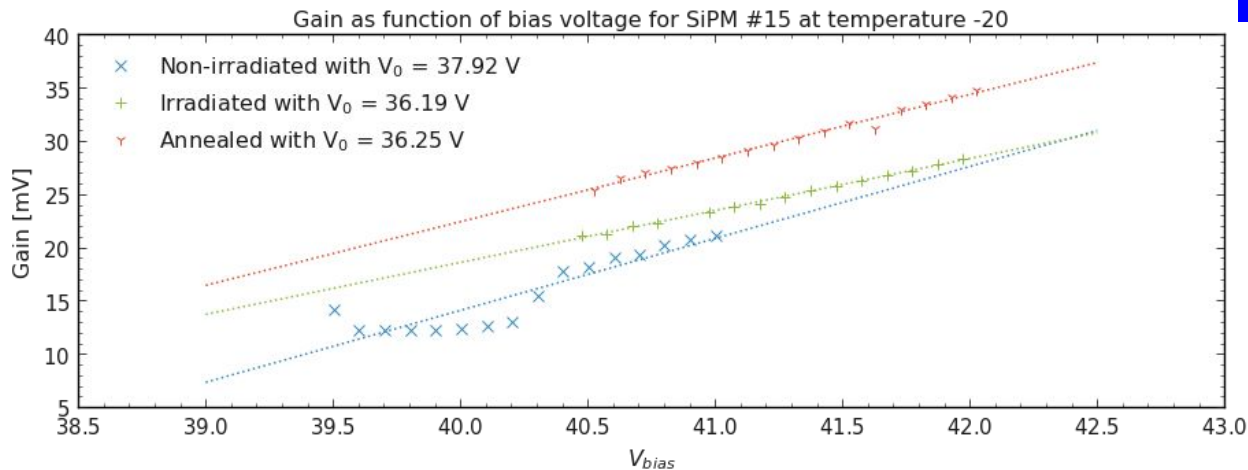
Gain as function of bias voltage



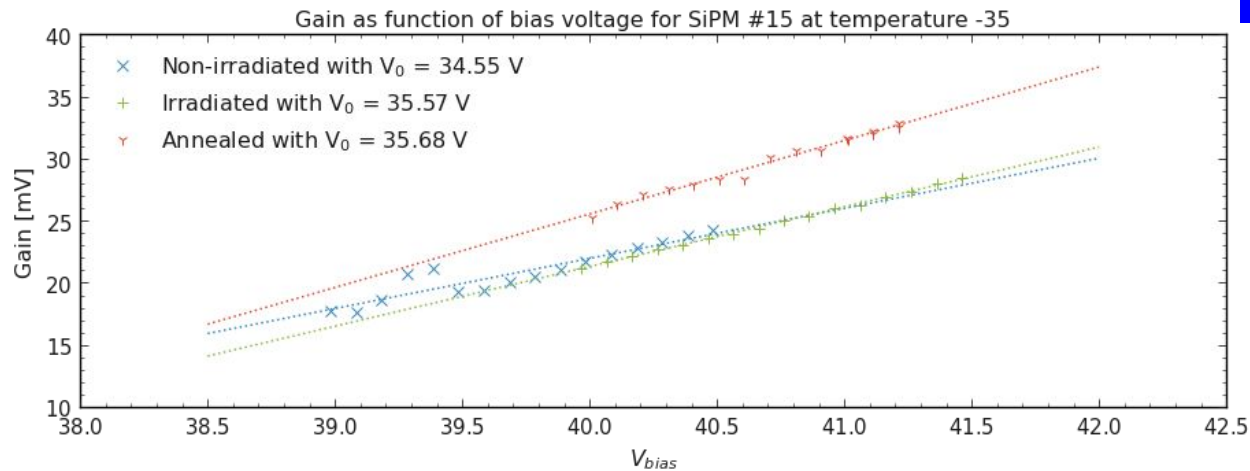
Gain as function of bias voltage



Gain as function of bias voltage

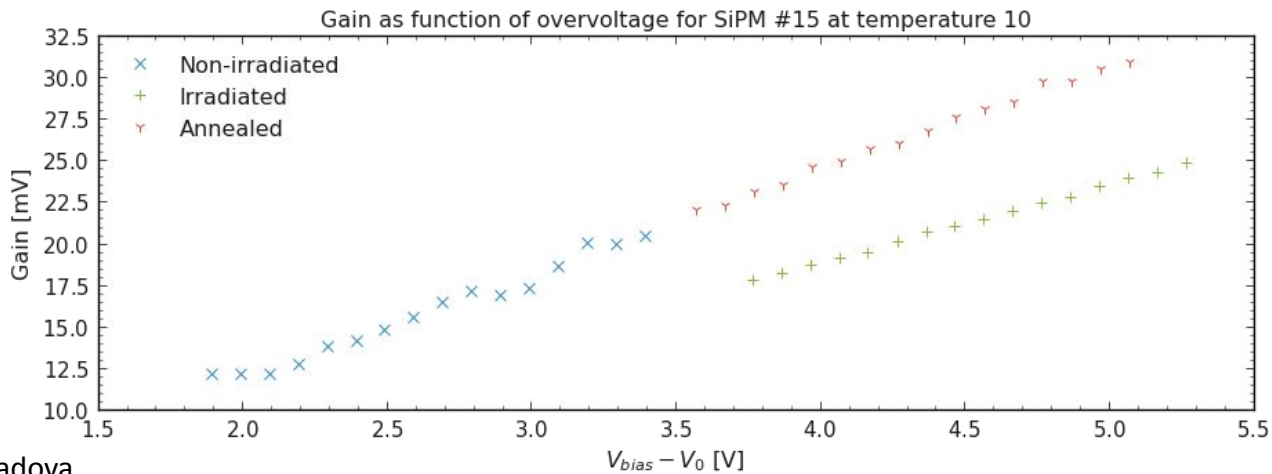
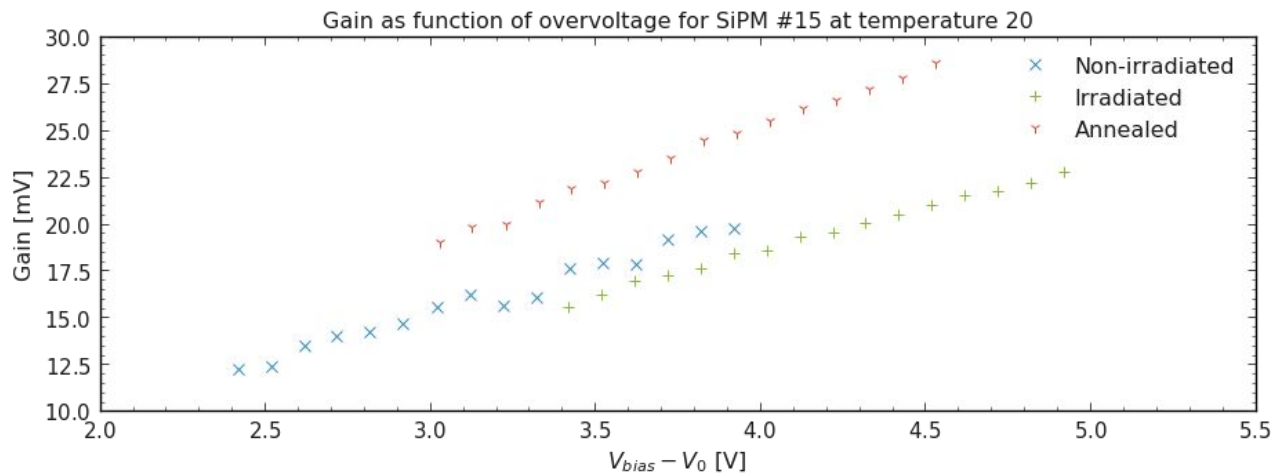


Gain as function of bias voltage

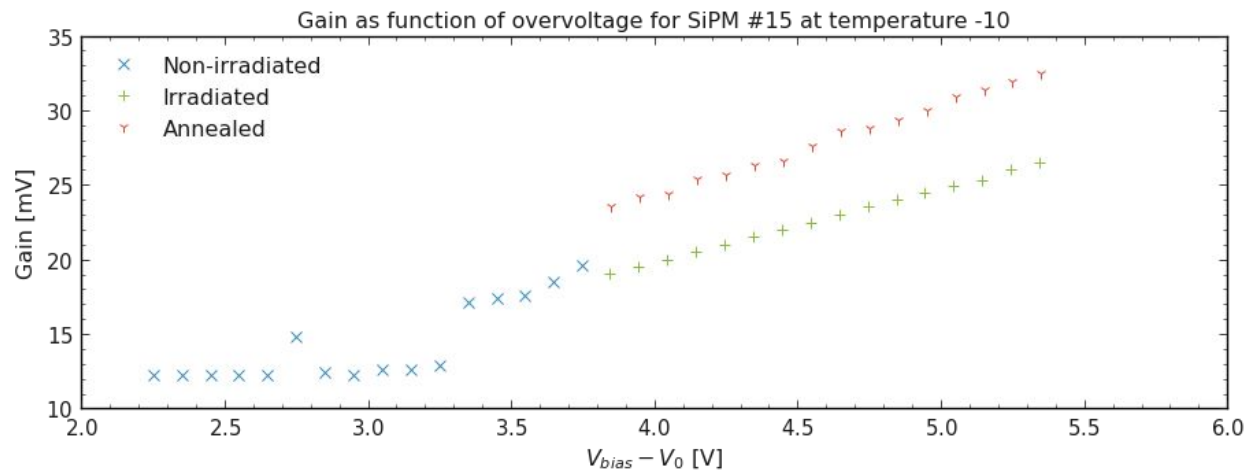
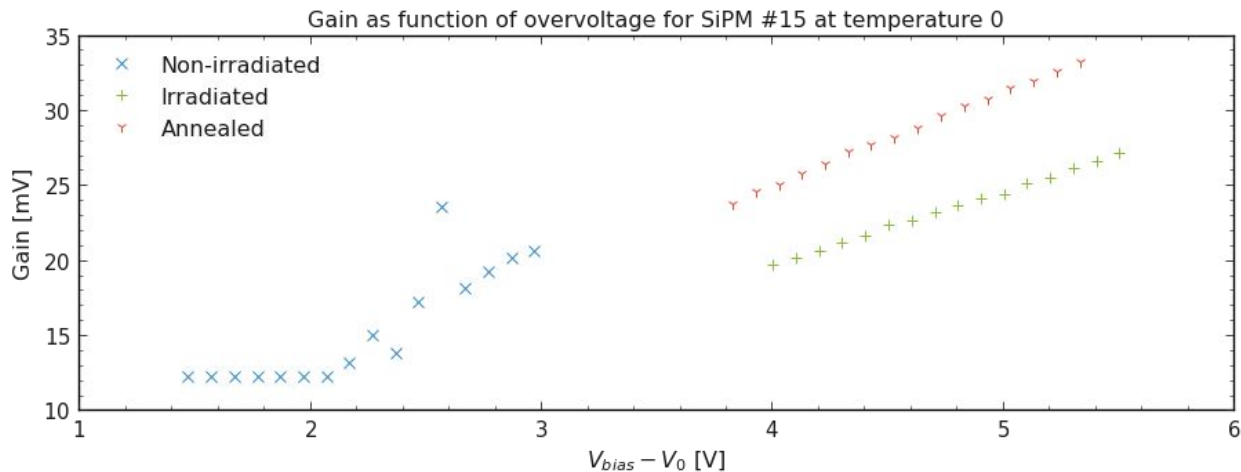


Gain as function of overvoltage for SiPM #15

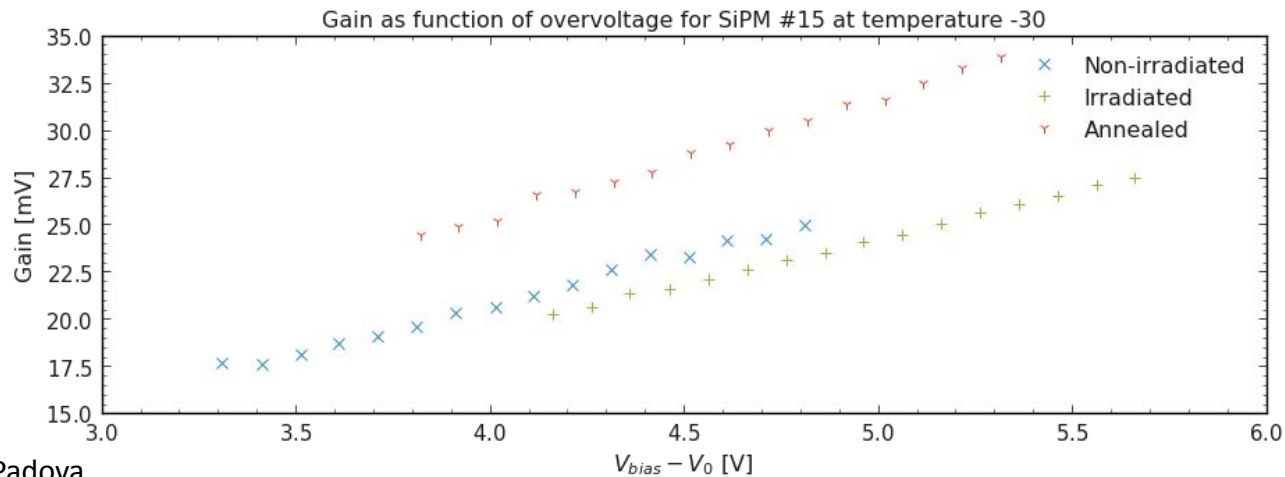
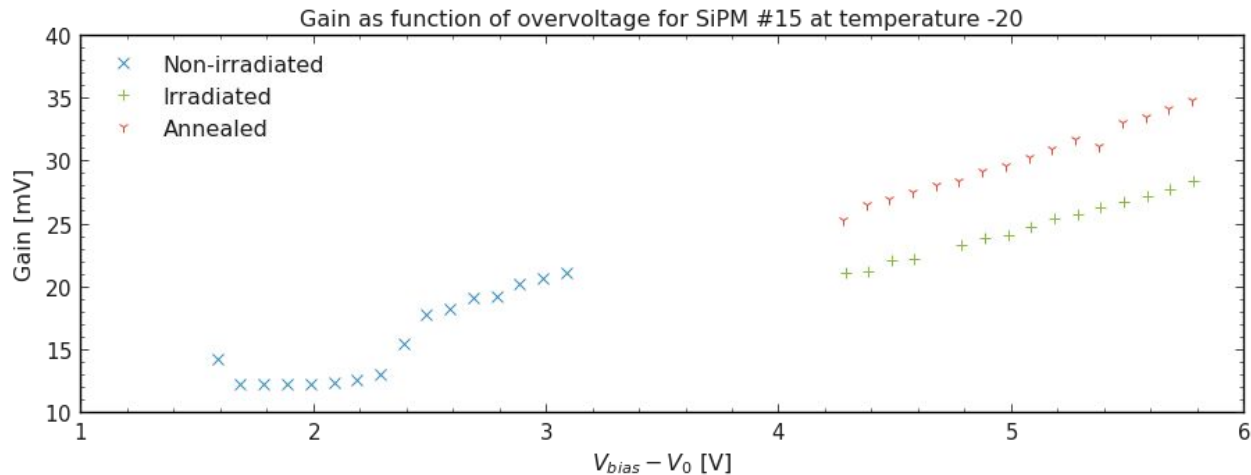
Gain as function of overvoltage



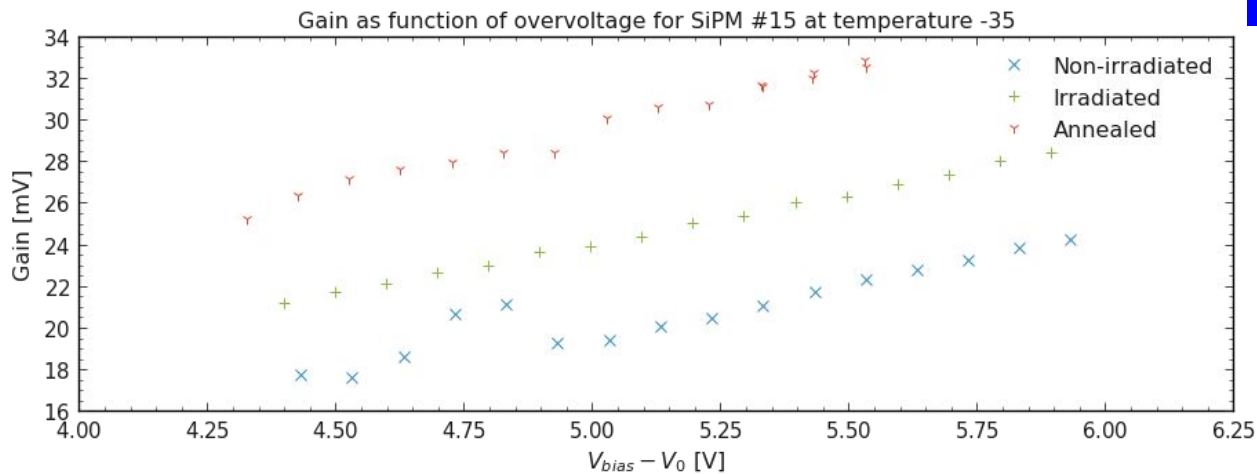
Gain as function of overvoltage



Gain as function of overvoltage



Gain as function of overvoltage

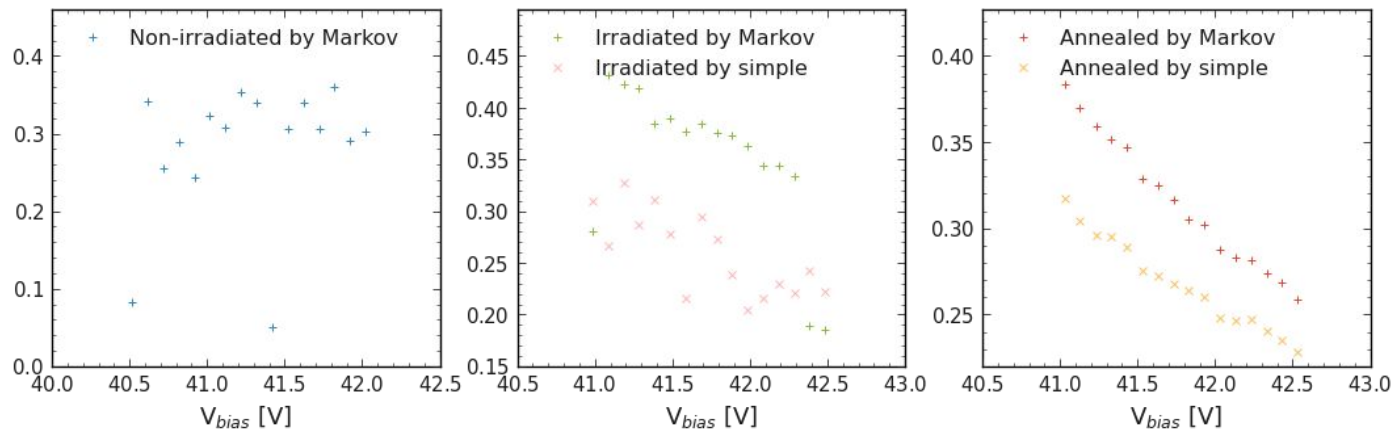


Time resolution for first photon peak for SiPM #15

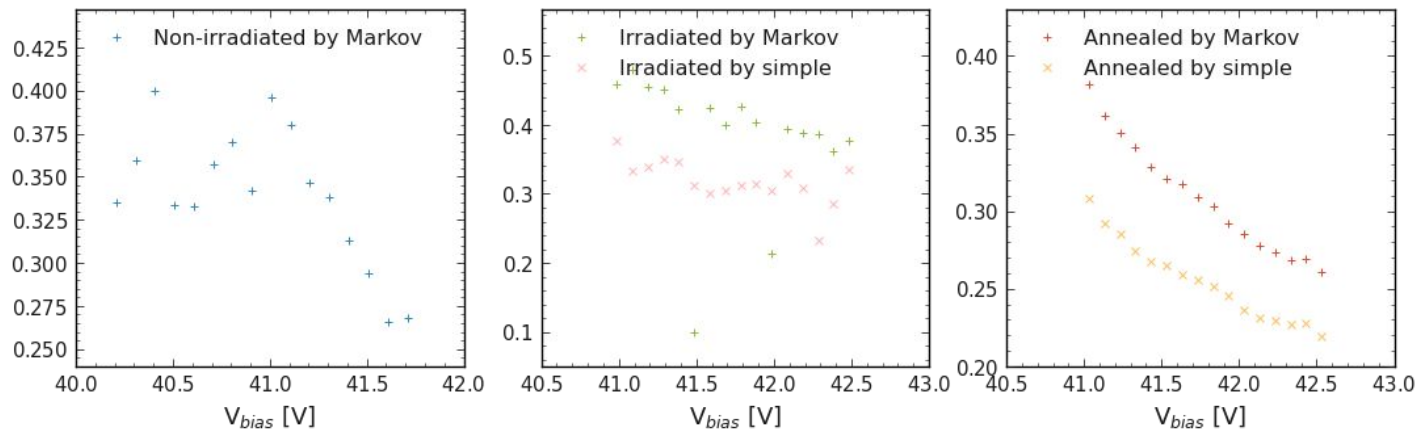
Time resolution for first photon peak



Time resolution of first peak for SiPM #15 at 20°



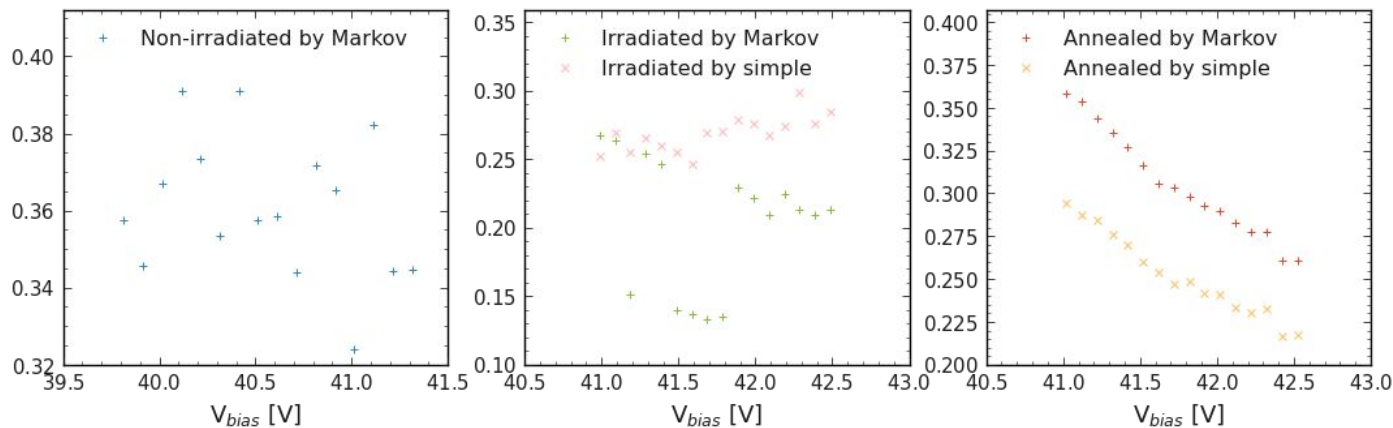
Time resolution of first peak for SiPM #15 at 10°



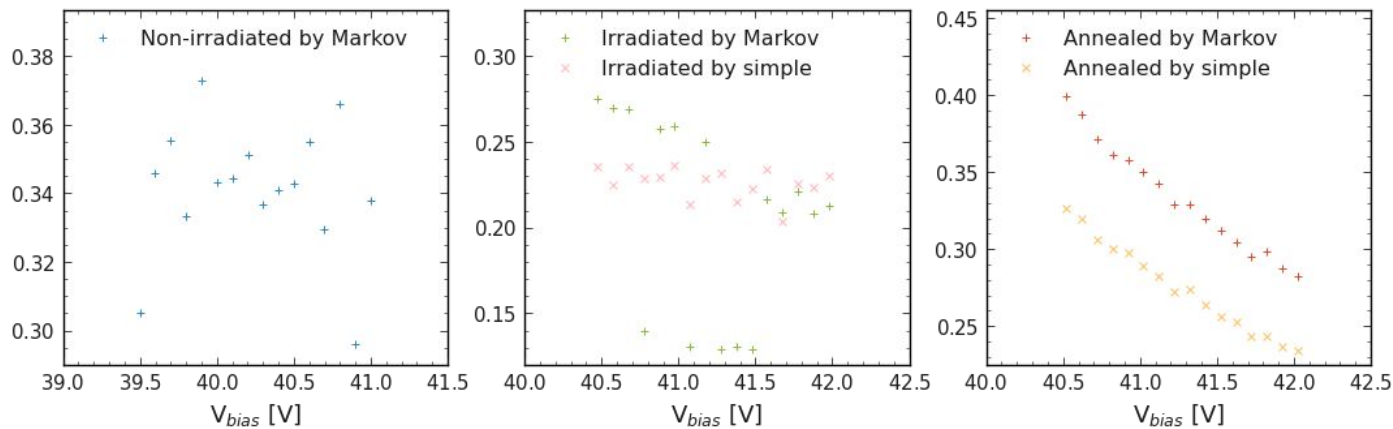
Time resolution for first photon peak



Time resolution of first peak for SiPM #15 at 0°



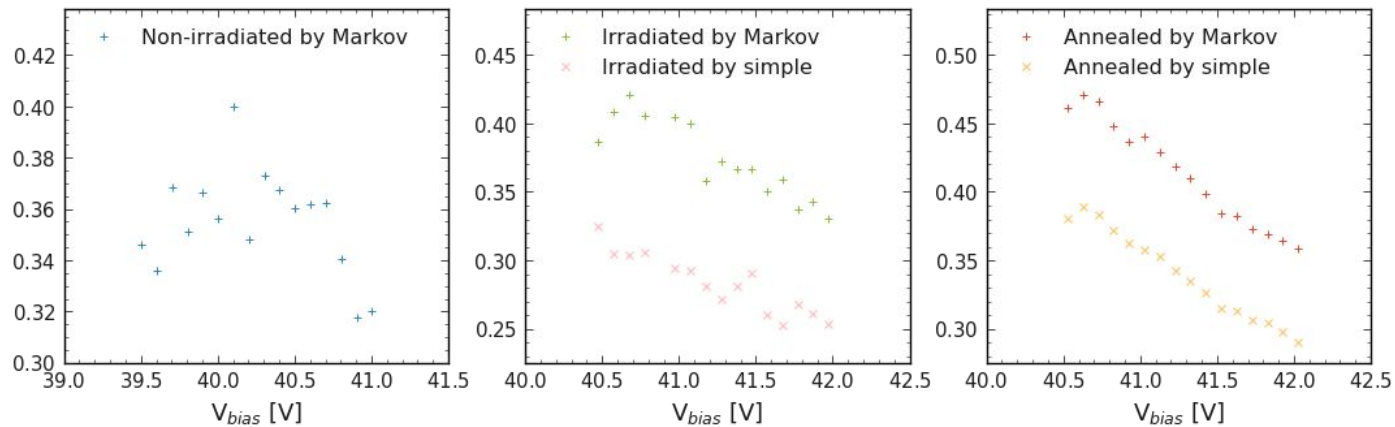
Time resolution of first peak for SiPM #15 at -10°



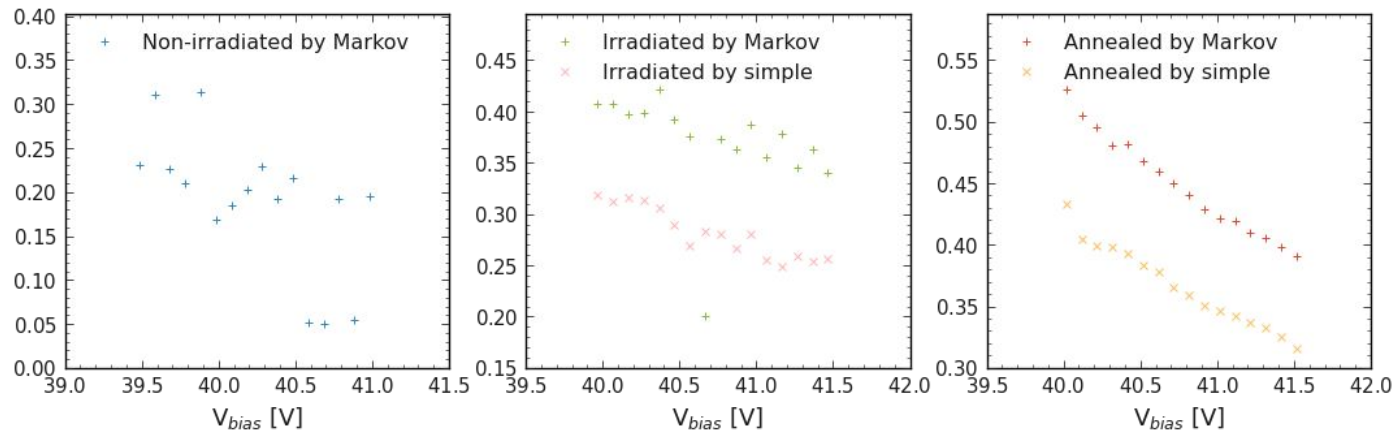
Time resolution for first photon peak



Time resolution of first peak for SiPM #15 at -20°



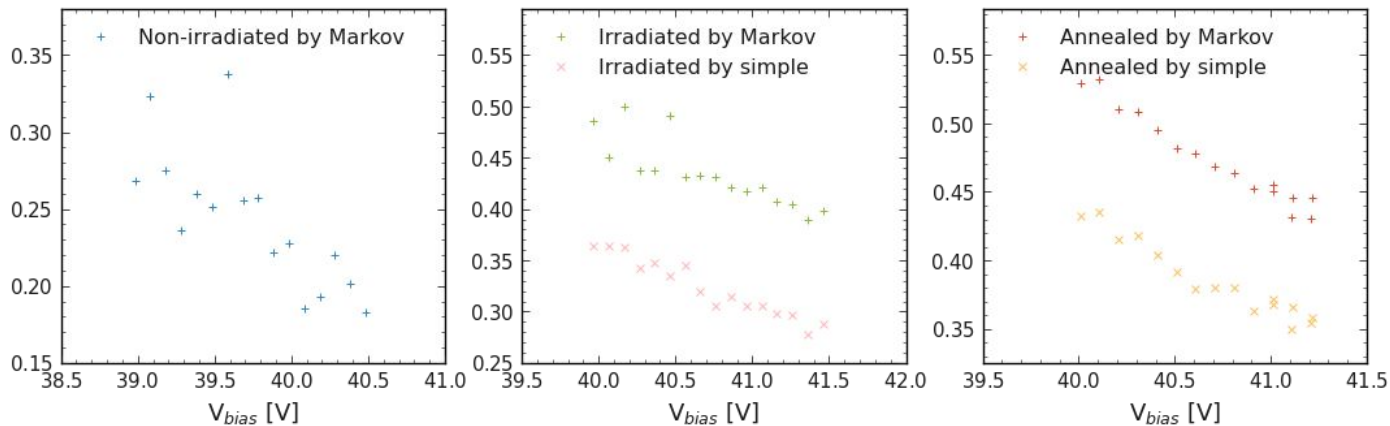
Time resolution of first peak for SiPM #15 at -30°



Time resolution for first photon peak



Time resolution of first peak for SiPM #15 at -35°



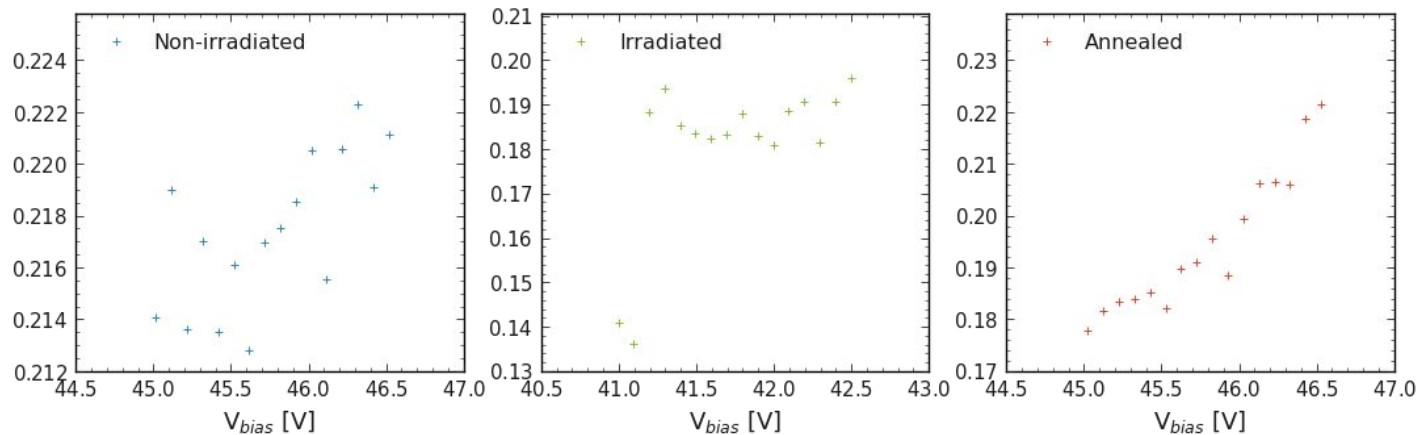
SIMP #8

Time resolution for all photon peaks for SiPM #8

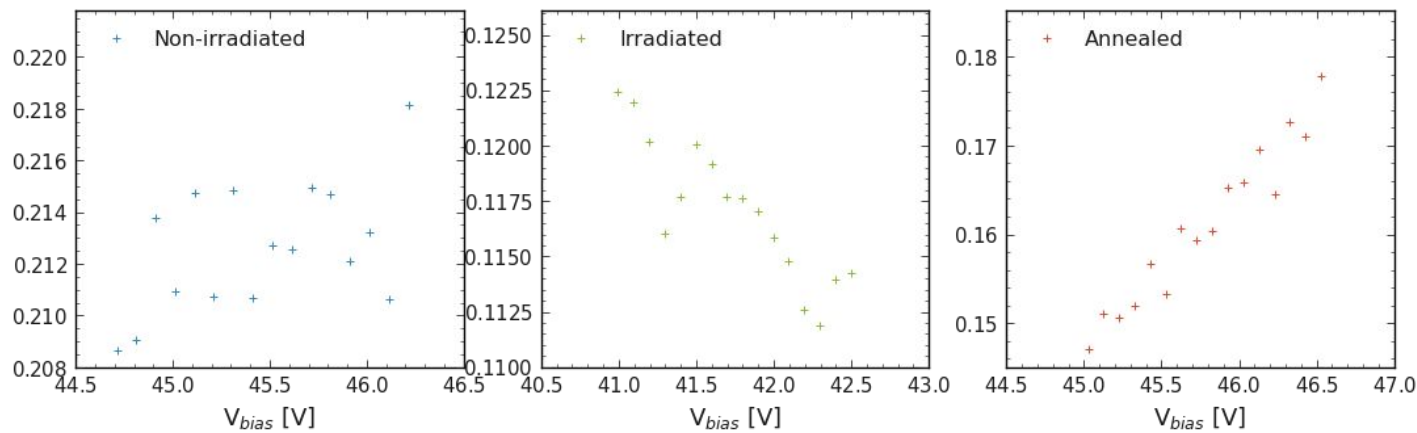
Time resolution for first photon peak



Time resolution of all peaks for SiPM #8 at 20°



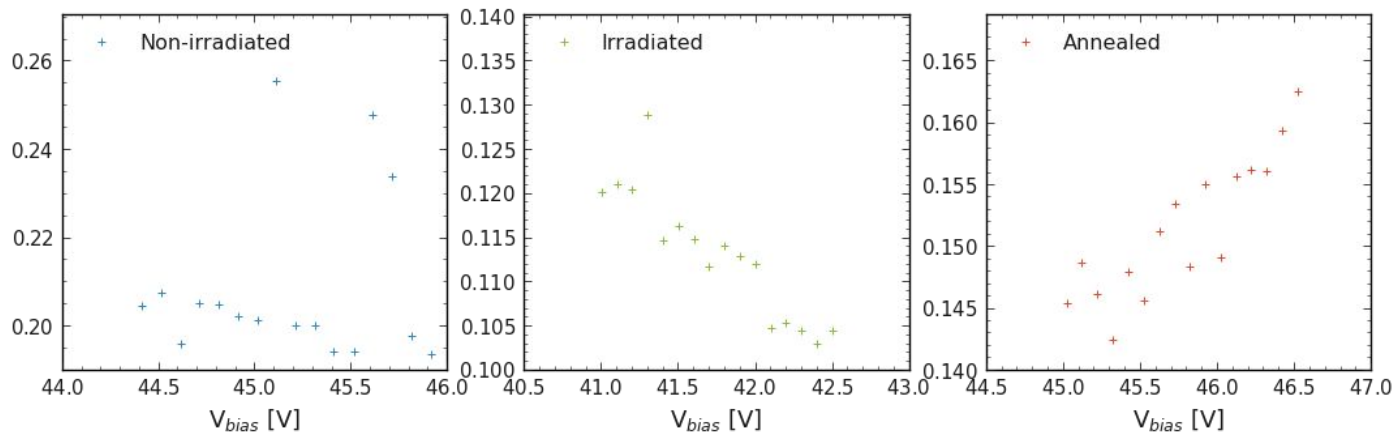
Time resolution of all peaks for SiPM #8 at 10°



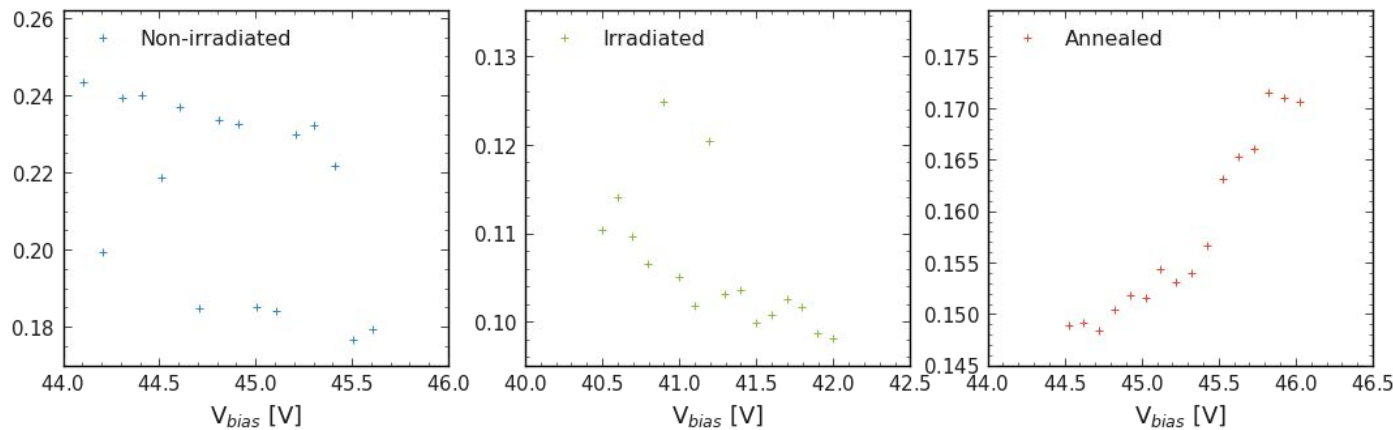
Time resolution for first photon peak



Time resolution of all peaks for SiPM #8 at 0°



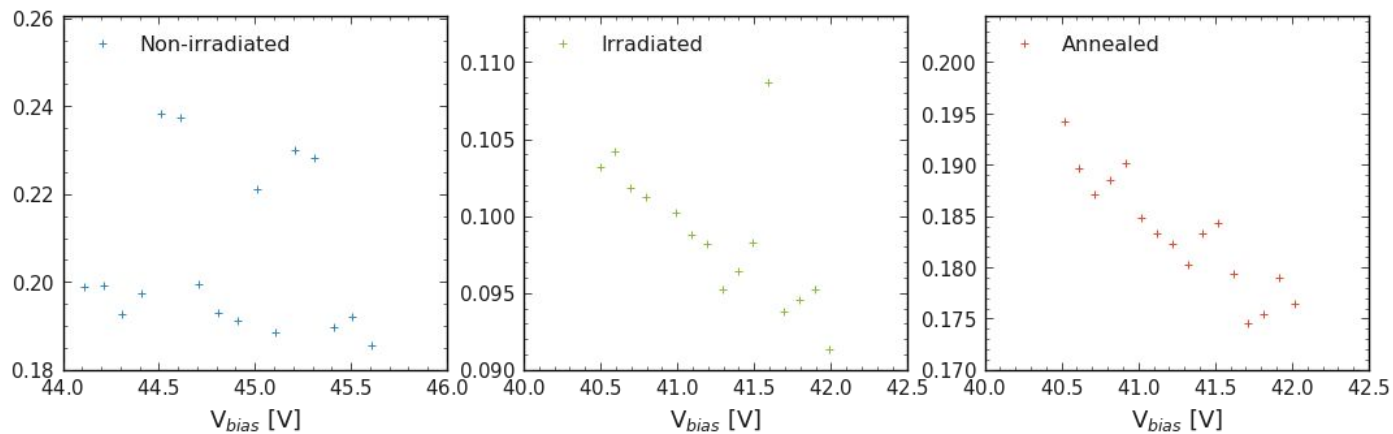
Time resolution of all peaks for SiPM #8 at -10°



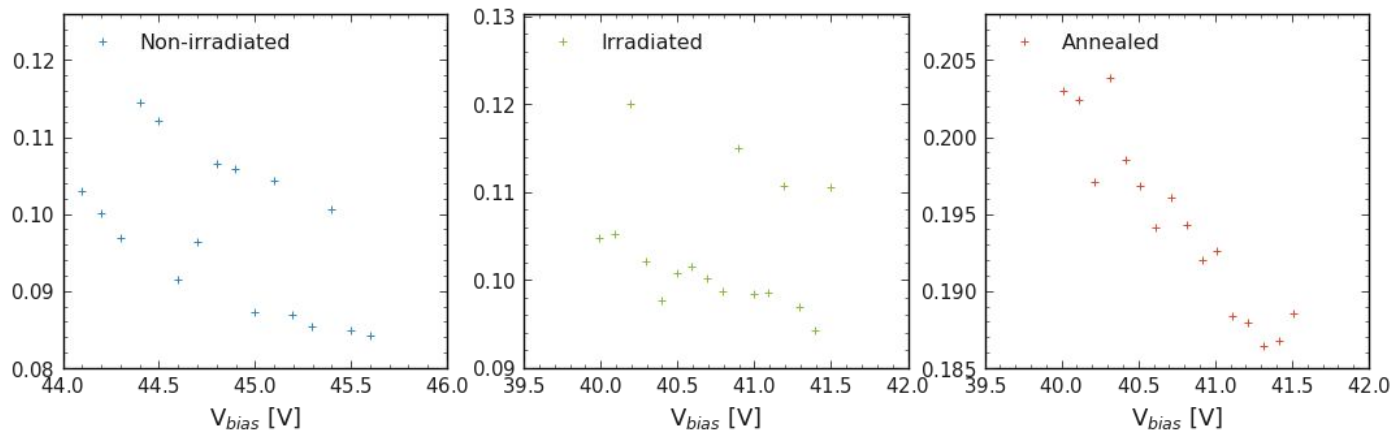
Time resolution for first photon peak



Time resolution of all peaks for SiPM #8 at -20°



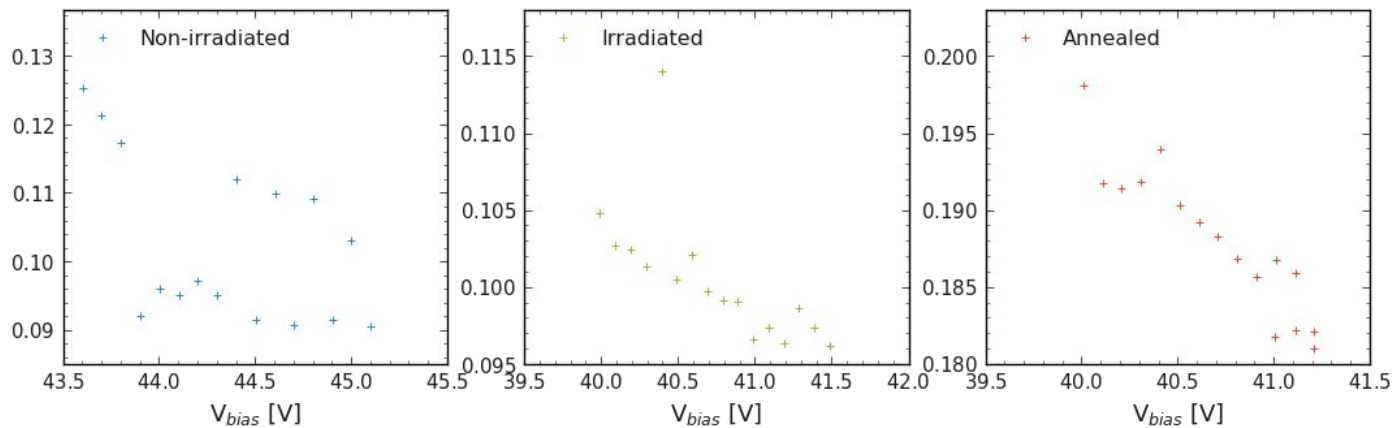
Time resolution of all peaks for SiPM #8 at -30°



Time resolution for first photon peak



Time resolution of all peaks for SiPM #8 at -35°





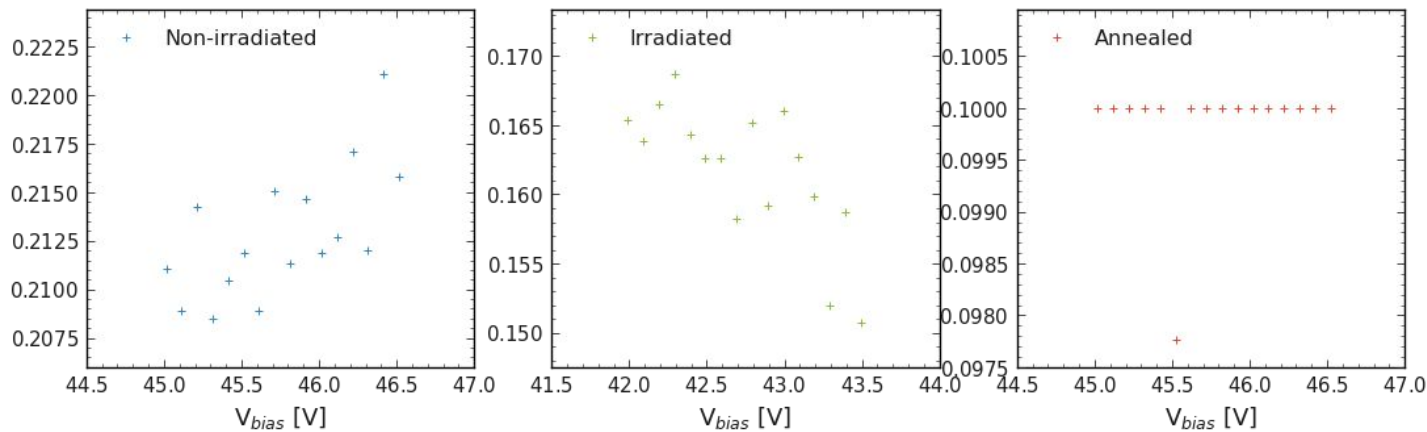
SIMP #9

Time resolution for all photon peaks for SiPM #9

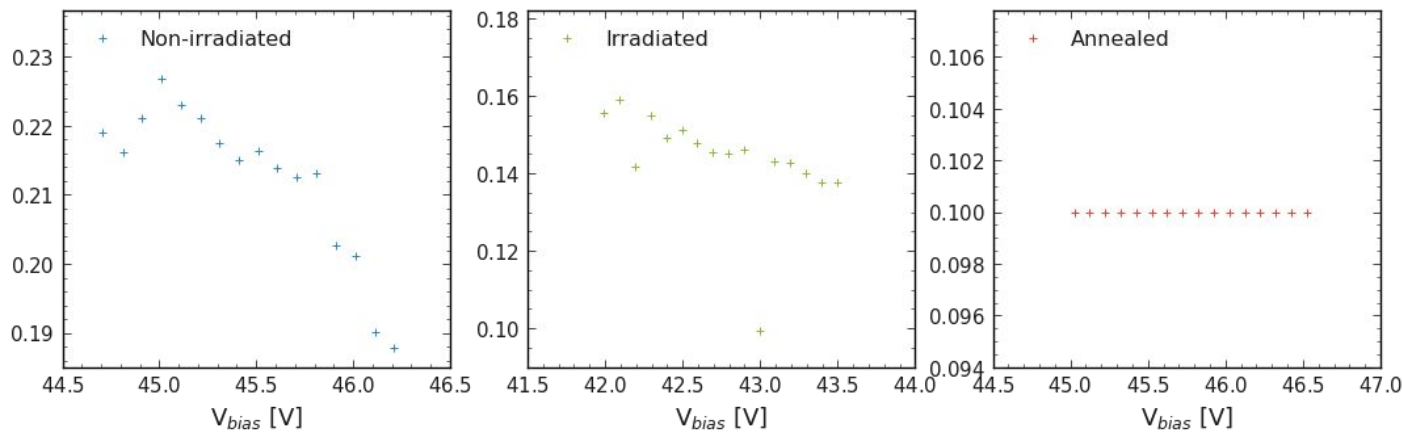
Time resolution for first photon peak



Time resolution of all peaks for SiPM #9 at 20°



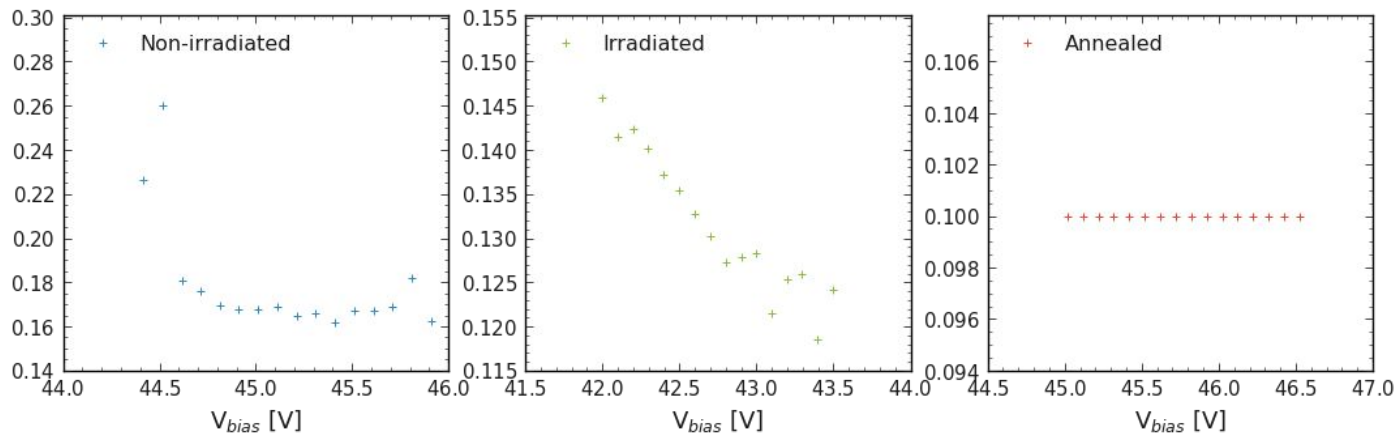
Time resolution of all peaks for SiPM #9 at 10°



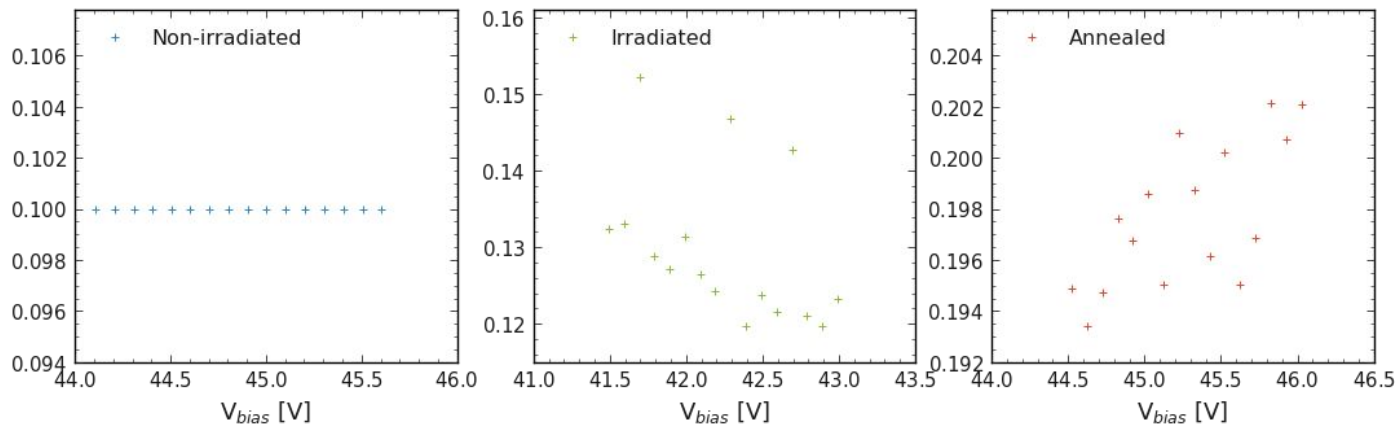
Time resolution for first photon peak



Time resolution of all peaks for SiPM #9 at 0°



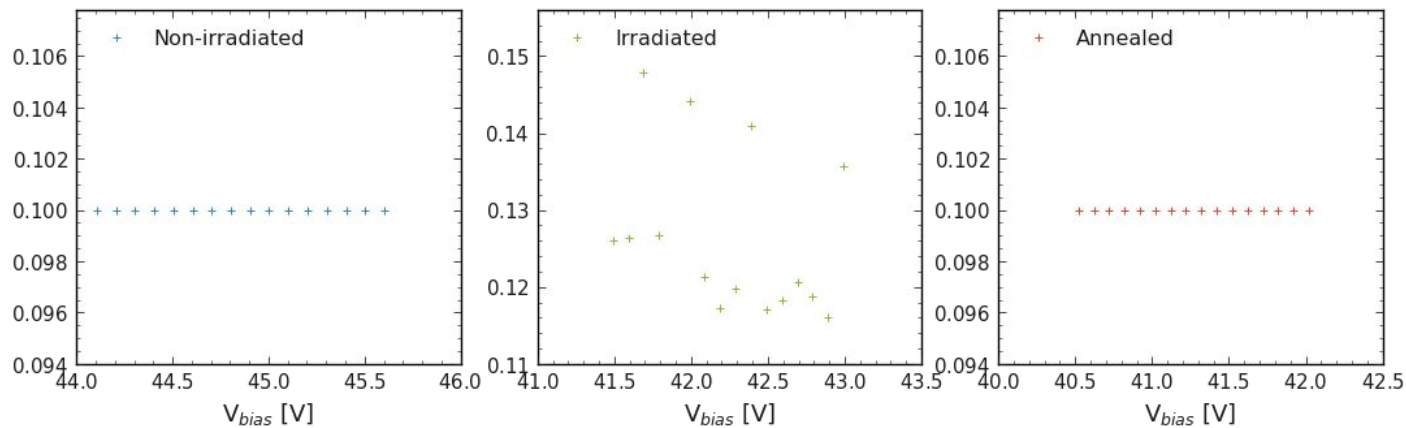
Time resolution of all peaks for SiPM #9 at -10°



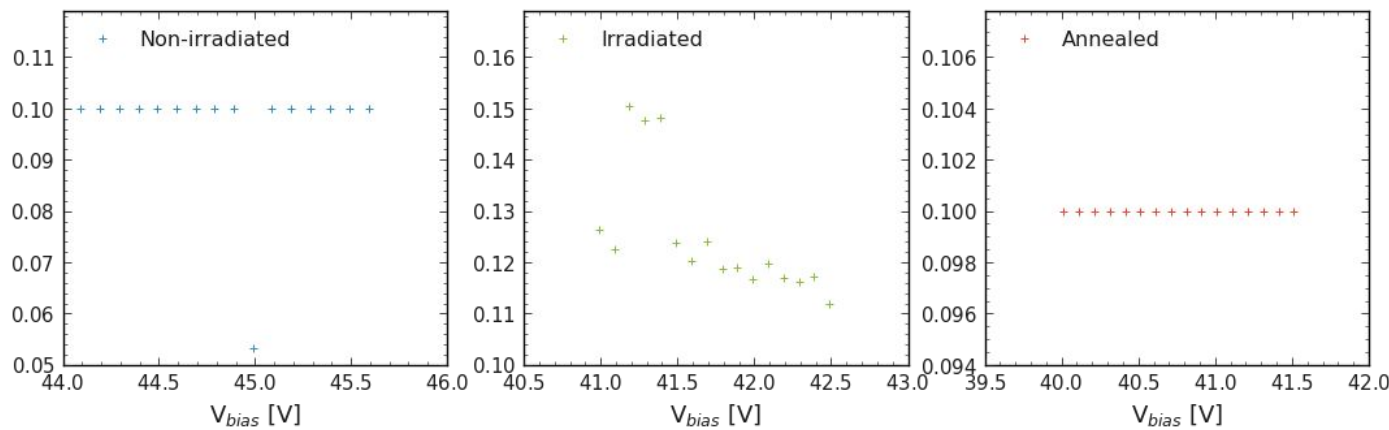
Time resolution for first photon peak



Time resolution of all peaks for SiPM #9 at -20°



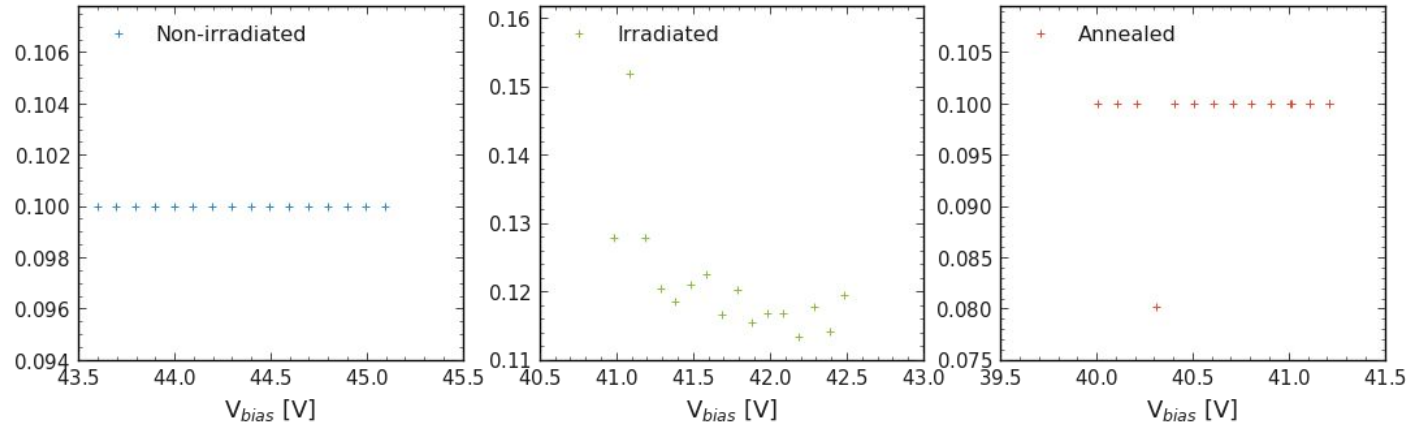
Time resolution of all peaks for SiPM #9 at -30°



Time resolution for first photon peak



Time resolution of all peaks for SiPM #9 at -35°



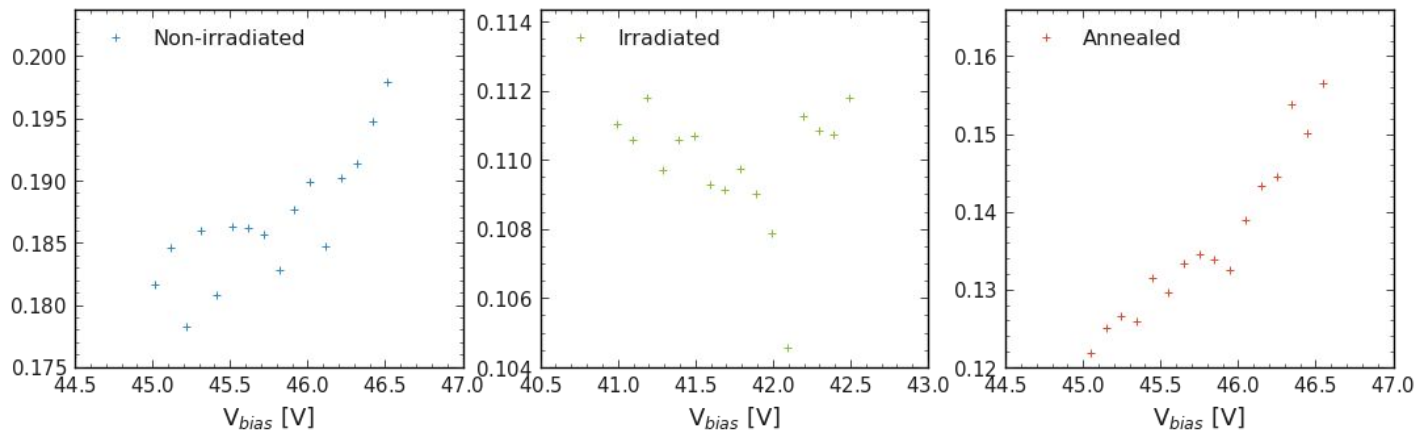
SiMP #10

Time resolution for all photon peaks for SiPM #10

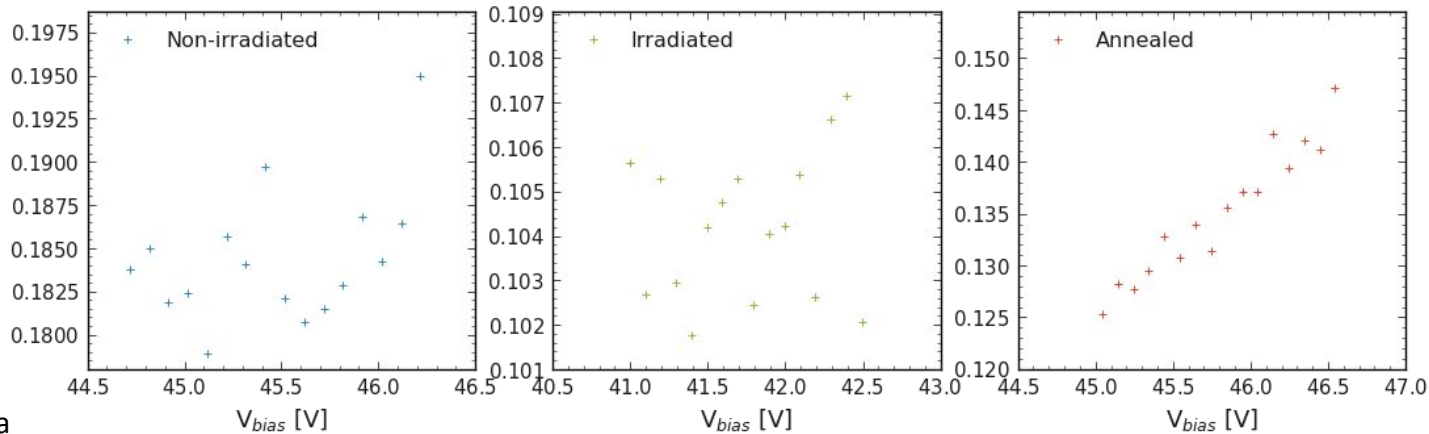
Time resolution for first photon peak



Time resolution of all peaks for SiPM #10 at 20°



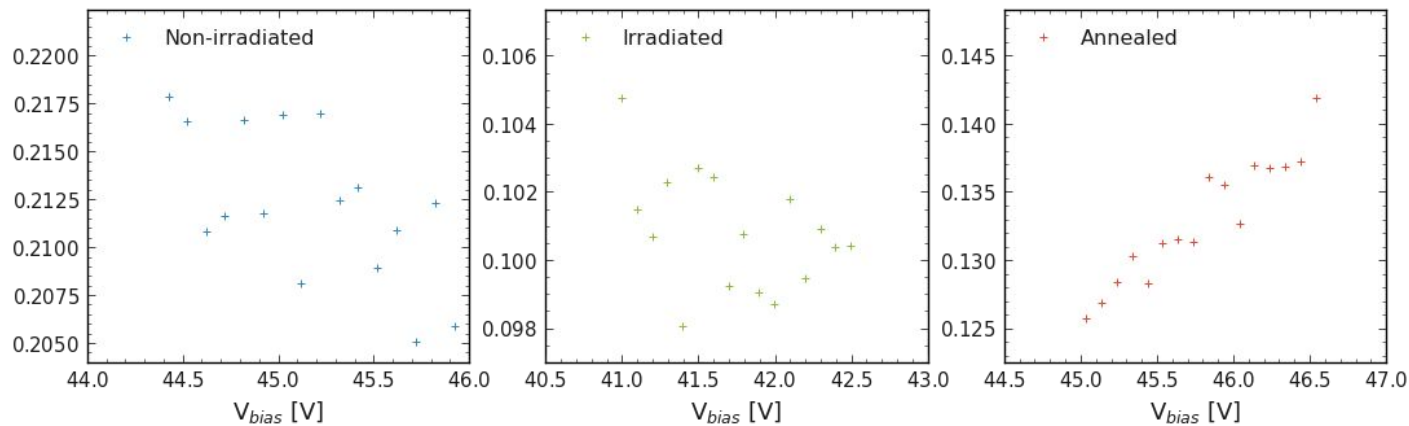
Time resolution of all peaks for SiPM #10 at 10°



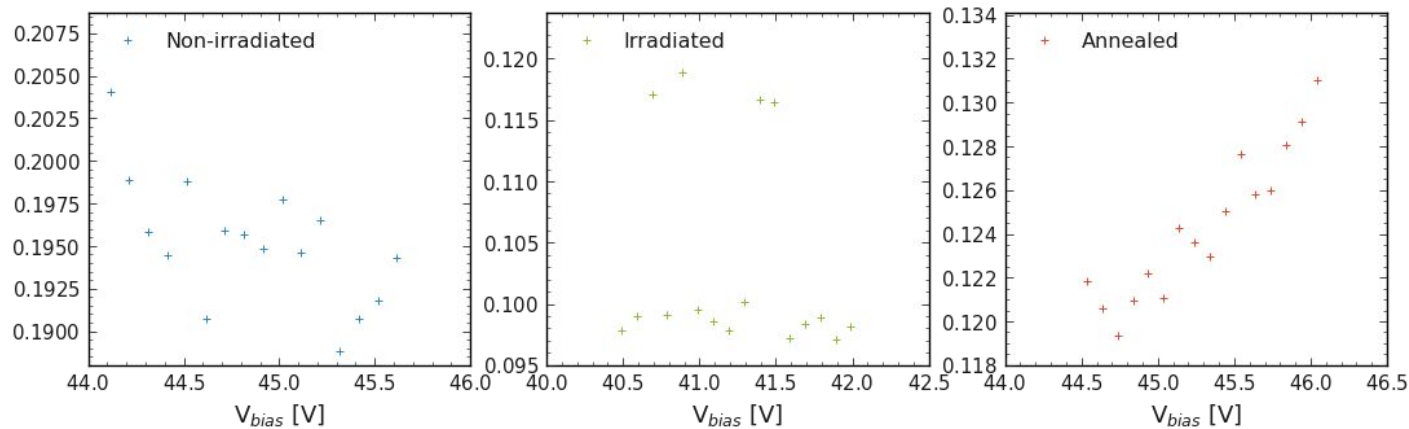
Time resolution for first photon peak



Time resolution of all peaks for SiPM #10 at 0°



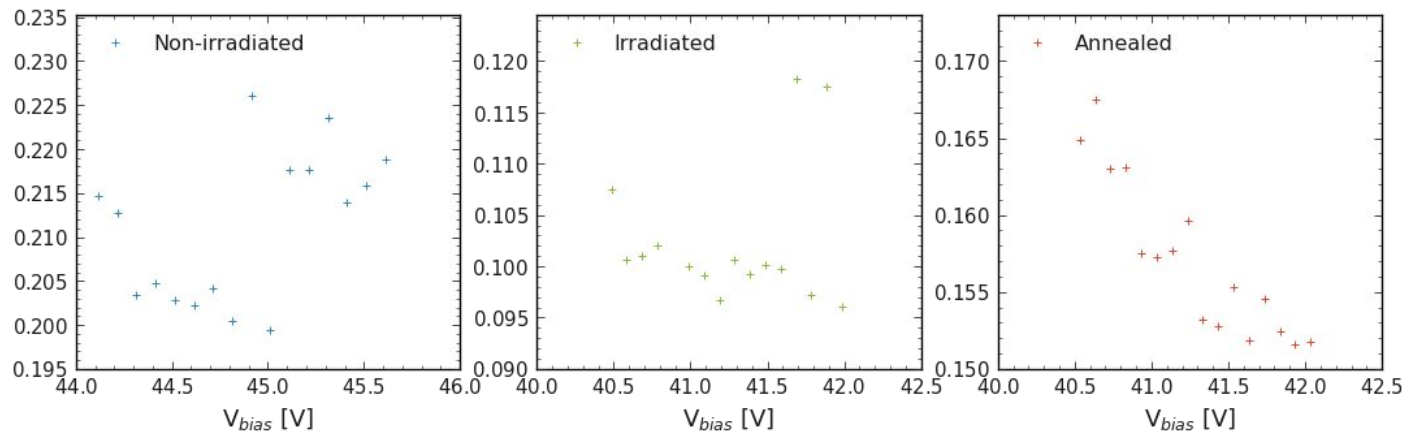
Time resolution of all peaks for SiPM #10 at -10°



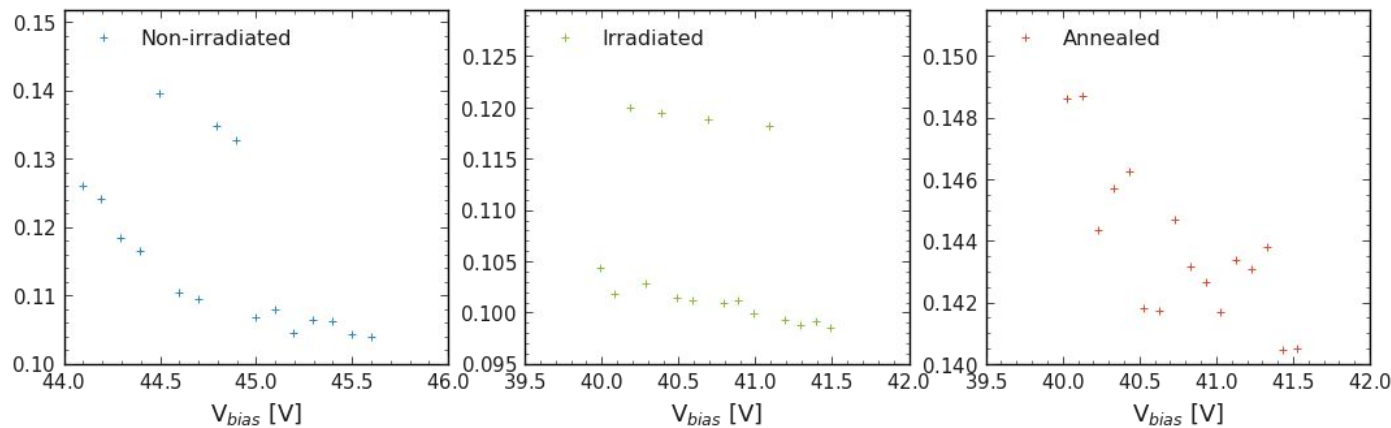
Time resolution for first photon peak



Time resolution of all peaks for SiPM #10 at -20°



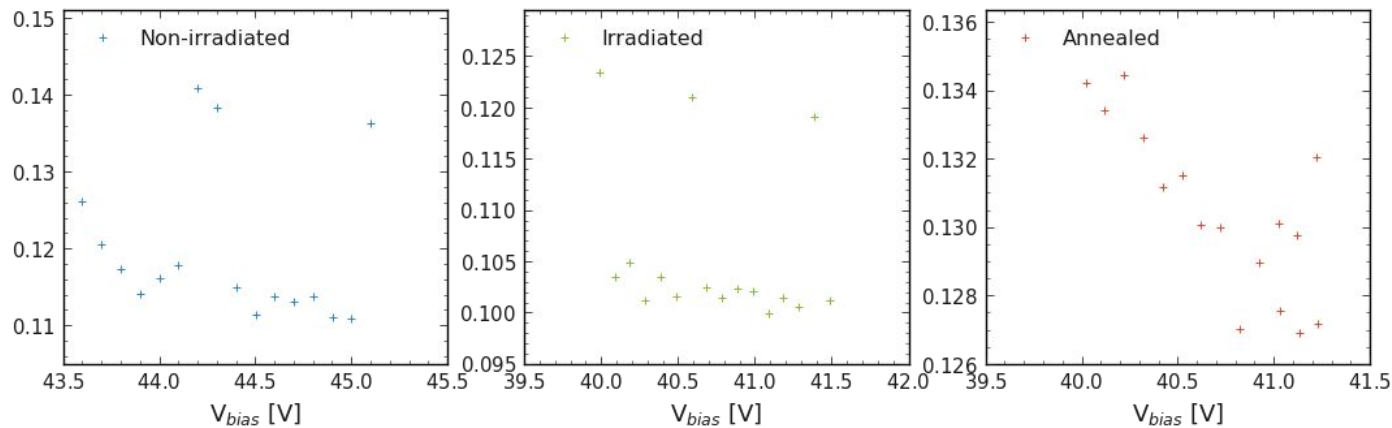
Time resolution of all peaks for SiPM #10 at -30°



Time resolution for first photon peak



Time resolution of all peaks for SiPM #10 at -35°



Backup

Breakdown voltages at temperatures for SiPMs



Index of SiPM	11		12		13		14		15	
Producer	FBK		FBK		FBK		FBK		Hamamatsu	
Dimension [mm×mm]	1 × 1		1 × 1		1 × 1		1 × 1		3 × 3	
Pitch [μm]	15		15		15		15		50	
Temperature [$^{\circ}$]	Breakdown voltage [V_0]		Breakdown voltage [V_0]		Breakdown voltage [V_0]		Breakdown voltage [V_0]		Breakdown voltage [V_0]	
	non-irr	irr	non-irr	irr	non-irr	irr	non-irr	irr	non-irr	irr
20	33.13	32.63	33.15	32.03	32.56	31.78	32.43	32.17	38.16	37.66
10	33.78	32.20	32.06	31.77	31.93	31.60	32.22	31.89	37.73	37.08
0	31.16	28.45	31.53	31.37	31.81	31.26	31.31	31.50	37.76	37.00
-10	31.36	31.64	31.55	30.25	30.79	30.97	31.20	31.16	37.39	36.65
-20	31.19	31.06	30.95	30.94	31.20	30.71	31.43	31.05	36.88	36.16
-30	31.53	30.79	31.25	30.69	30.81	30.49	30.65	30.54	35.77	35.83
-35	30.45	30.50	30.76	30.44	30.62	30.32	30.41	29.85	35.73	35.63
-40	29.97	30.16	30.59	30.40	30.05	30.29	30.48	30.35	35.26	36.66

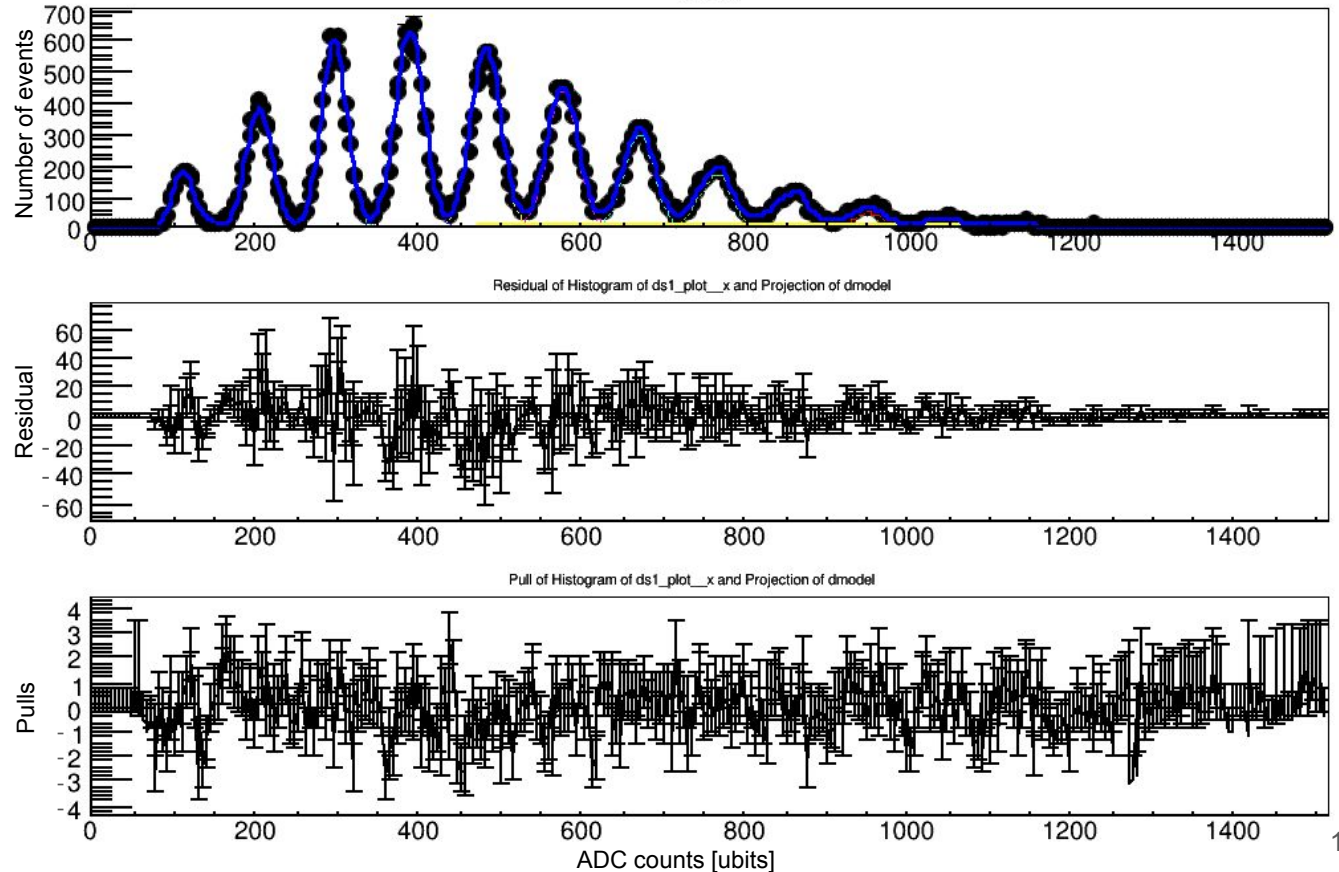
- For Hamamatsu device the breakdown voltages agree with previous measurements
- For some FBK devices, the breakdown voltages do not agree with previous measurements.
- After finishing studies related to breakdown voltage, we will continue with extraction time resolution

Fit of photon spectra



- Photon spectra are extracted
- Photon spectra are fitted sum of convolution poissonian and gaussian distribution to extract gain and average of photons
- From gain we can extract breakdown voltage

SiPM #13



Fit of time resolution



- Split photon spectra into two regions: first photon peak (green) and other photon peaks (red)
- For #13 SiPMs, we fit first photon peak (green) and all photon peaks (green + red)

