

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

Padova meeting  
14/3/2024

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INFN Padova

## 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
- Time resolution for others photon peaks (Markov and simple) for SiPMs with recognized spectra
- Darkcount rates for SiPMs - Preliminary (Missing and no-processed data)
- Change parameters in Markov algorithm and share them - Backup

## To Do:

- Add fitted spectra (one bias voltage  $\sim 1.0$  per temperature per SiPM)
- Check results and provide better fits if needed
- Update table with fitted breakdown voltages and slope with uncertainties
- Irradiation campaign in Legnaro from 22<sup>th</sup> to 24<sup>th</sup> April 2024

# Tests with irradiated modules in Padova



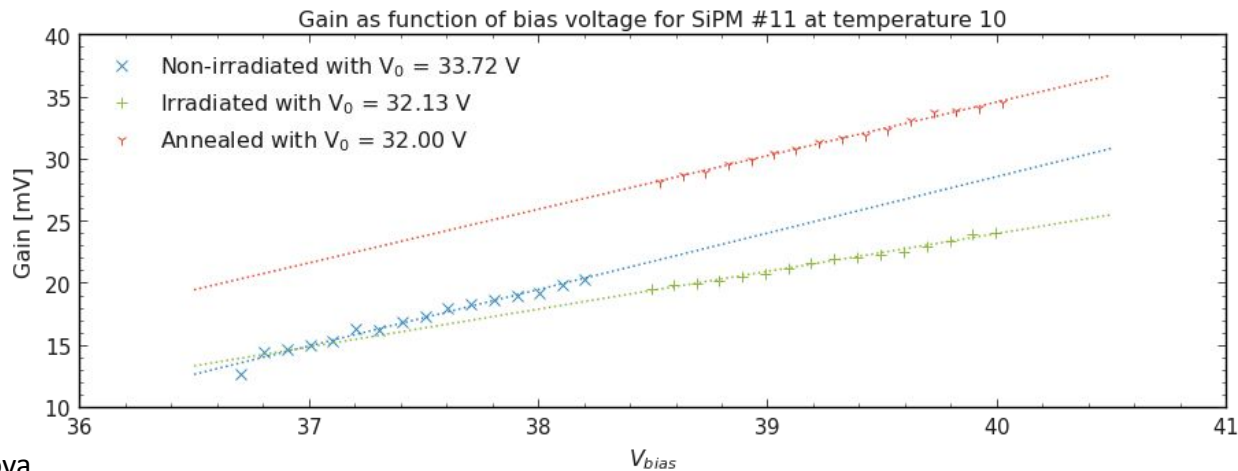
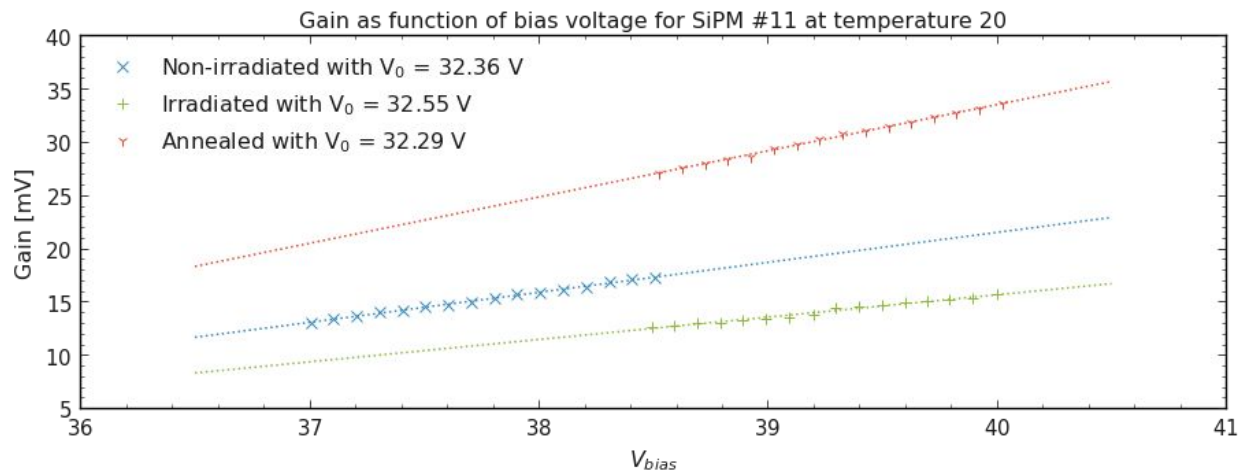
- In Belle II, MCP-PMTs with extended lifetime have been installed and they have limited lifetime depending on accumulated charge.
- We are trying to understand if they eventually can be replaced with SiPMs.
- We irradiated 24 SiPMs modules with different neutron fluxes and tested by laser.
- Eight of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

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

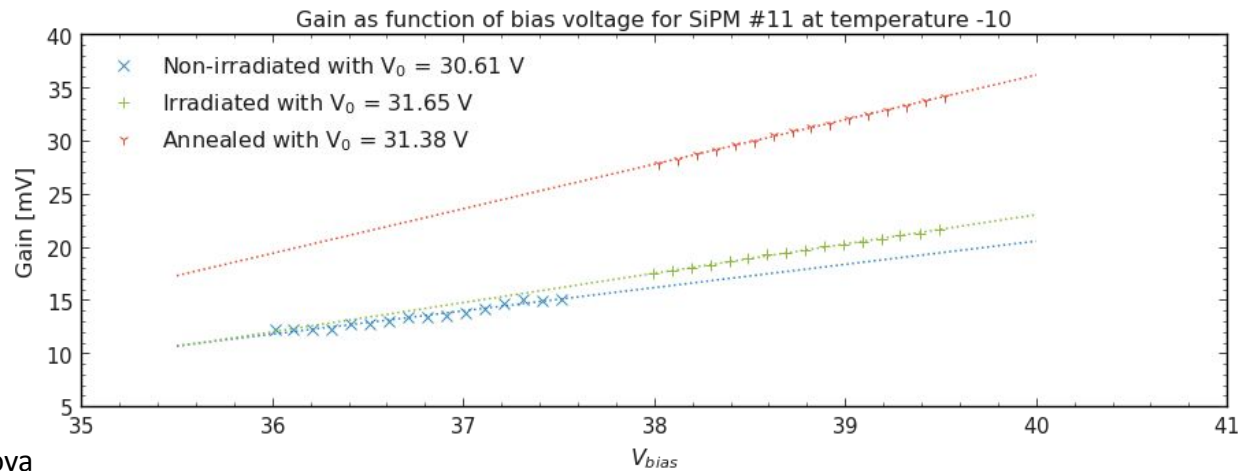
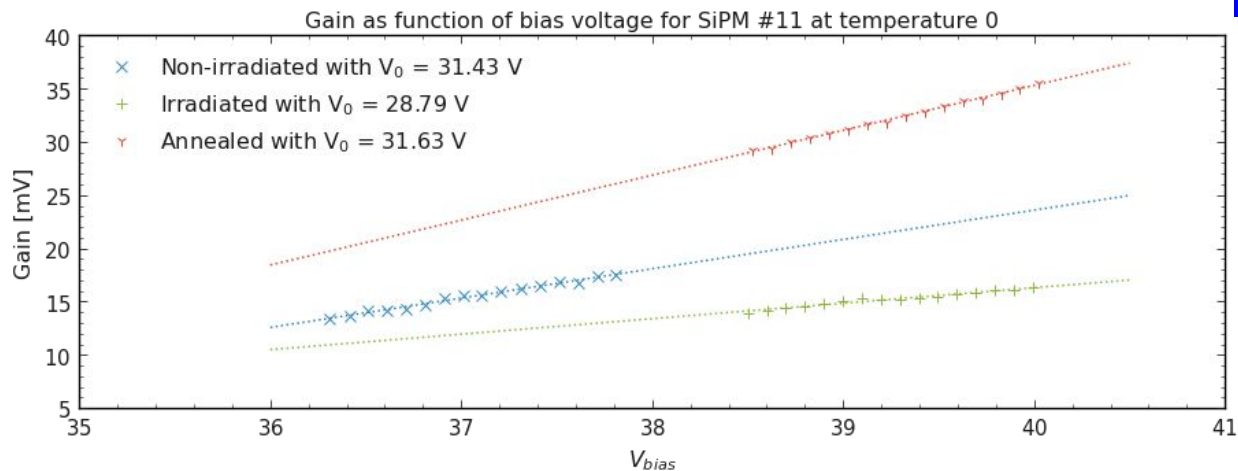
# SIMP #11

# Gain as function of bias voltage for SiPM #11

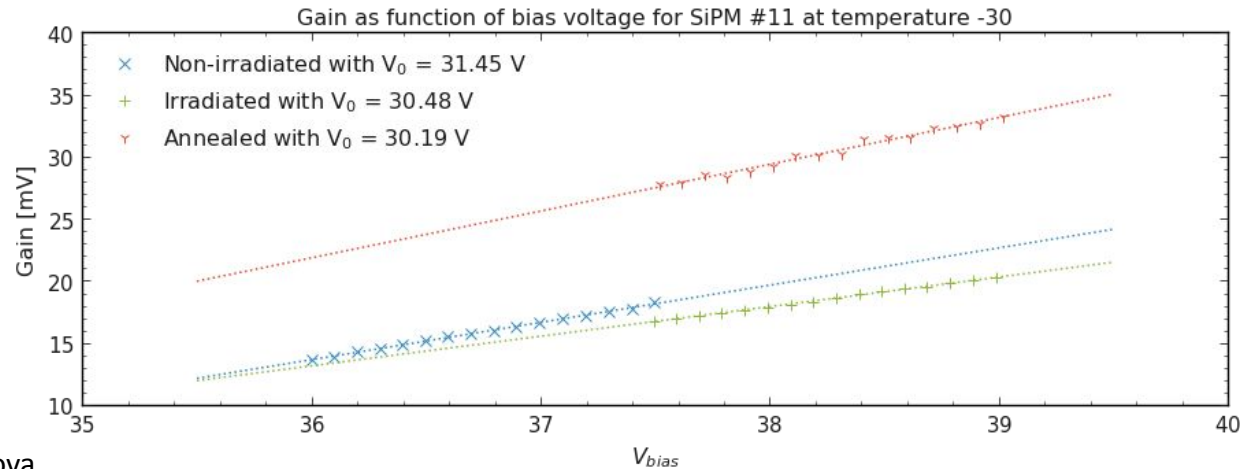
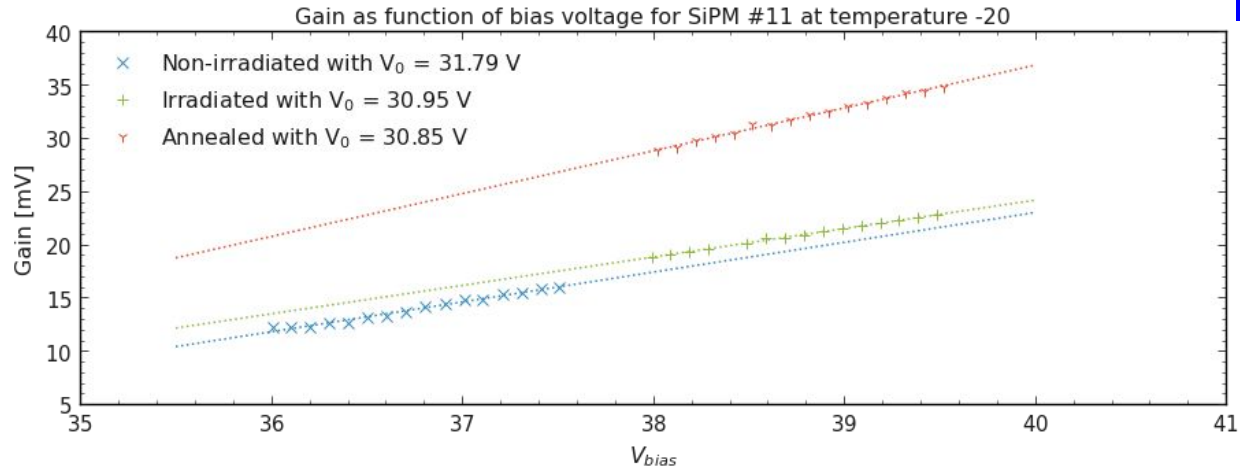
# Gain as function of bias voltage



# Gain as function of bias voltage

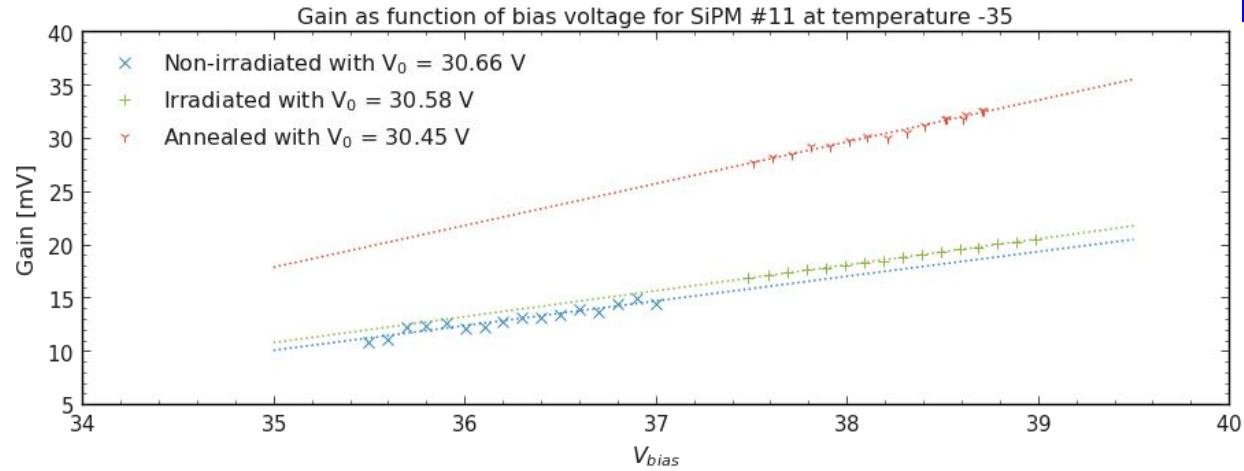


# Gain as function of bias voltage



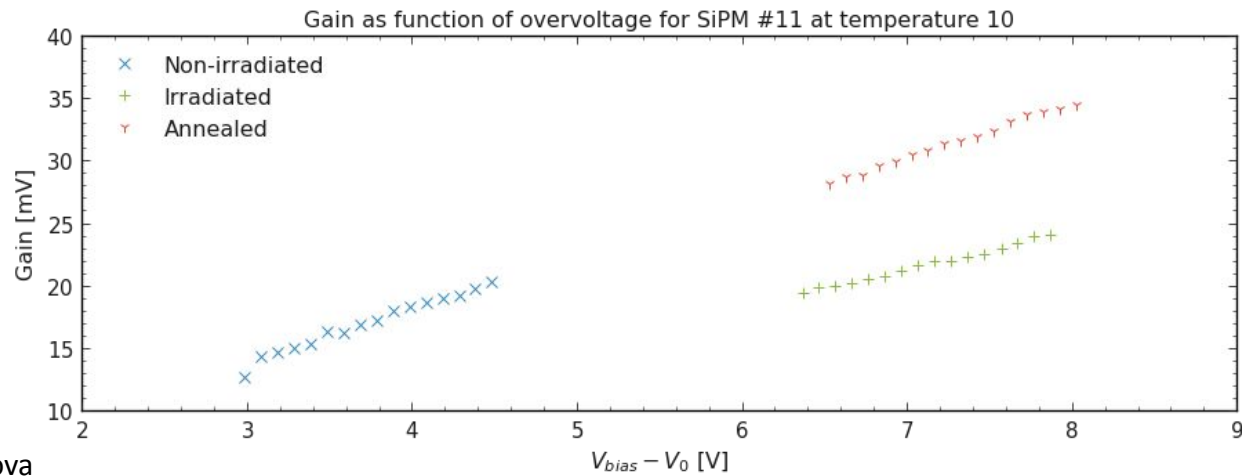
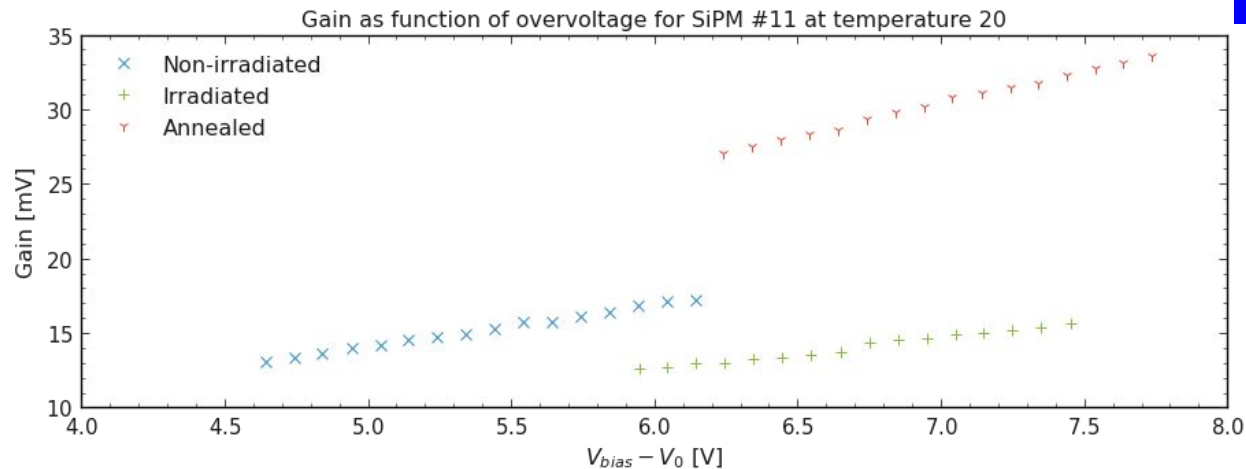


# Gain as function of bias voltage

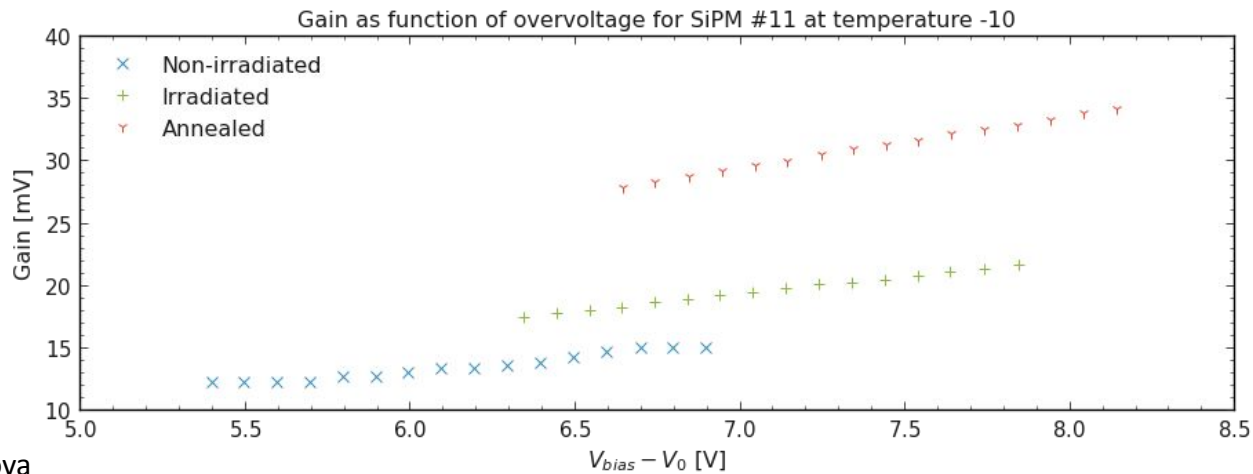
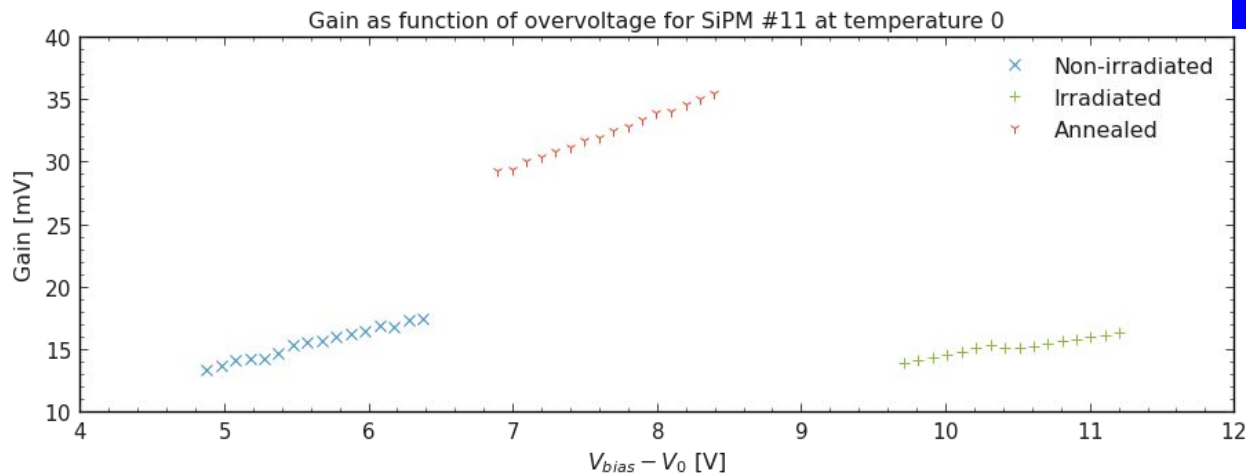


# Gain as function of overvoltage for SiPM #11

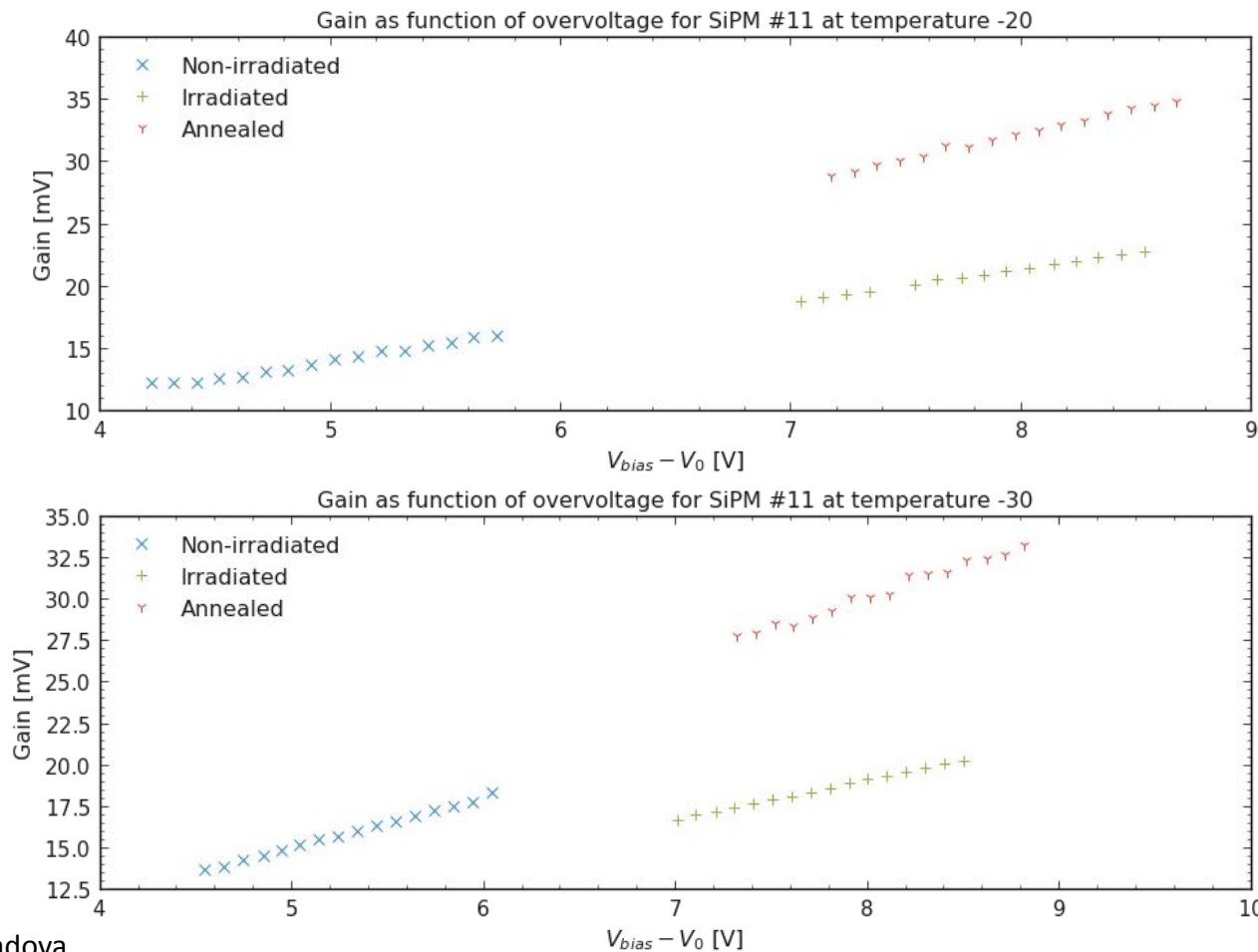
# Gain as function of overvoltage



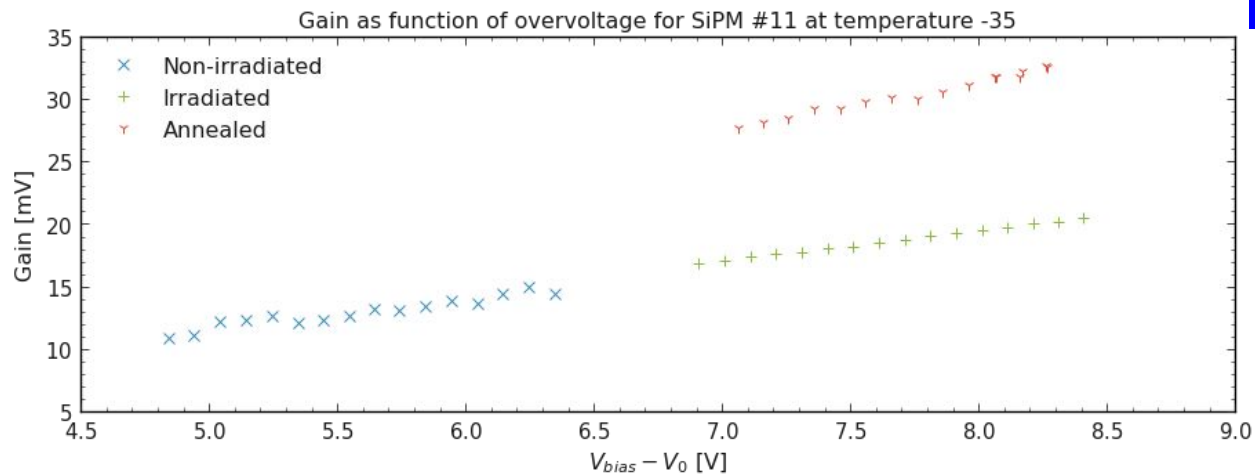
# Gain as function of overvoltage



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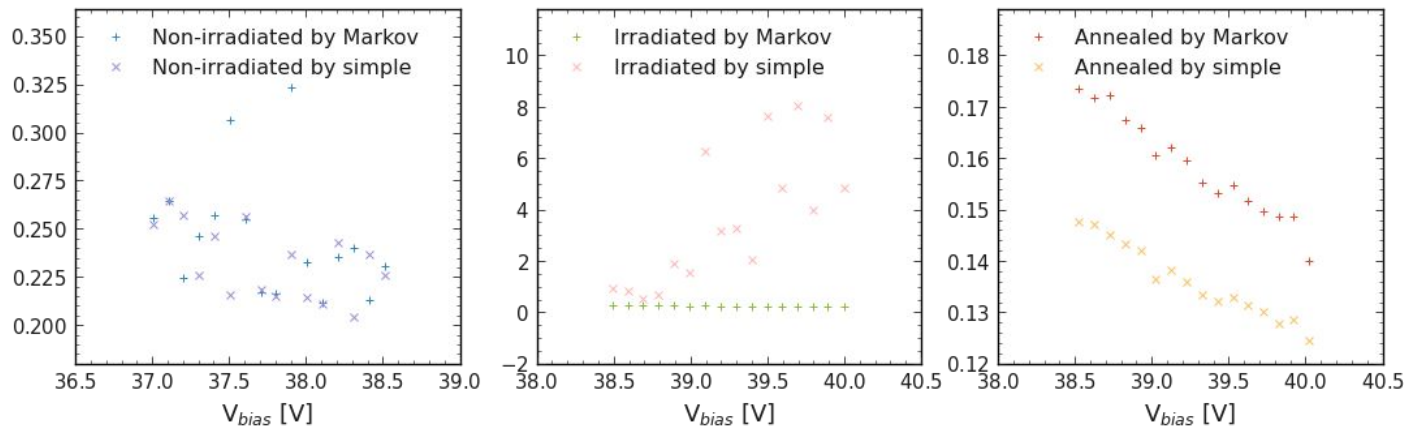


# Time resolution for first photon peak for SiPM #11

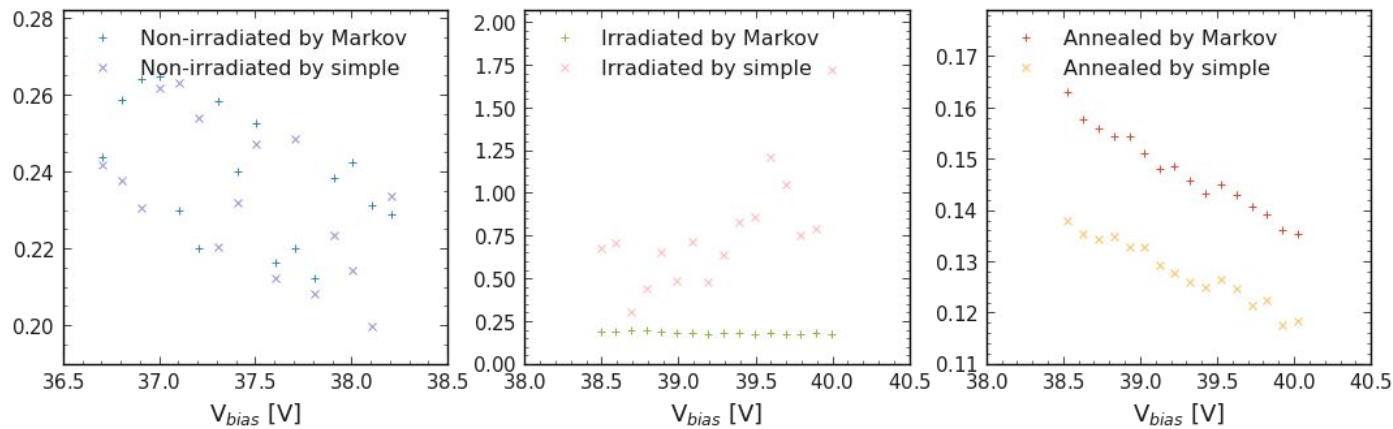
# Time resolution for first photon peak



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



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

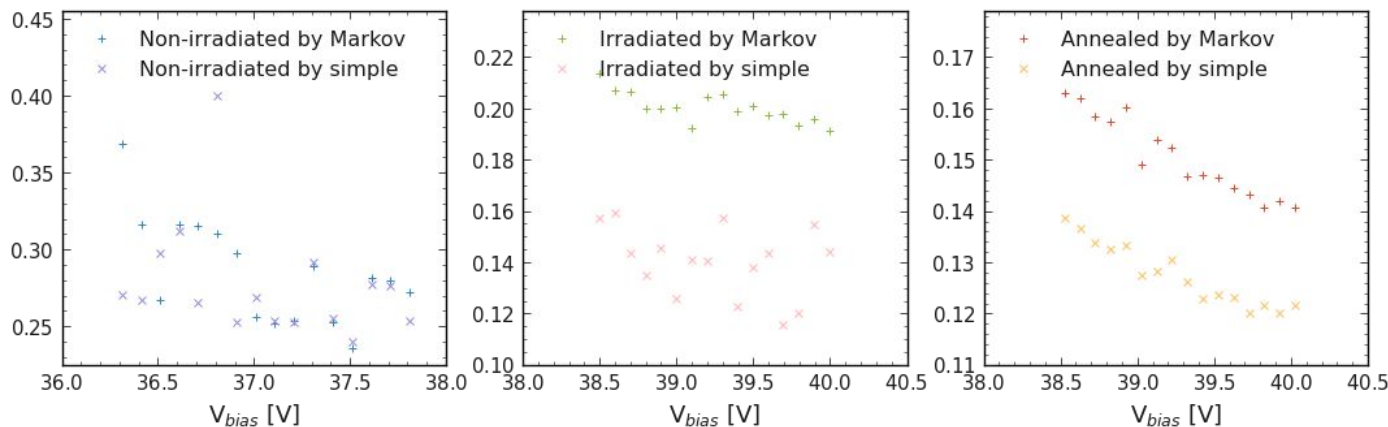




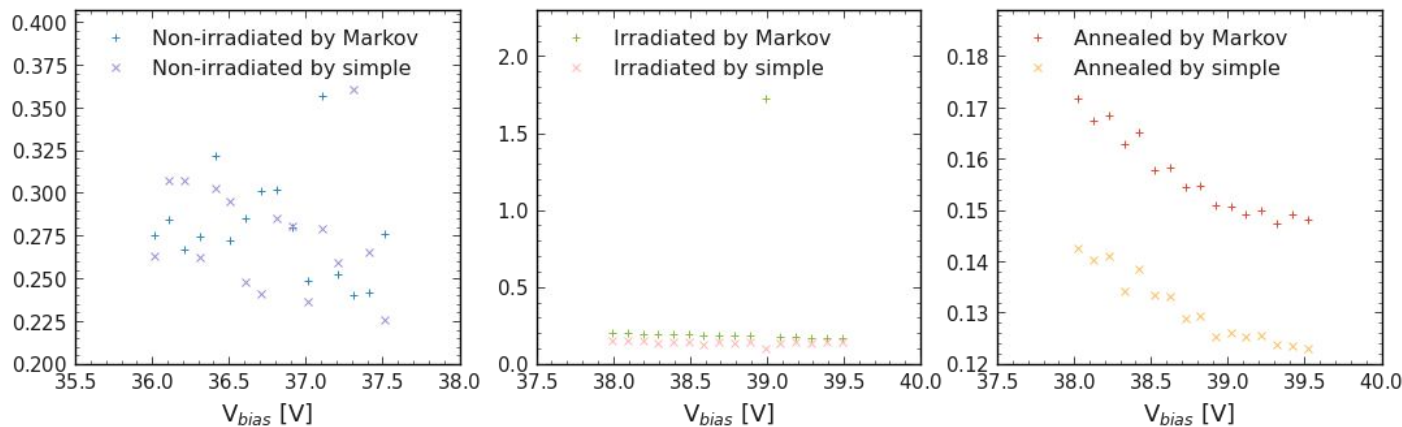
# Time resolution for first photon peak



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



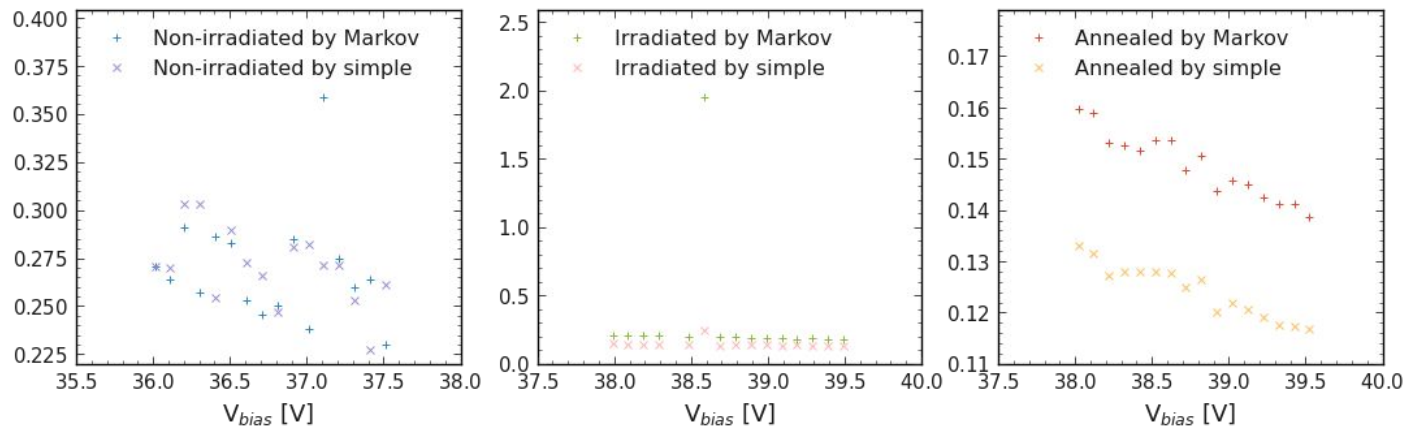
Time resolution of first peak for SiPM #11 at -10°



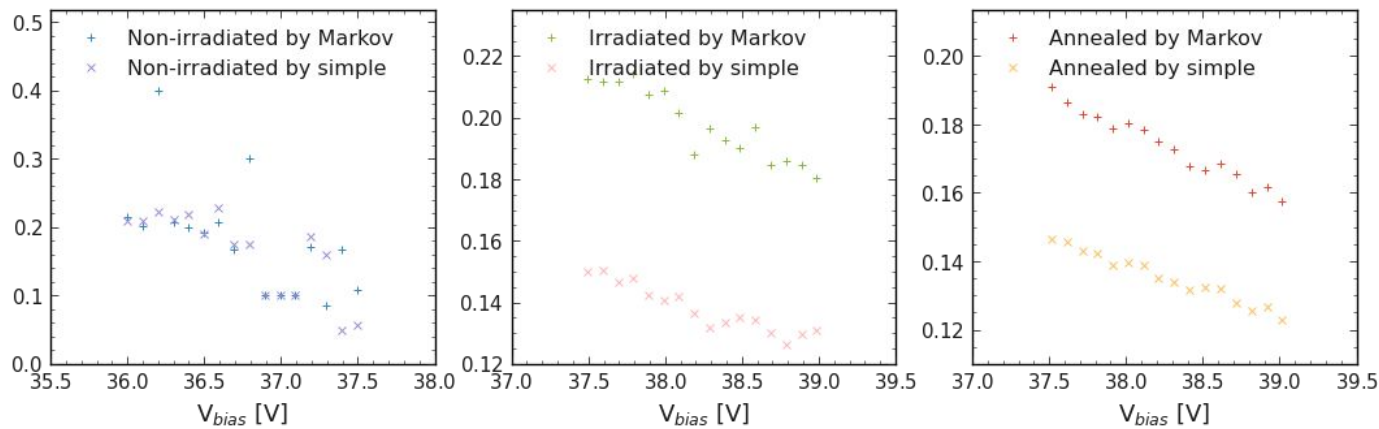
# Time resolution for first photon peak



Time resolution of first peak for SiPM #11 at  $-20^\circ$



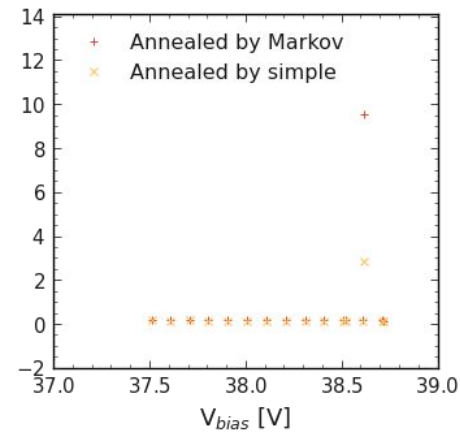
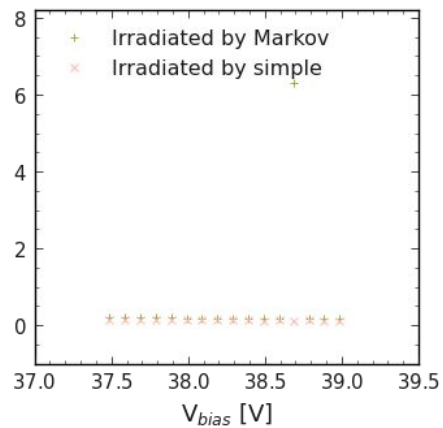
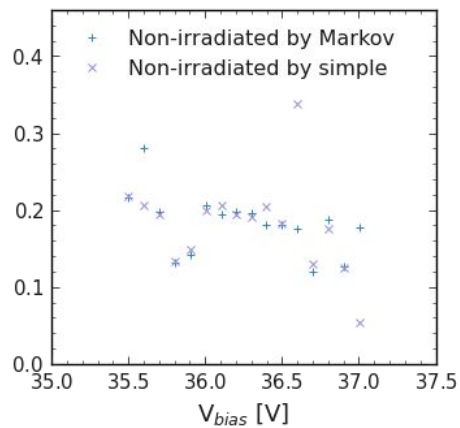
Time resolution of first peak for SiPM #11 at  $-30^\circ$



# Time resolution for first photon peak



Time resolution of first peak for SiPM #11 at  $-35^\circ$

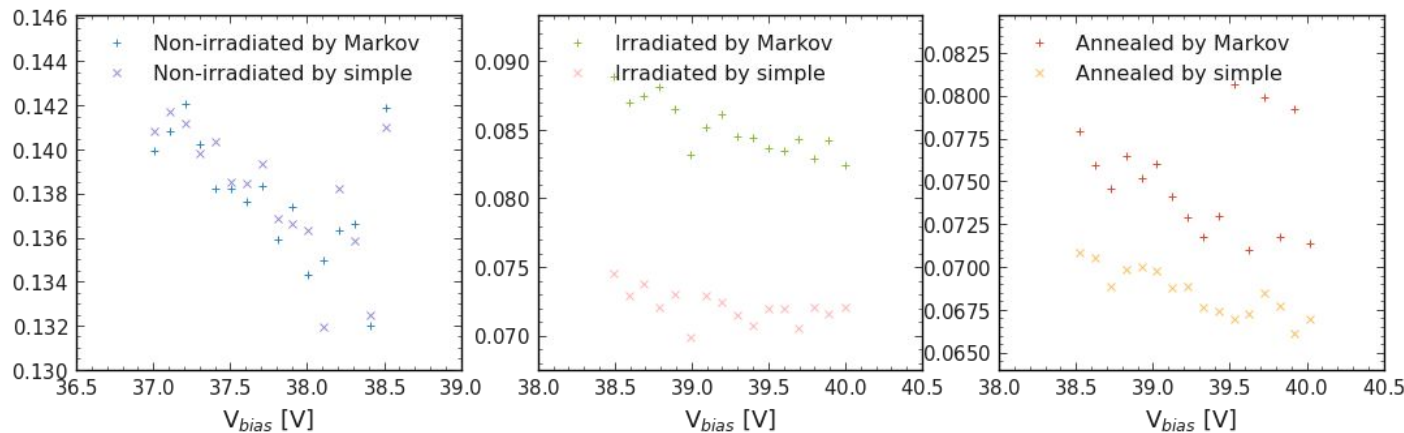


# Time resolution for other photon peaks for SiPM #11

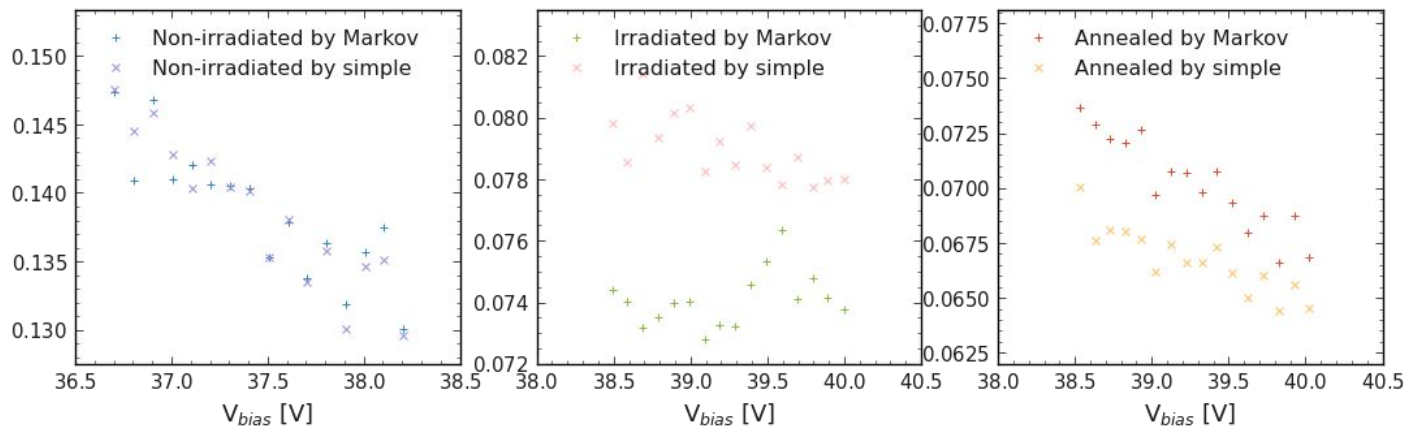
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #11 at 20°



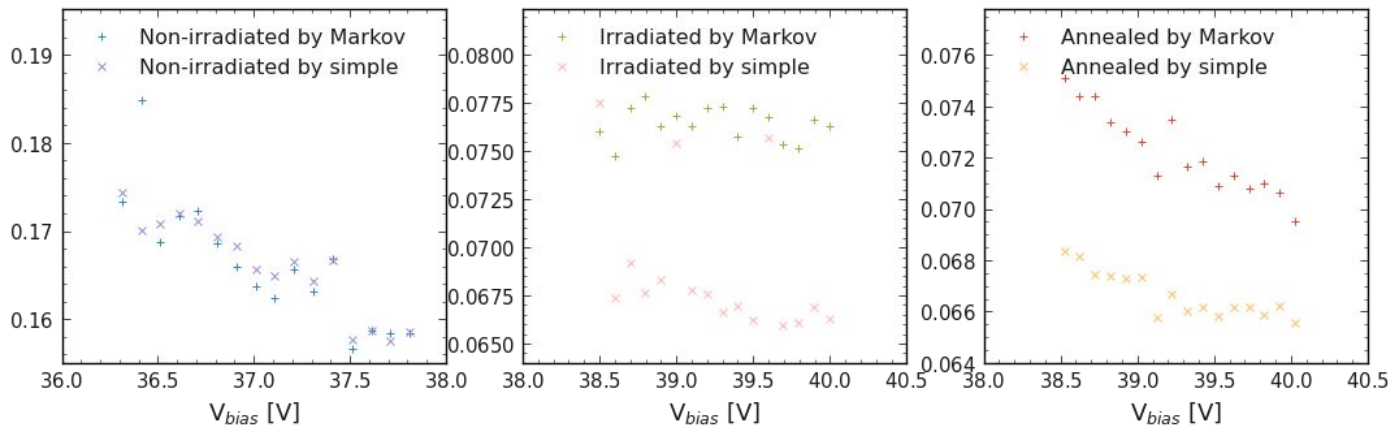
Time resolution of other peaks for SiPM #11 at 10°



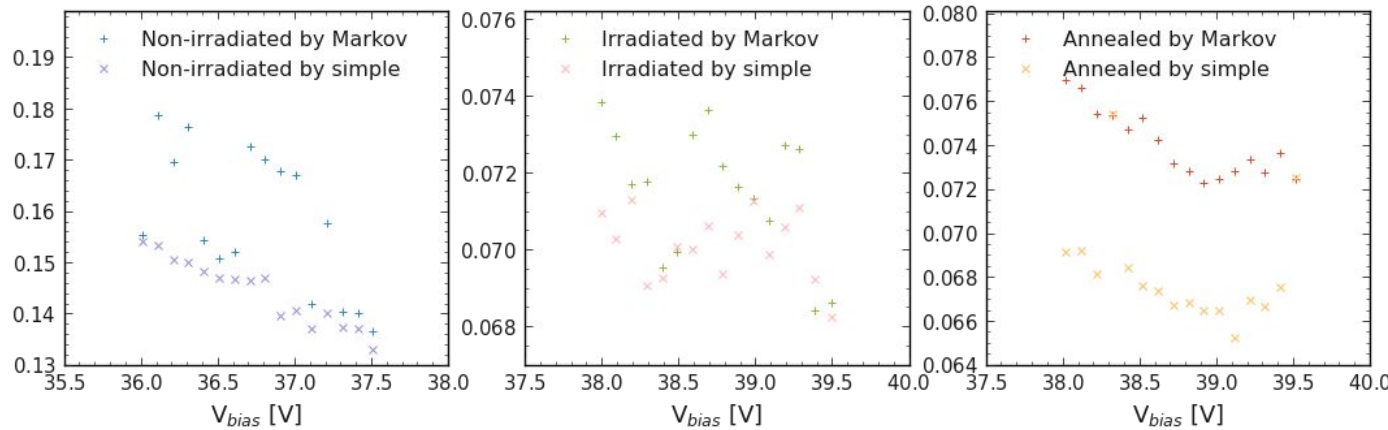
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #11 at 0°



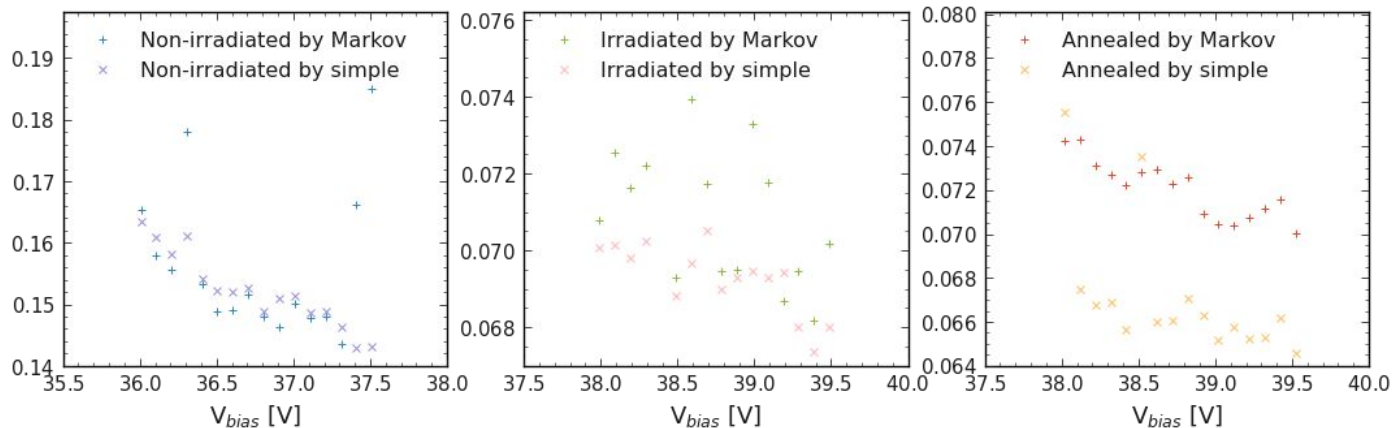
Time resolution of other peaks for SiPM #11 at -10°



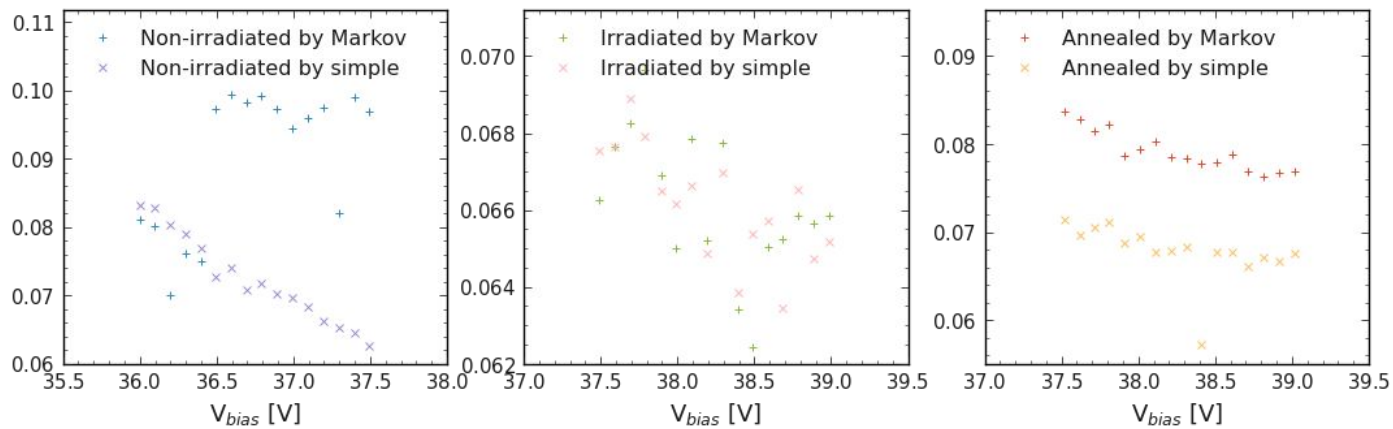
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #11 at  $-20^\circ$



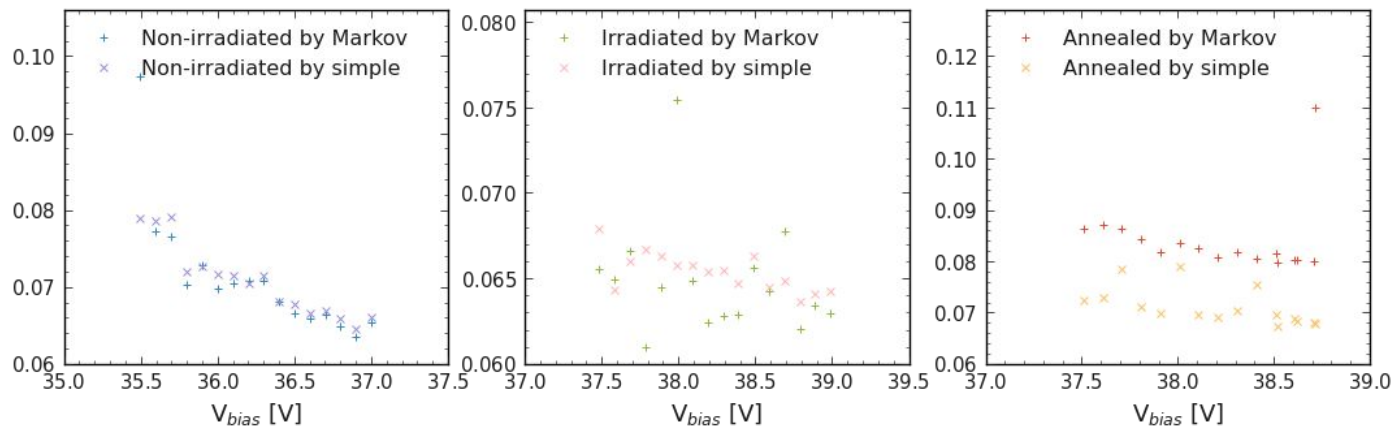
Time resolution of other peaks for SiPM #11 at  $-30^\circ$



# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #11 at  $-35^\circ$



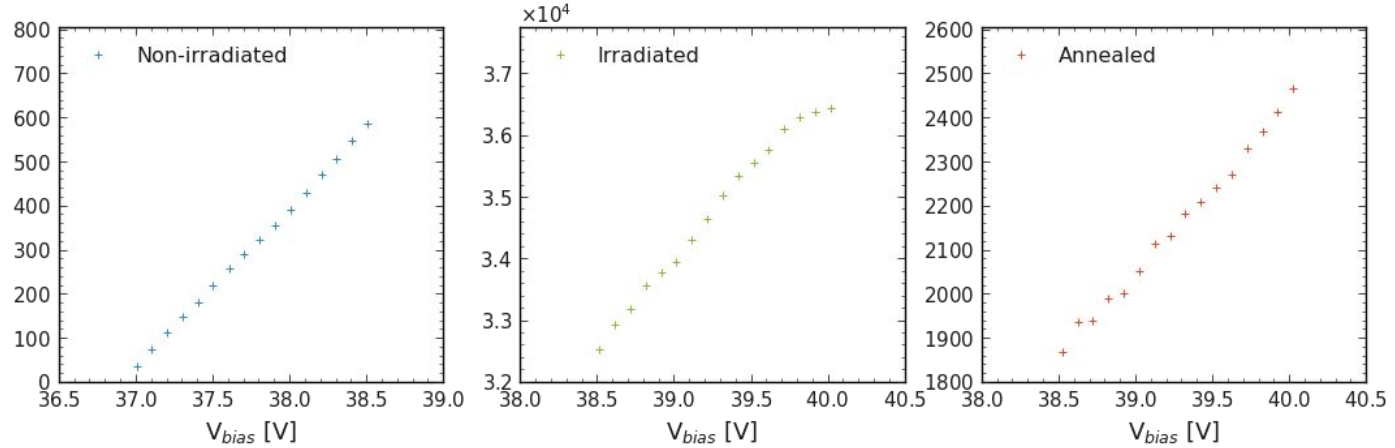


# Dark count rate for SiPM #11

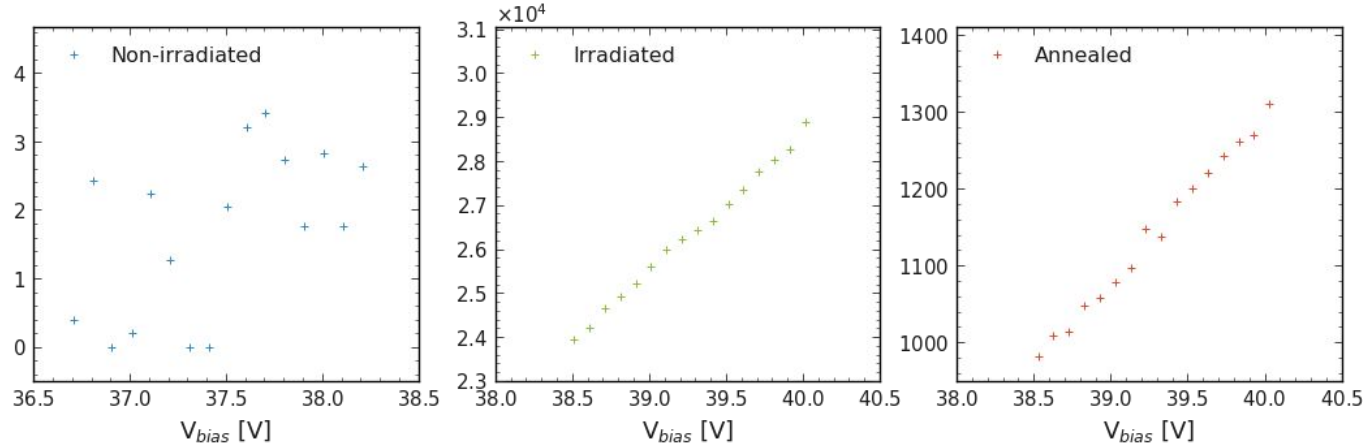
# Dark count rate



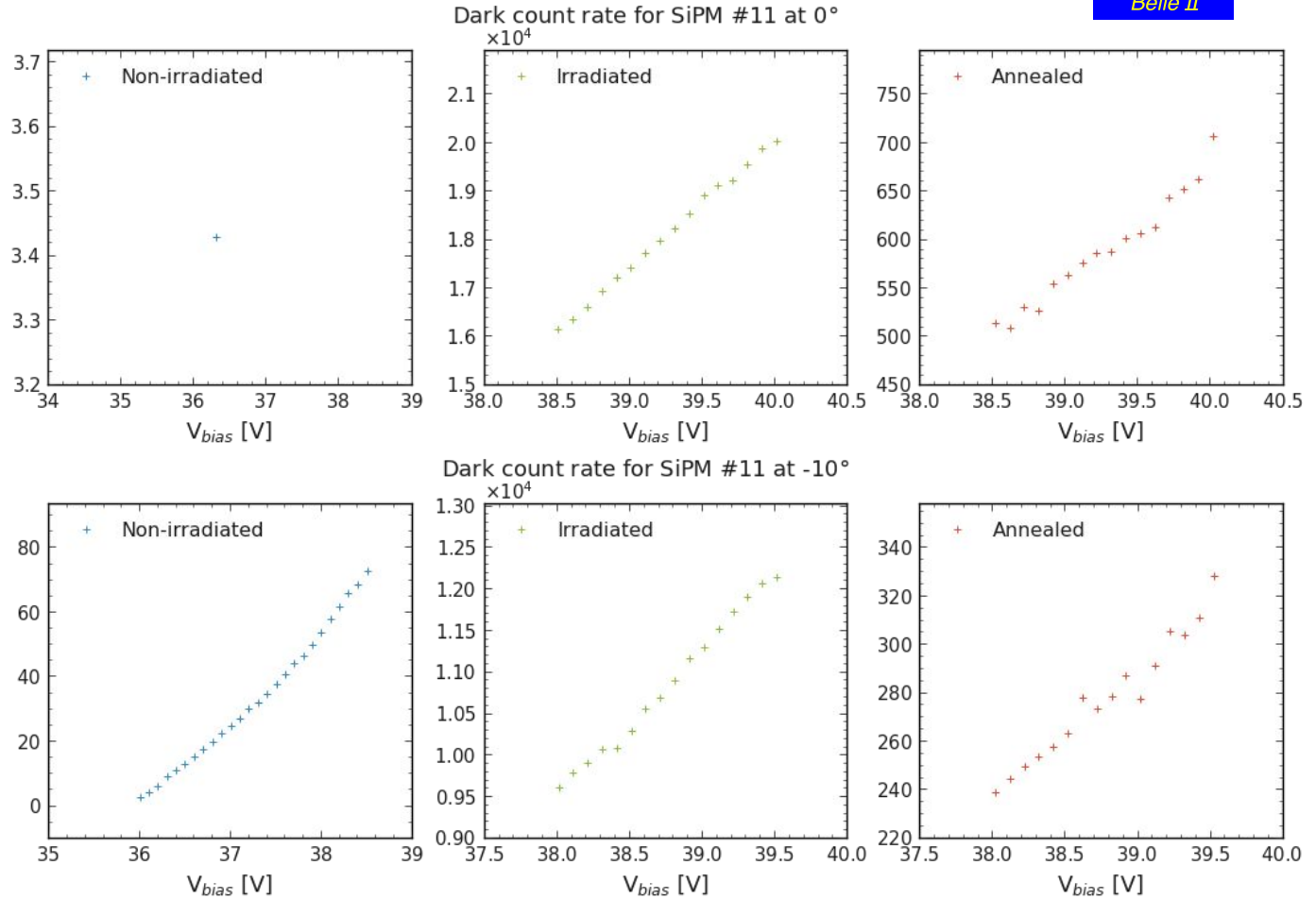
Dark count rate for SiPM #11 at 20°



Dark count rate for SiPM #11 at 10°



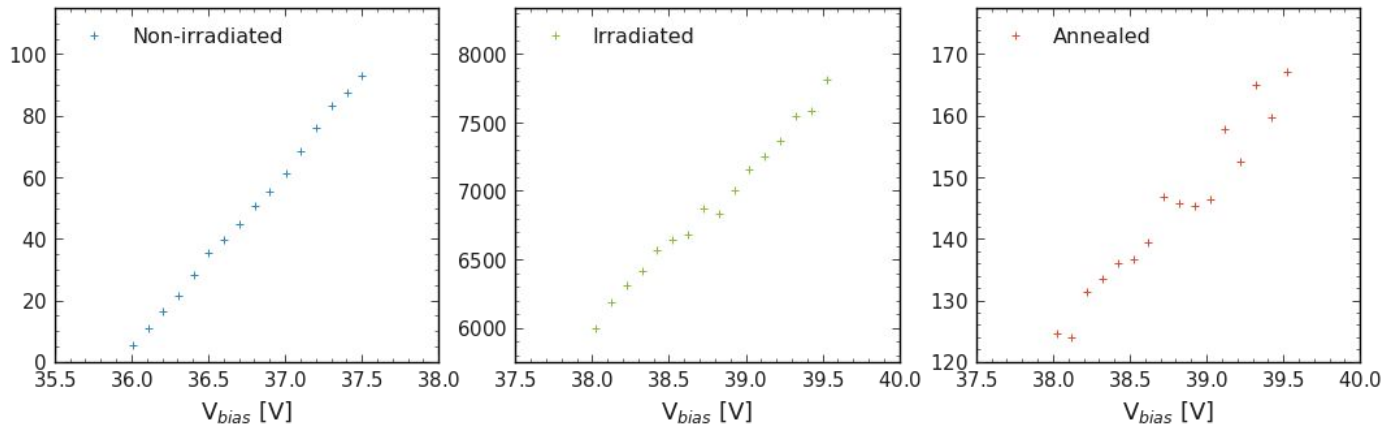
# Dark count rate



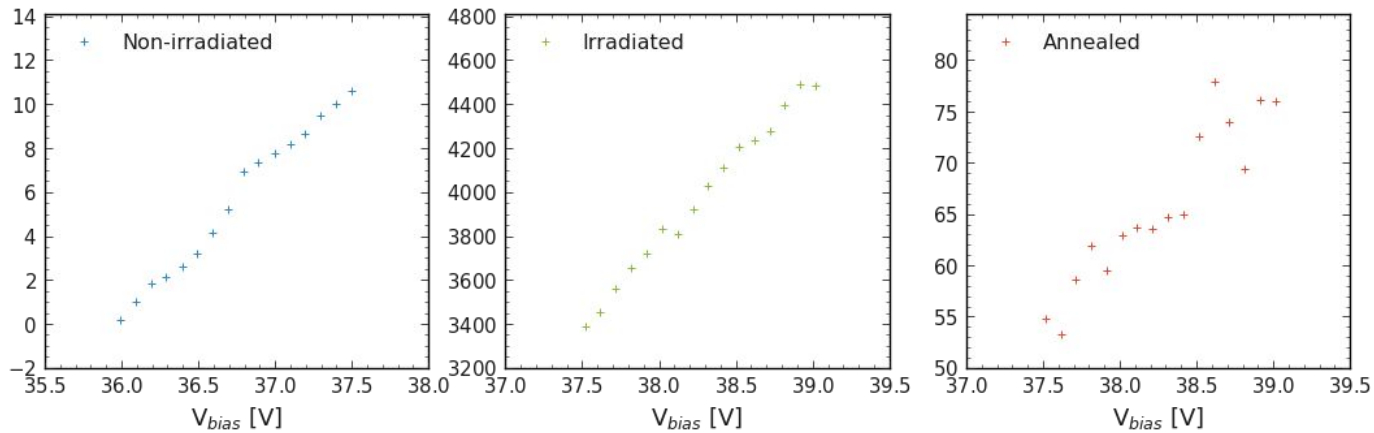
# Dark count rate



Dark count rate for SiPM #11 at  $-20^\circ$



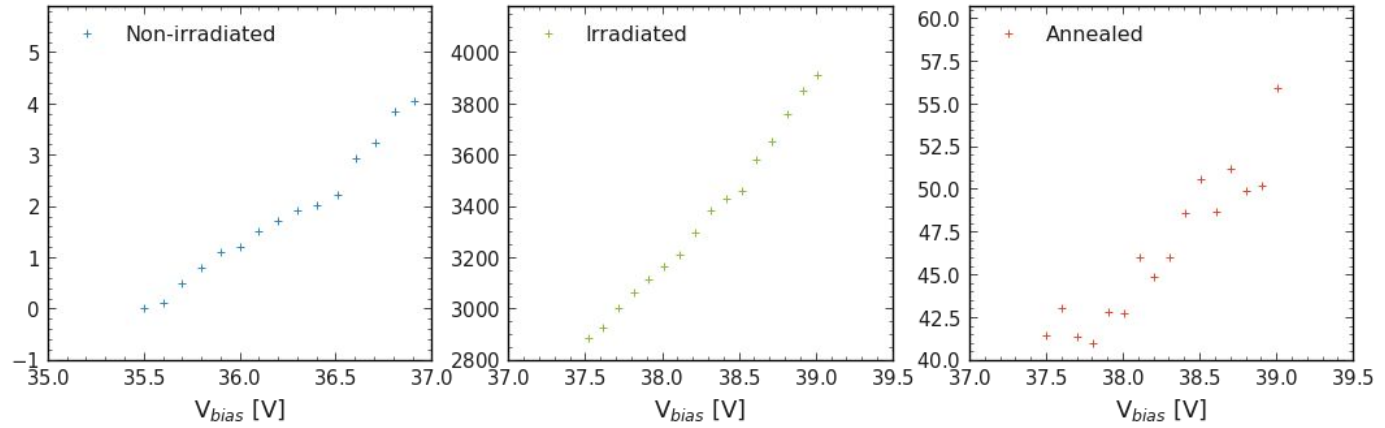
Dark count rate for SiPM #11 at  $-30^\circ$



# Dark count rate



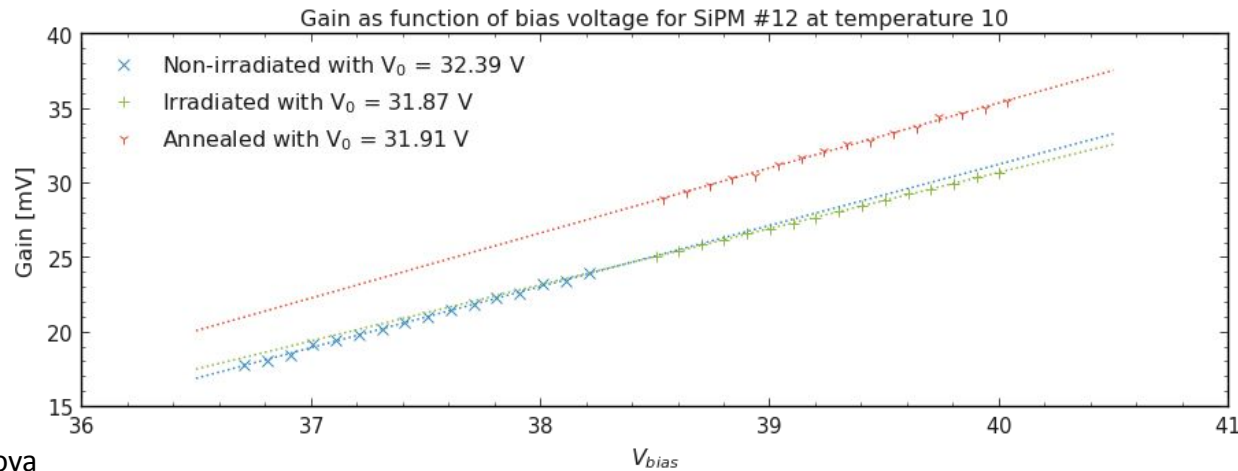
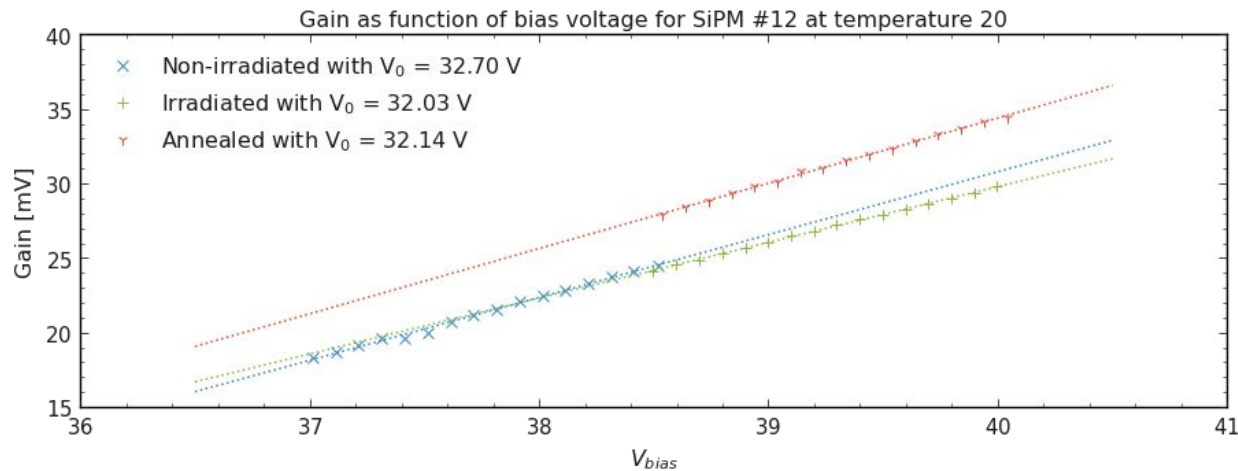
Dark count rate for SiPM #11 at  $-35^\circ$



# SIMP #12

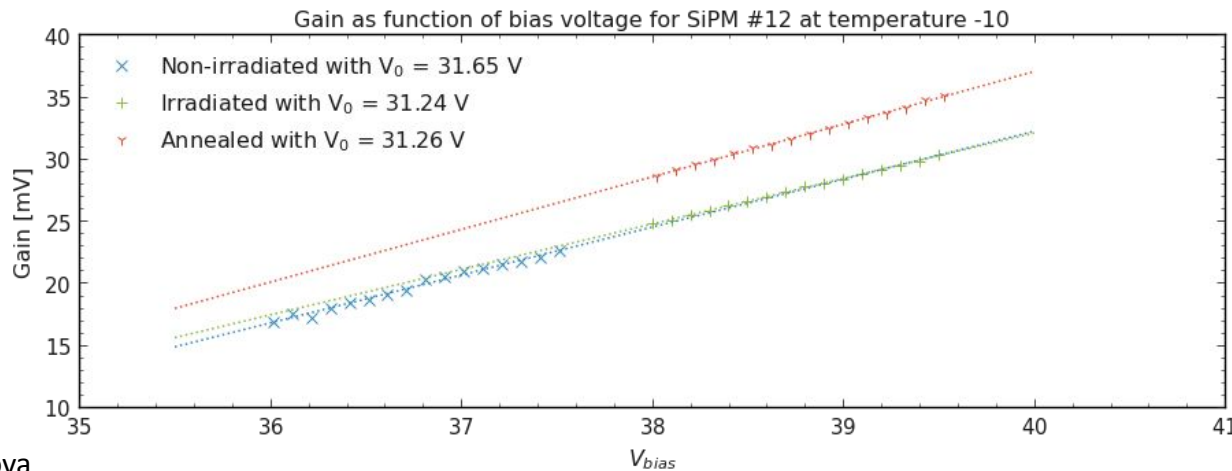
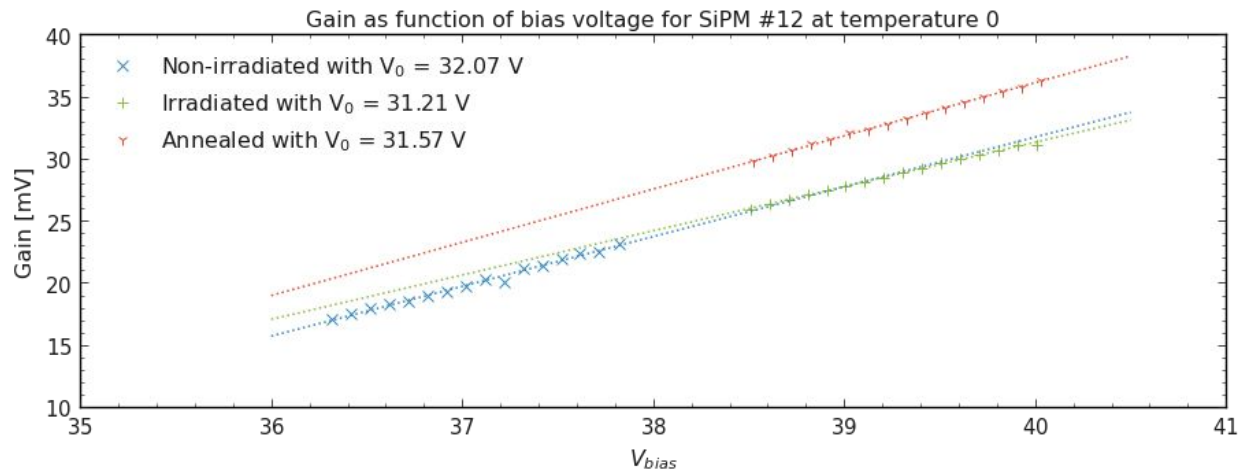
# Gain as function of bias voltage for SiPM #12

# Gain as function of bias voltage

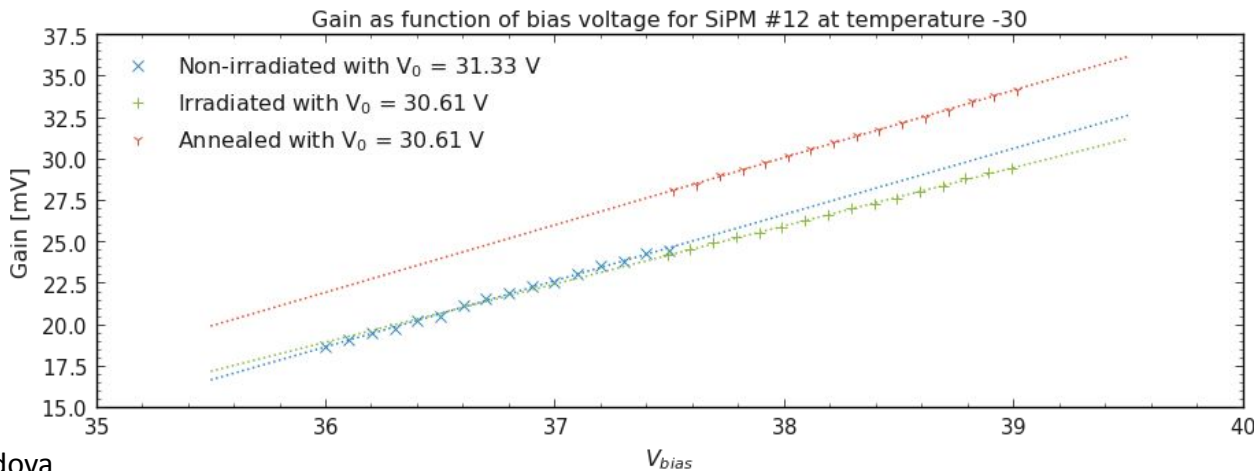
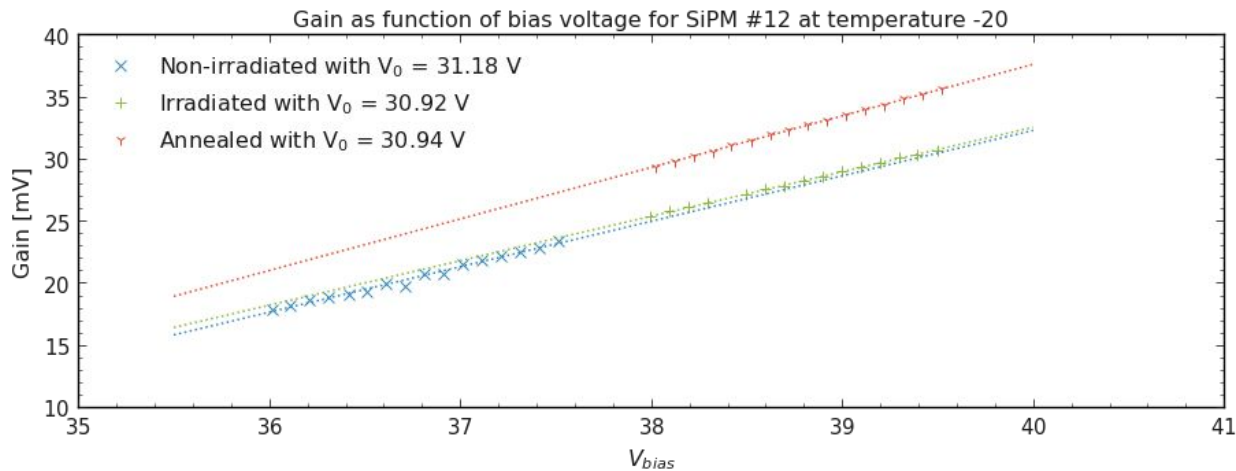




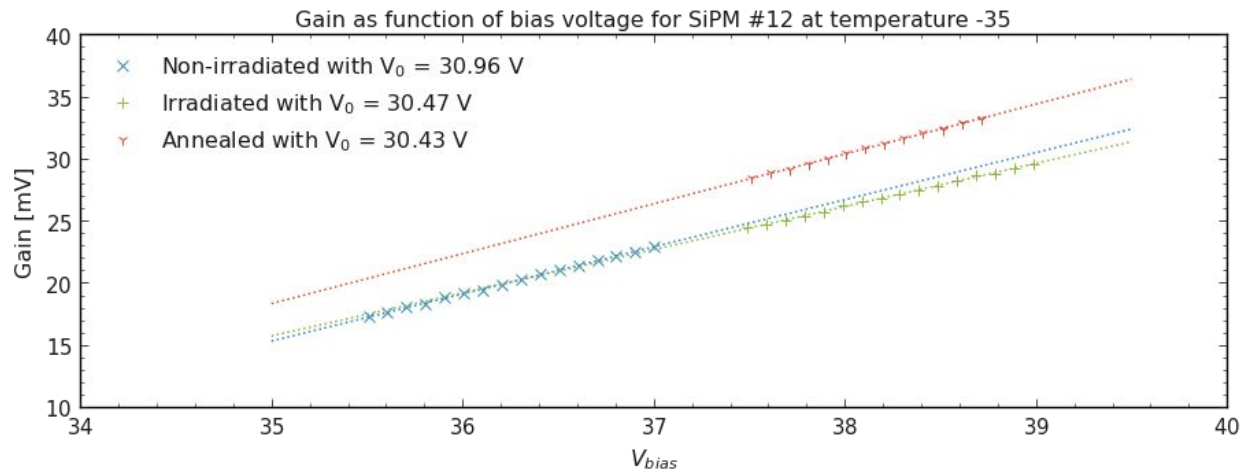
# Gain as function of bias voltage



# Gain as function of bias voltage

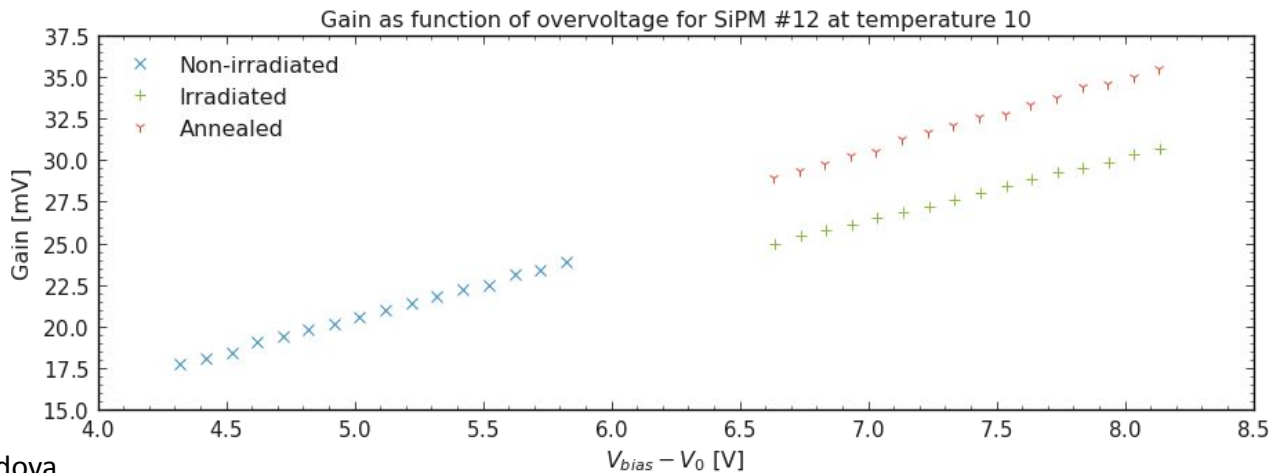
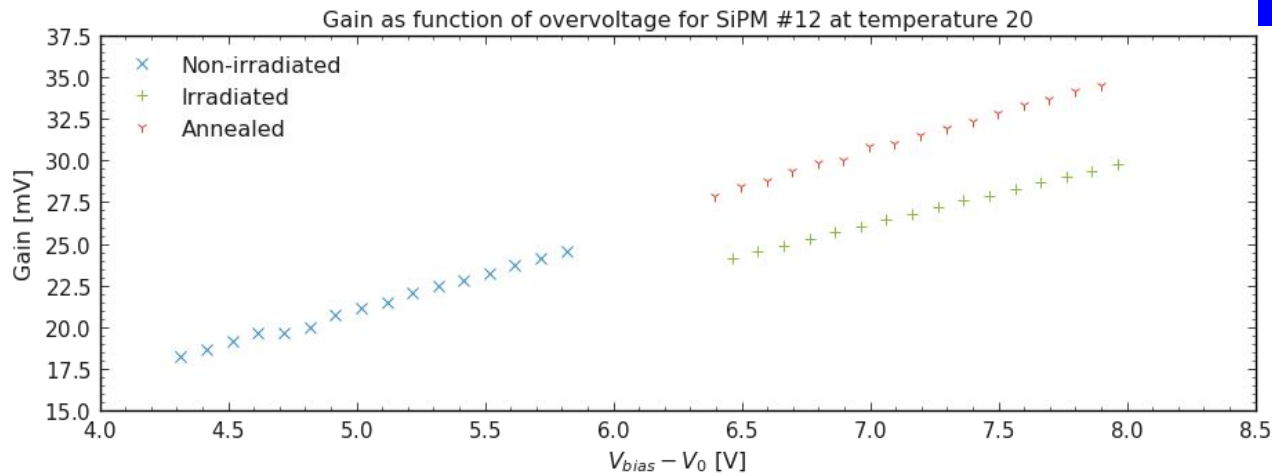


# Gain as function of bias voltage

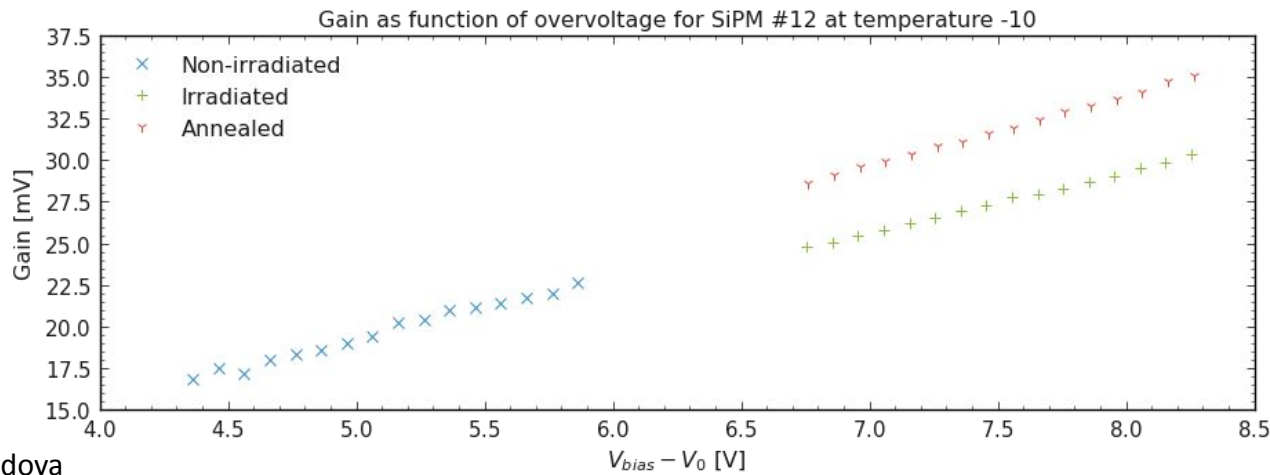
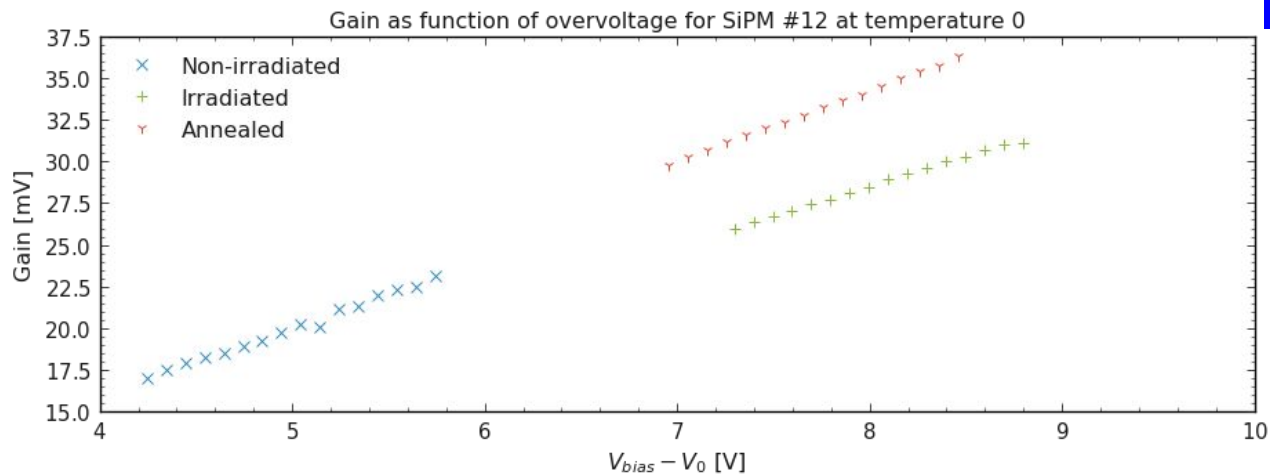


# Gain as function of overvoltage for SiPM #12

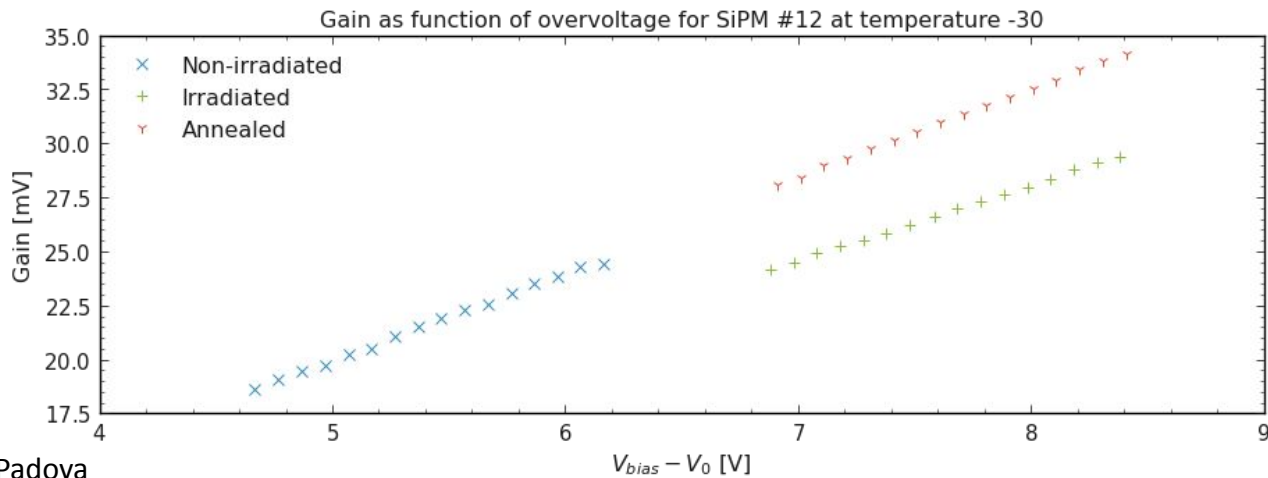
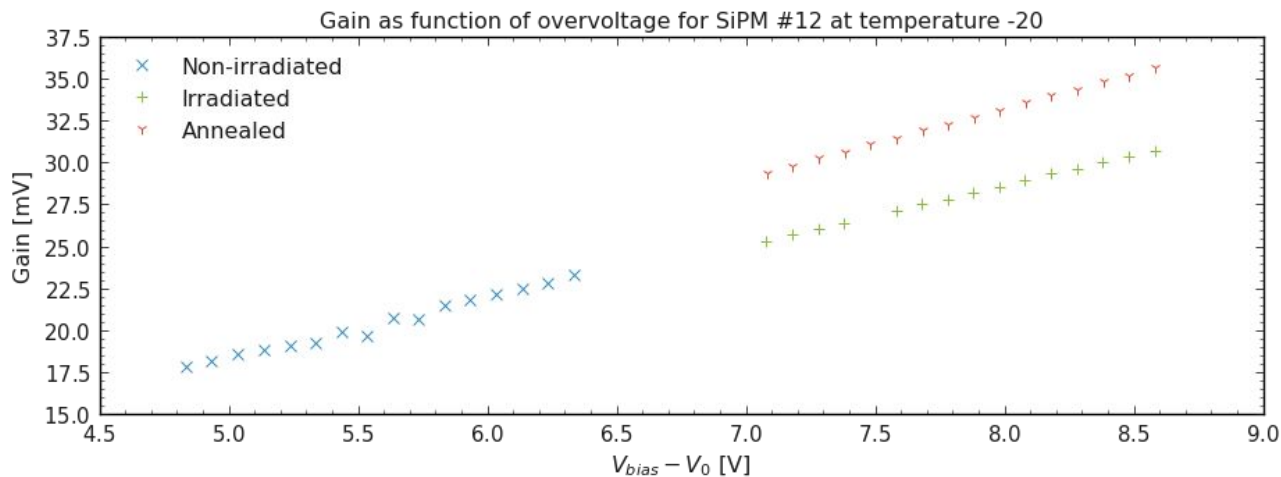
# Gain as function of overvoltage



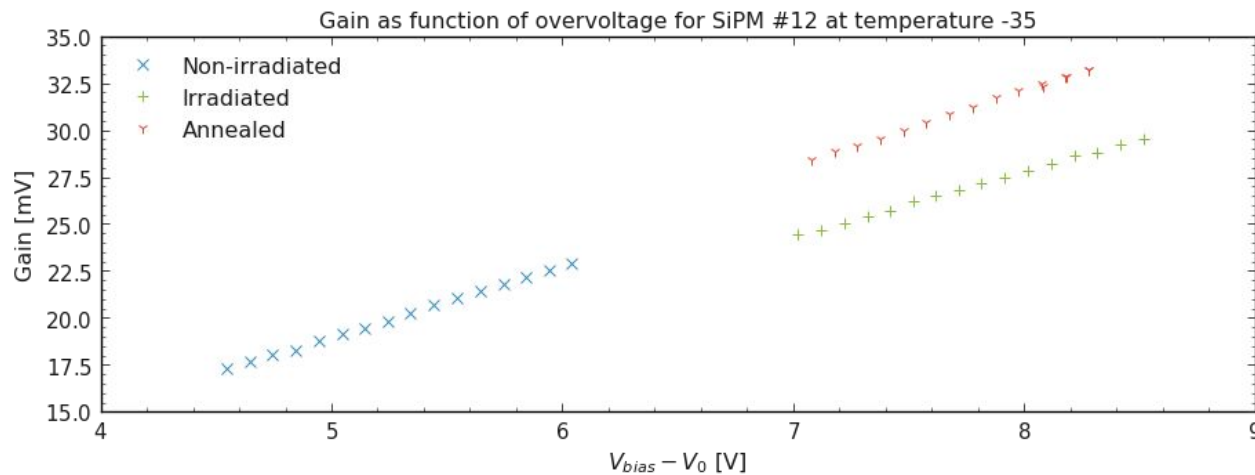
# Gain as function of overvoltage



# Gain as function of overvoltage



# Gain as function of overvoltage



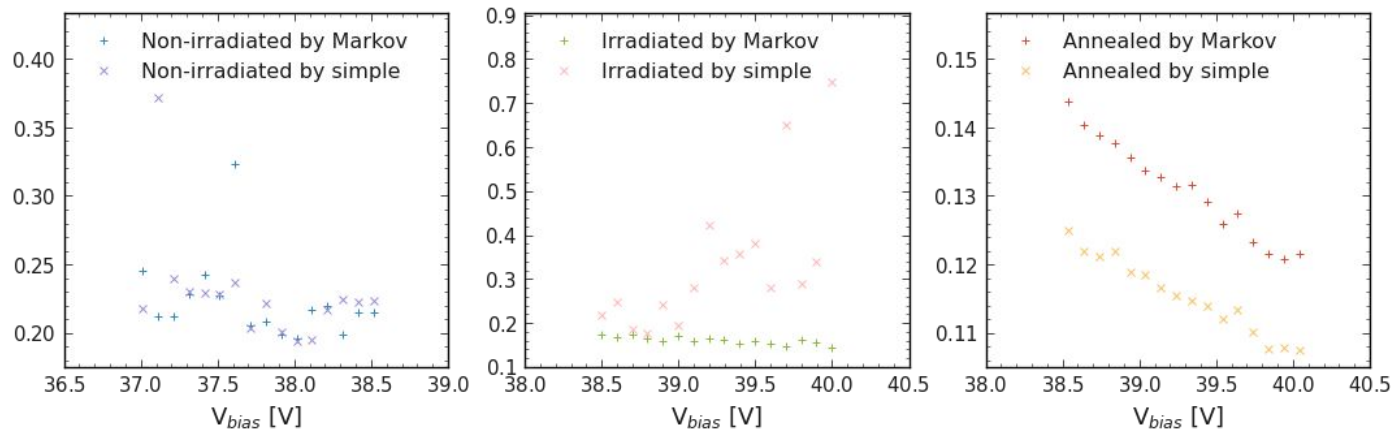


# Time resolution for first photon peak for SiPM #12

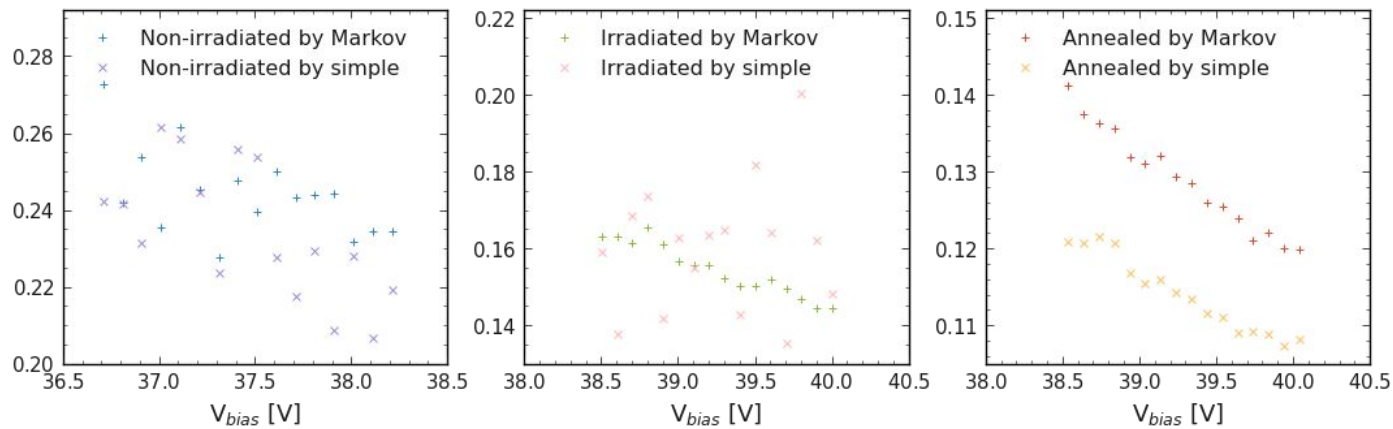
# Time resolution for first photon peak



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



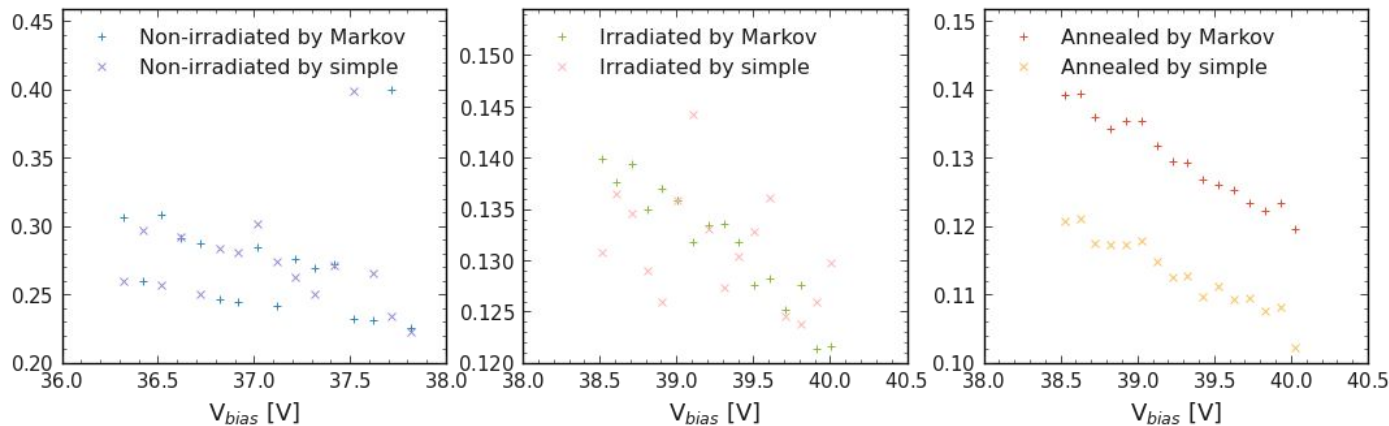
Time resolution of first peak for SiPM #12 at 10°



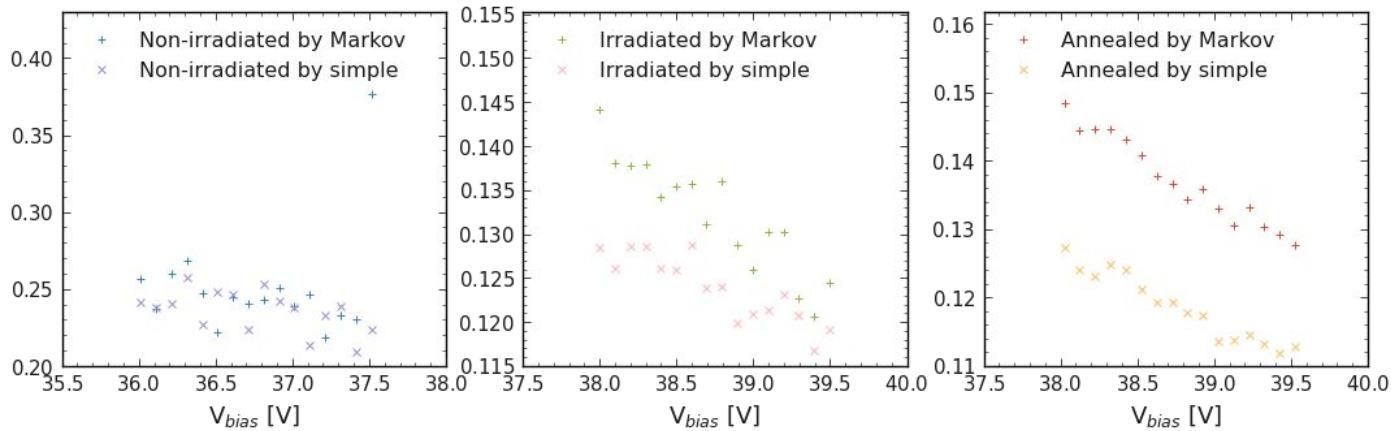
# Time resolution for first photon peak



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



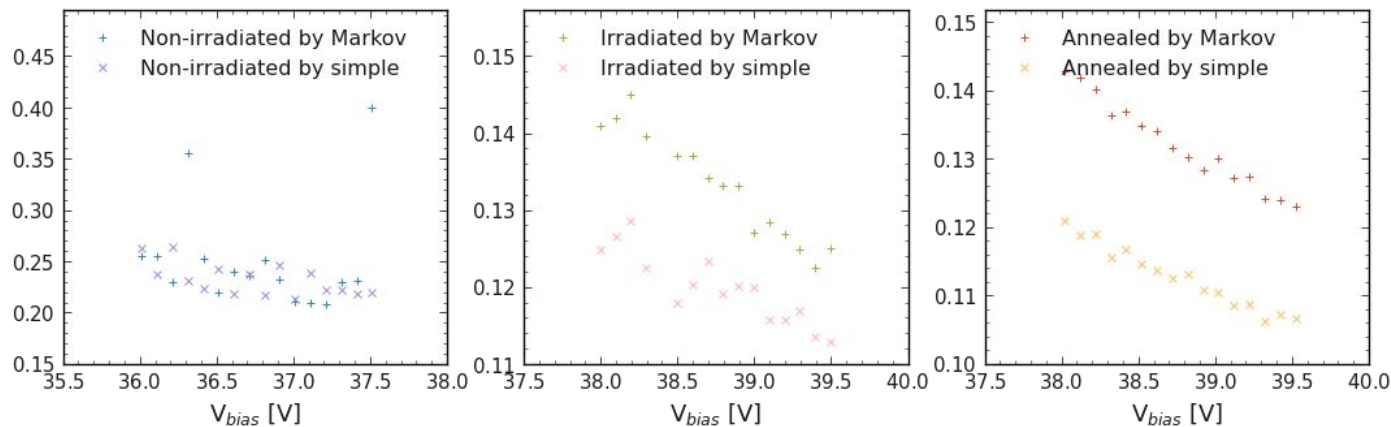
Time resolution of first peak for SiPM #12 at -10°



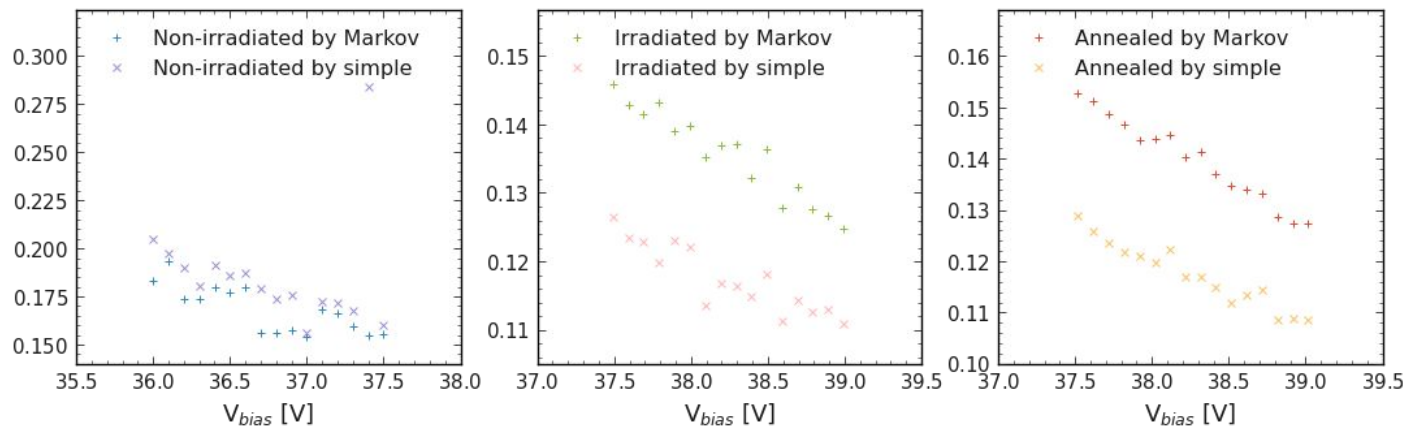
# Time resolution for first photon peak



Time resolution of first peak for SiPM #12 at  $-20^\circ$



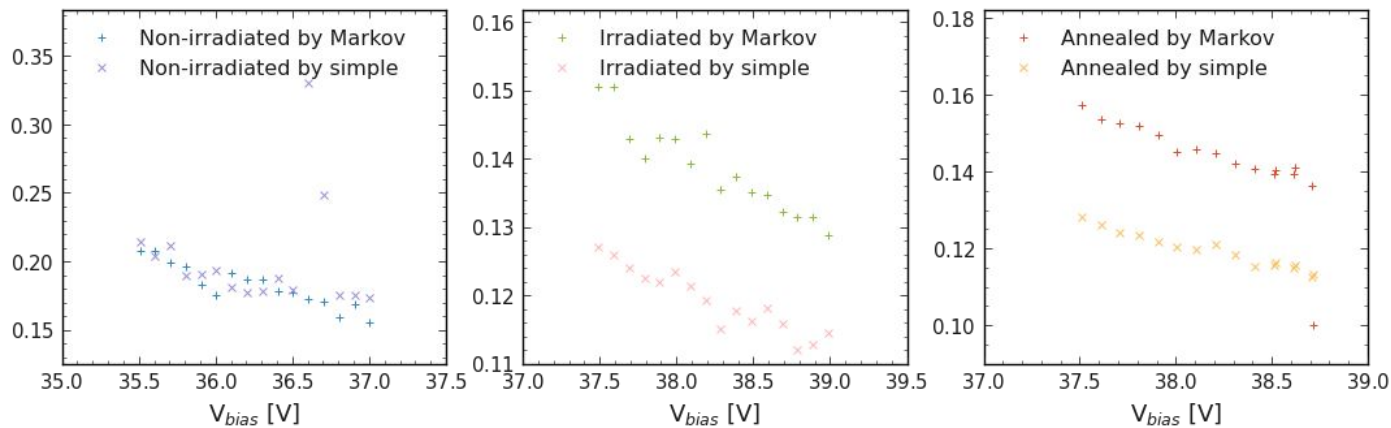
Time resolution of first peak for SiPM #12 at  $-30^\circ$



# Time resolution for first photon peak



Time resolution of first peak for SiPM #12 at  $-35^\circ$

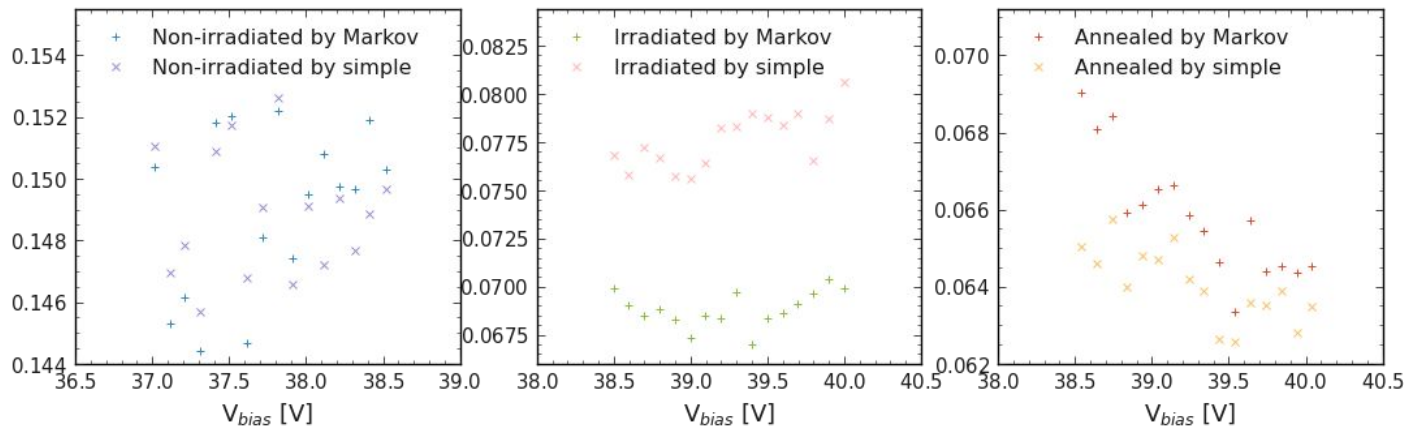


# Time resolution for other photon peaks for SiPM #12

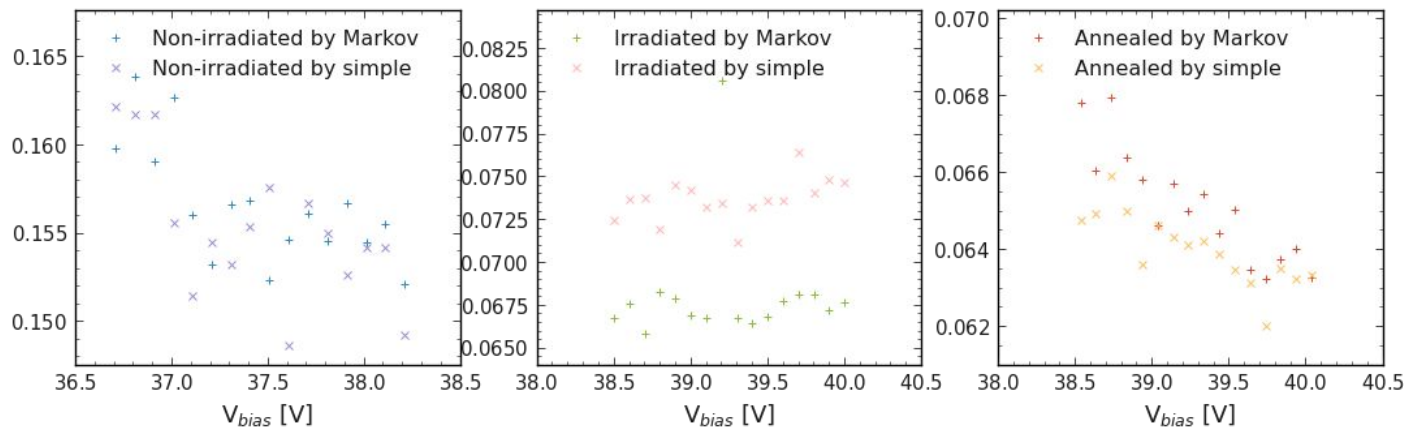
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #12 at 20°



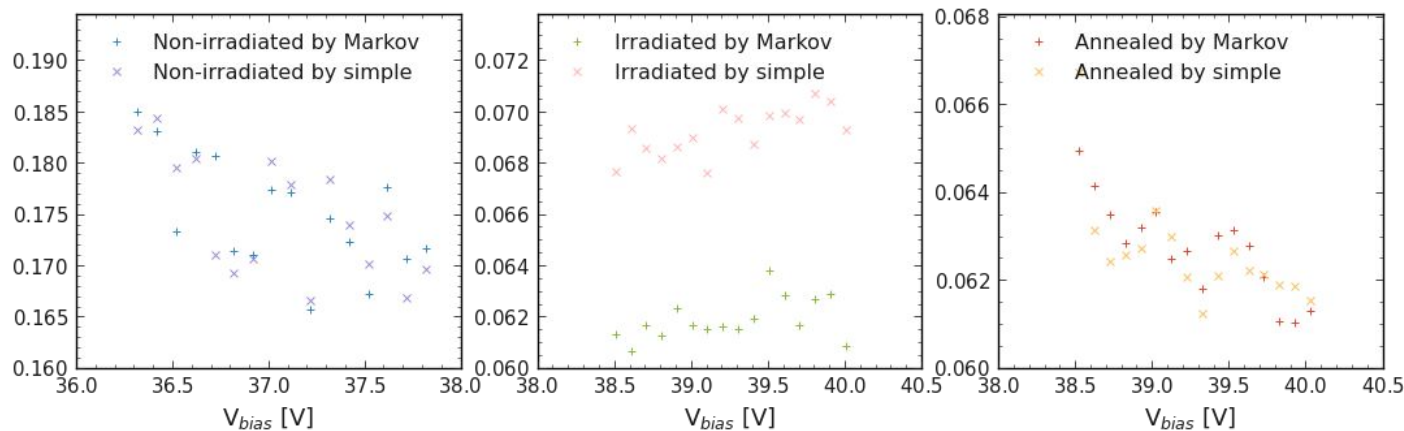
Time resolution of other peaks for SiPM #12 at 10°



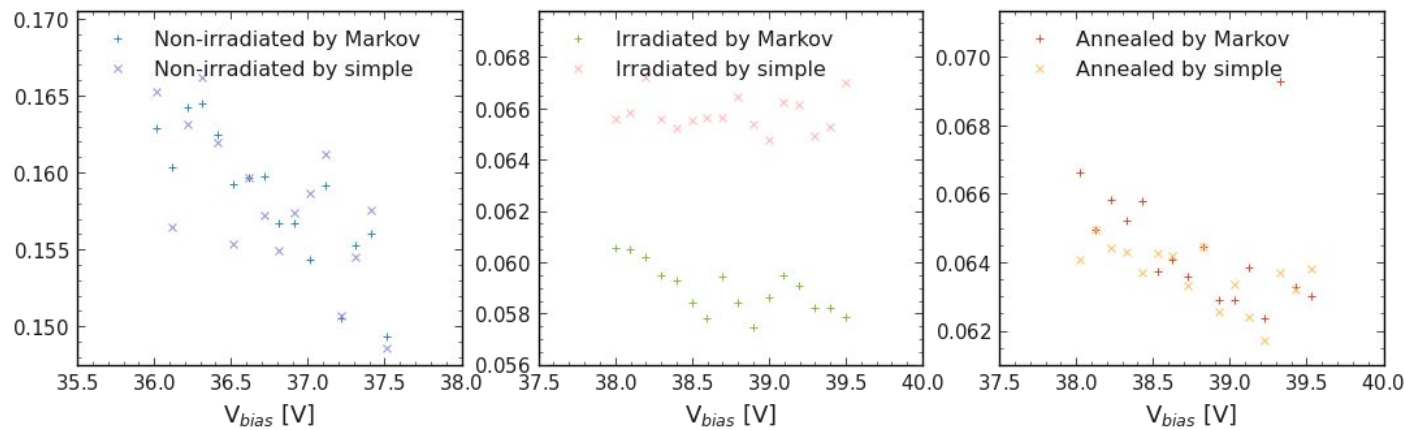
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #12 at 0°



Time resolution of other peaks for SiPM #12 at -10°

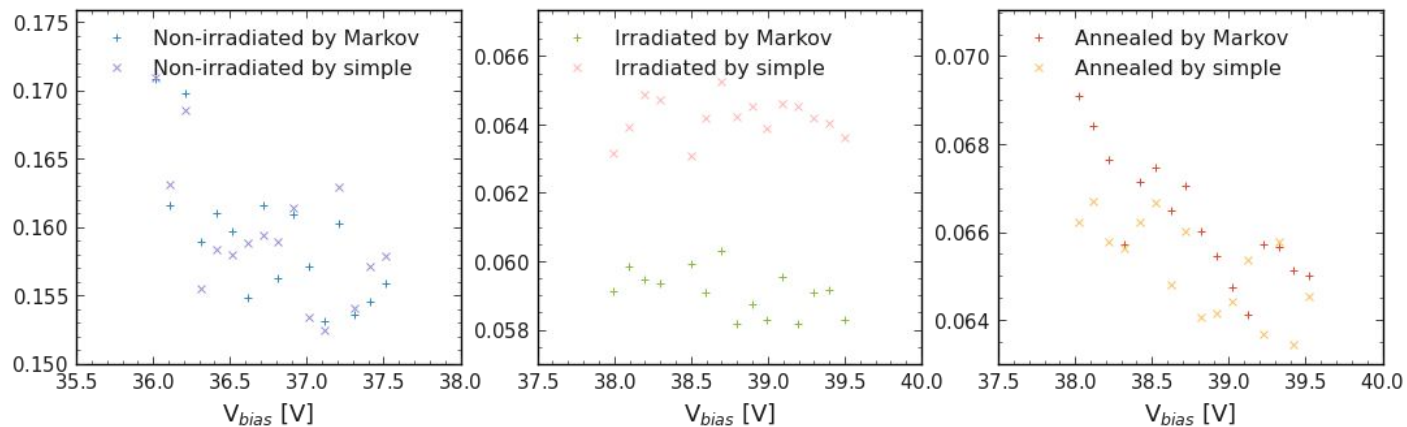




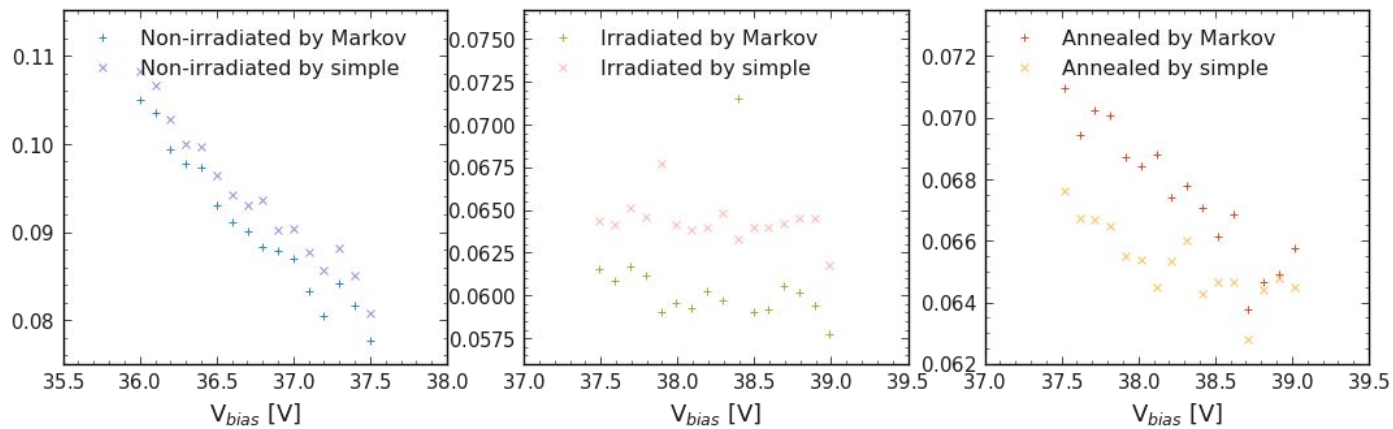
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #12 at  $-20^\circ$



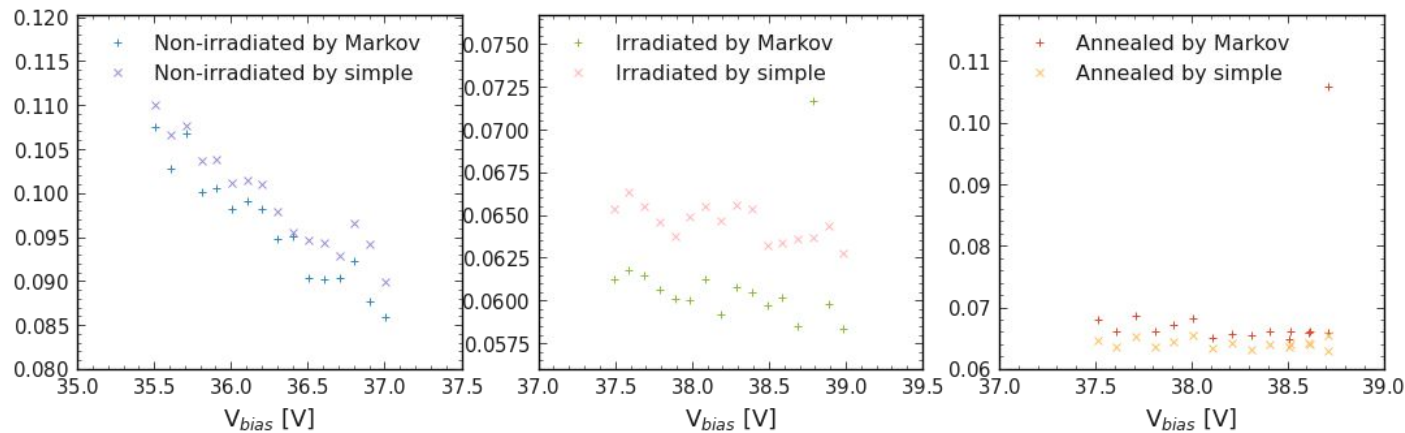
Time resolution of other peaks for SiPM #12 at  $-30^\circ$



# Time resolution for other photon peaks



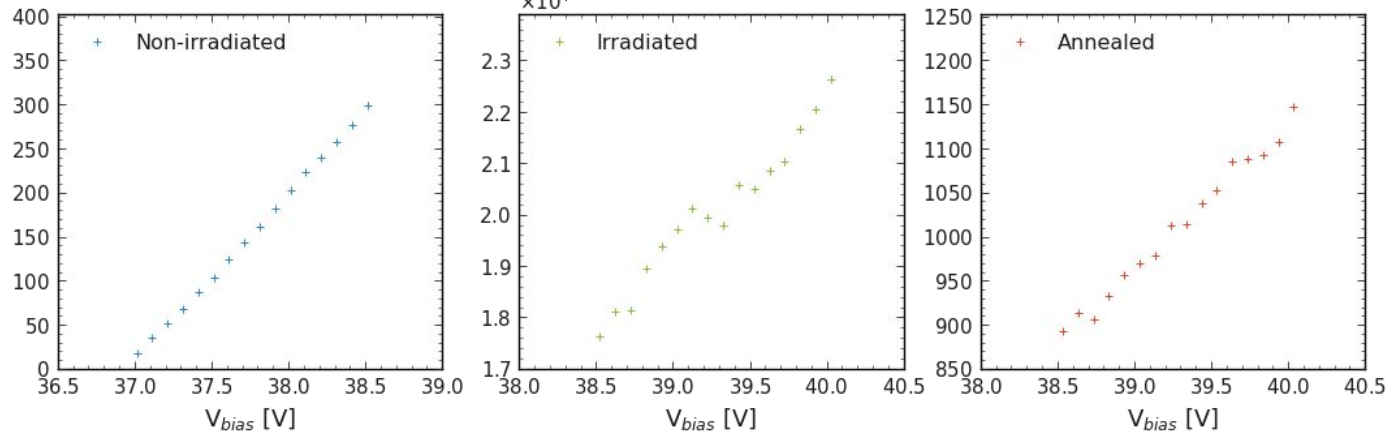
Time resolution of other peaks for SiPM #12 at  $-35^\circ$



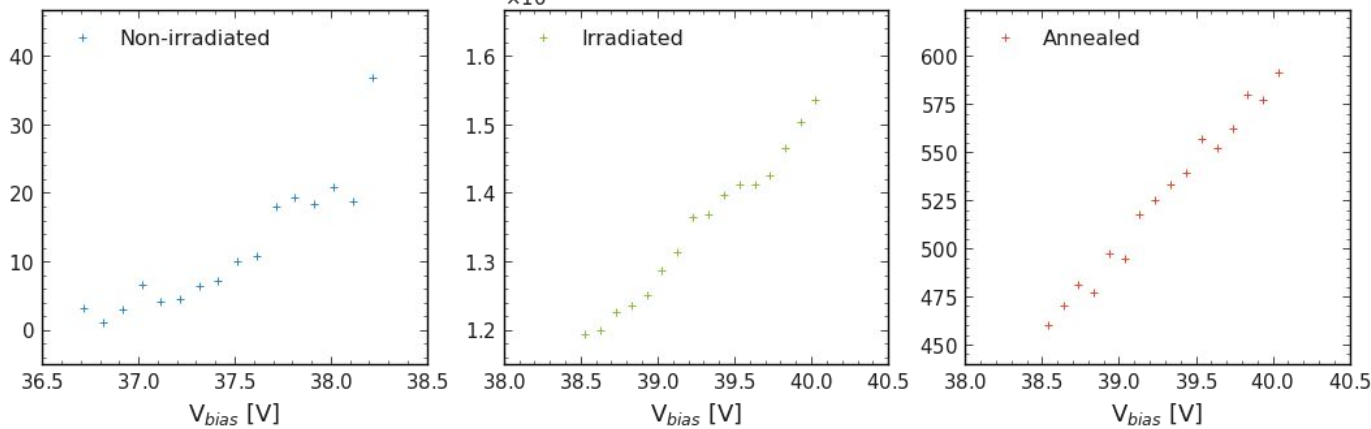
# Dark count rate for SiPM #12

# Dark count rate

Dark count rate for SiPM #12 at 20°



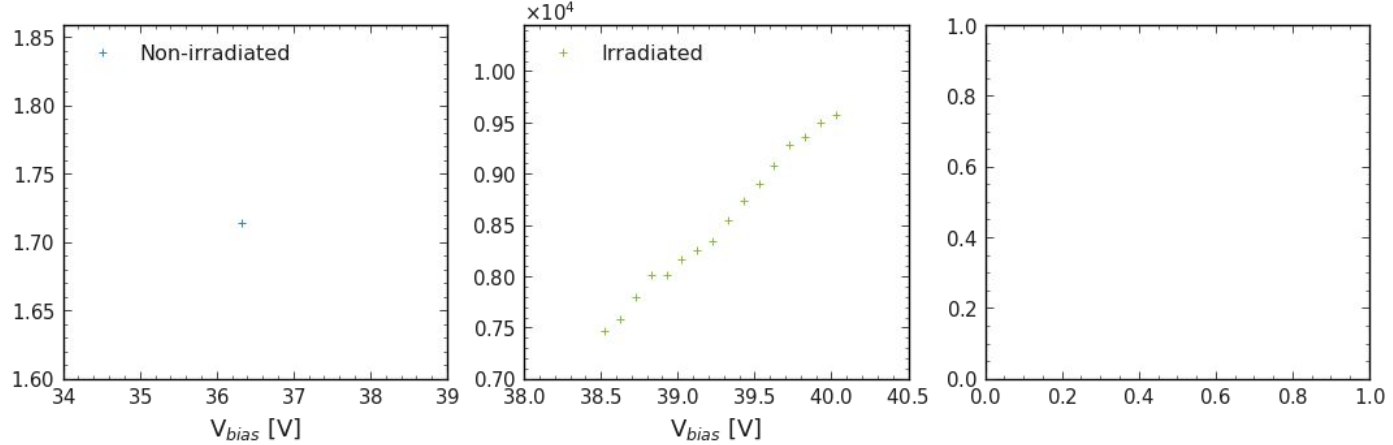
Dark count rate for SiPM #12 at 10°



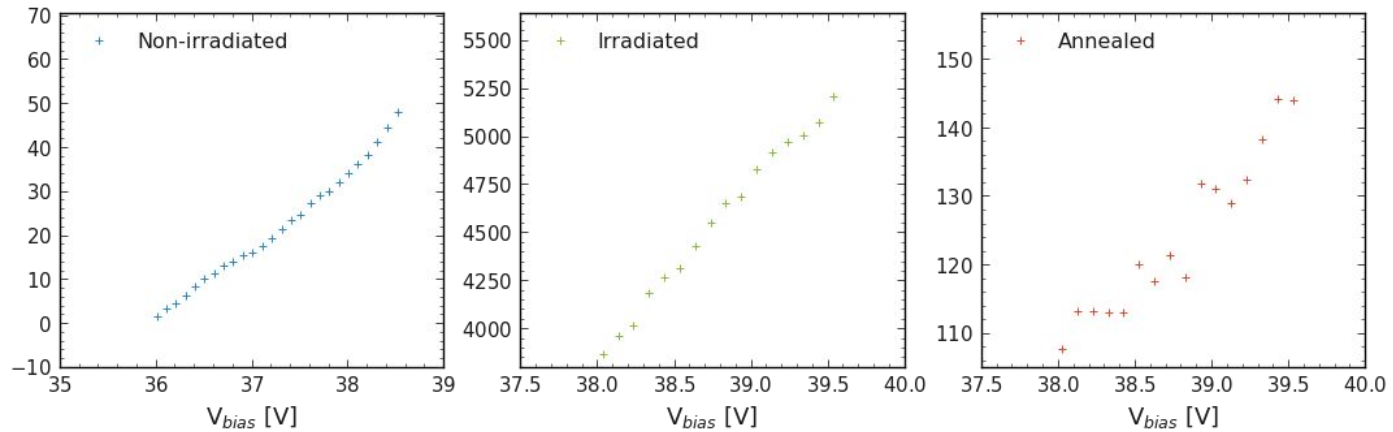
# Dark count rate



Dark count rate for SiPM #12 at 0°



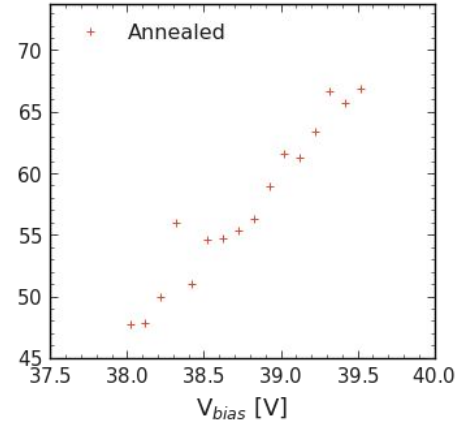
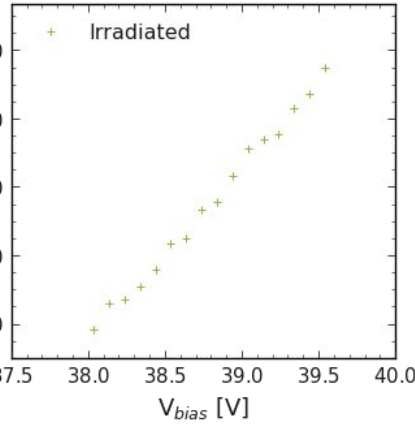
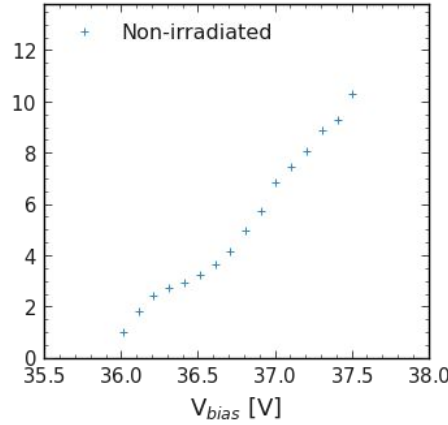
Dark count rate for SiPM #12 at -10°



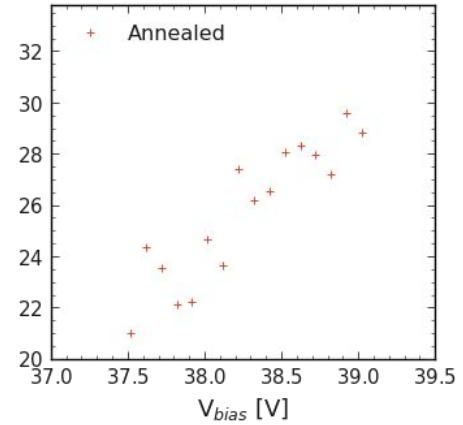
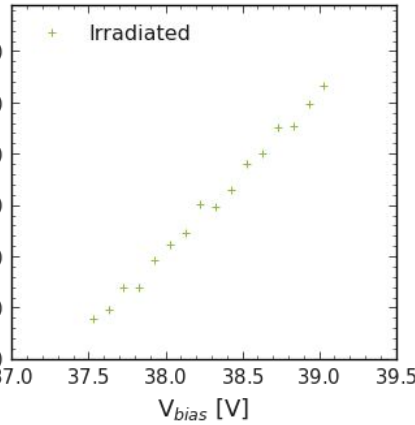
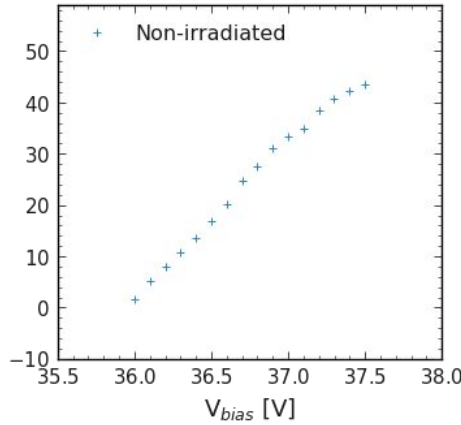
# Dark count rate



Dark count rate for SiPM #12 at  $-20^\circ$



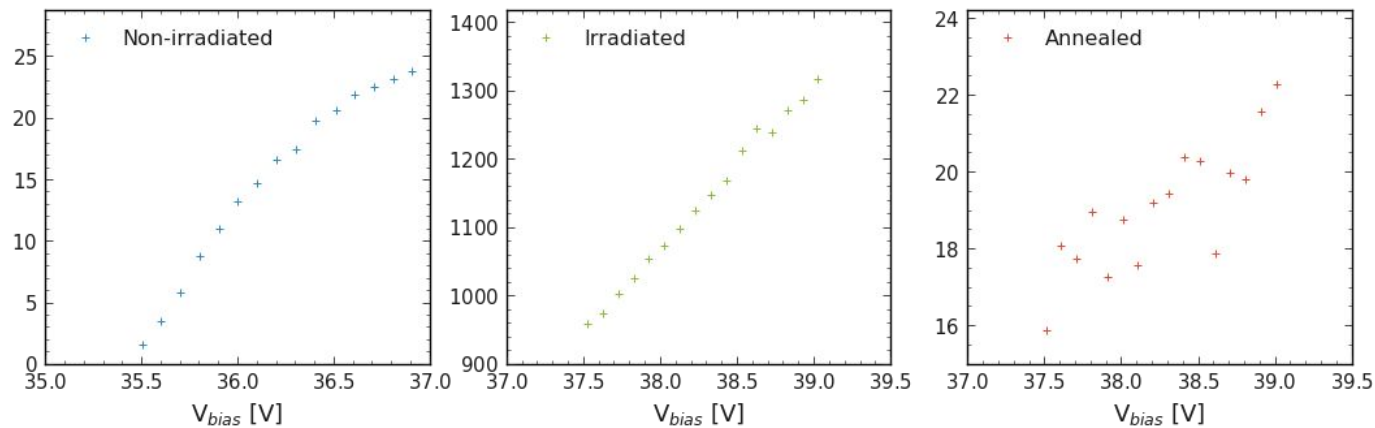
Dark count rate for SiPM #12 at  $-30^\circ$



# Dark count rate



Dark count rate for SiPM #12 at  $-35^\circ$

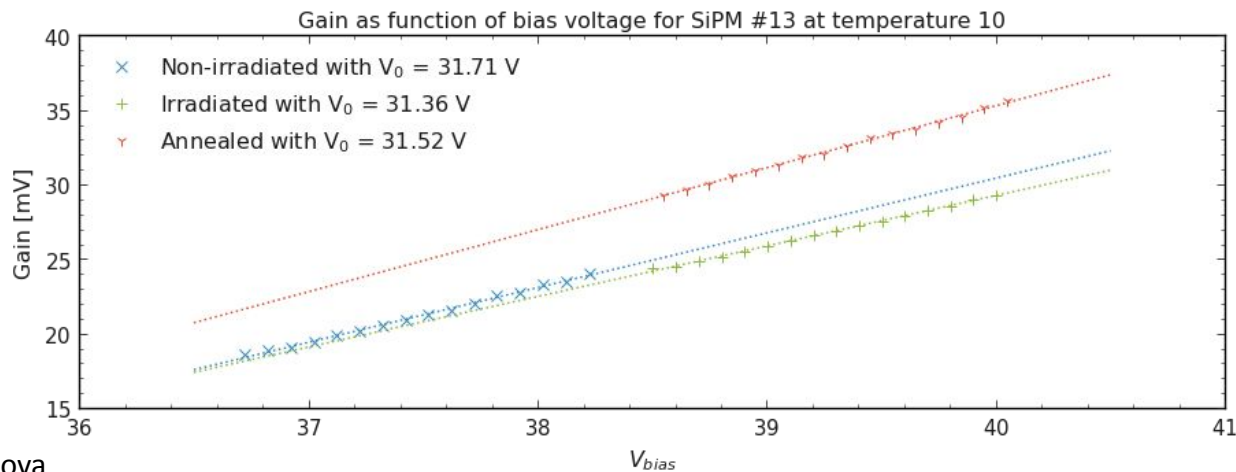
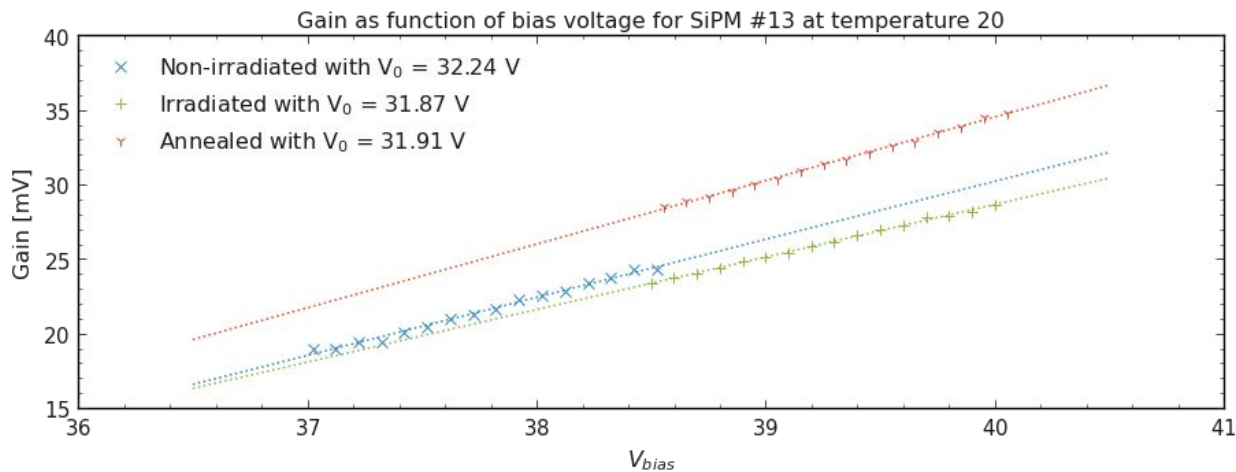


# SIMP #13

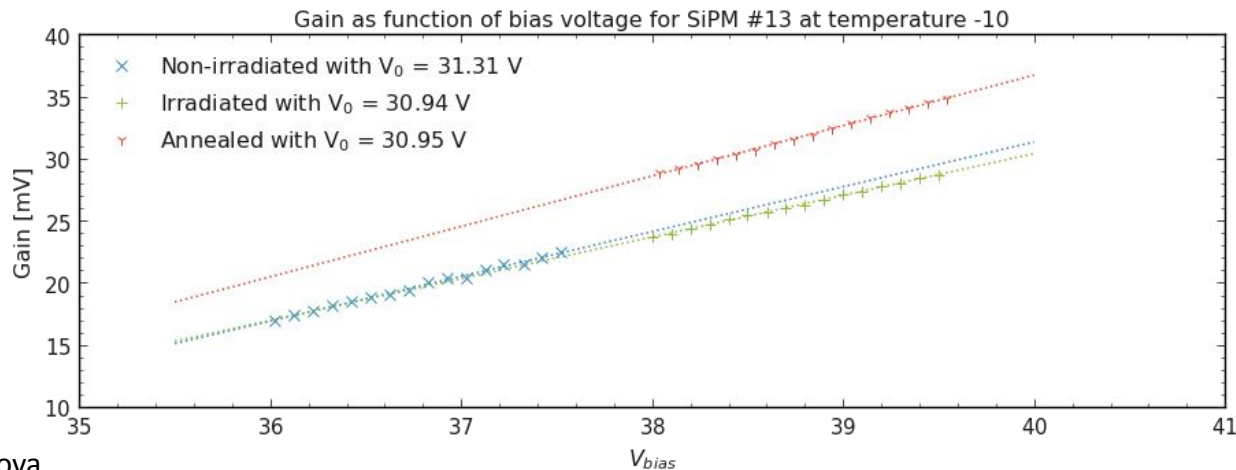
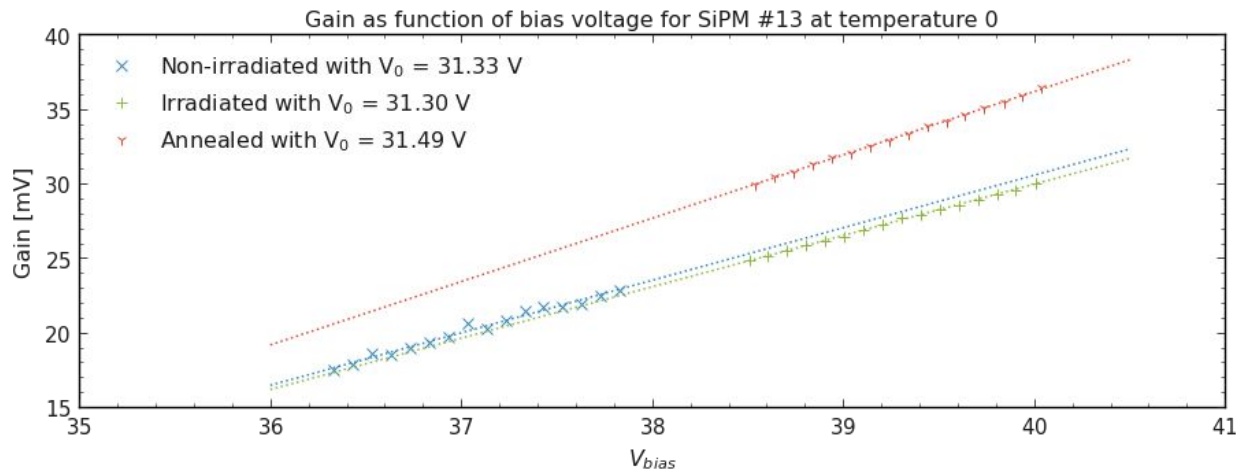


# Gain as function of bias voltage for SiPM #13

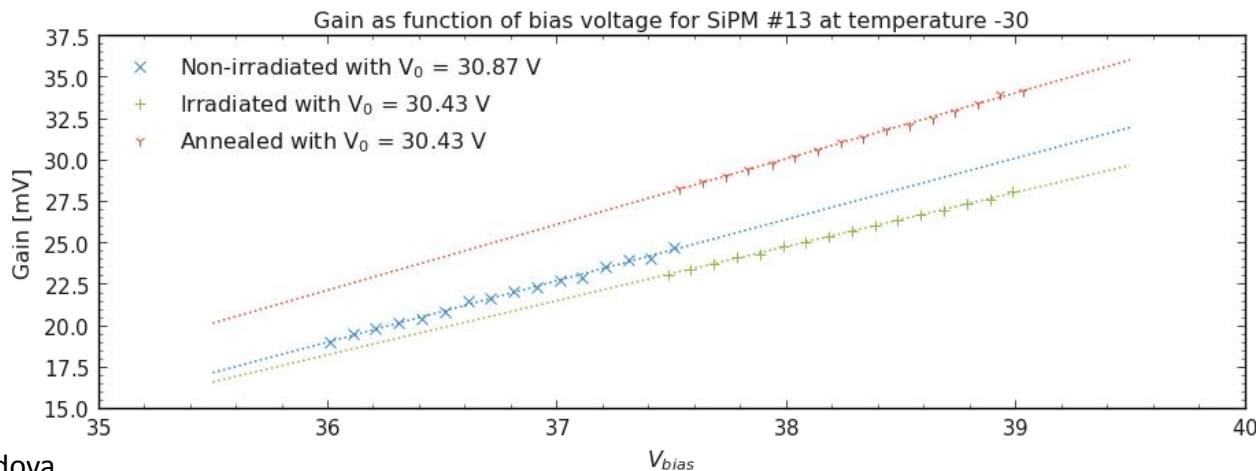
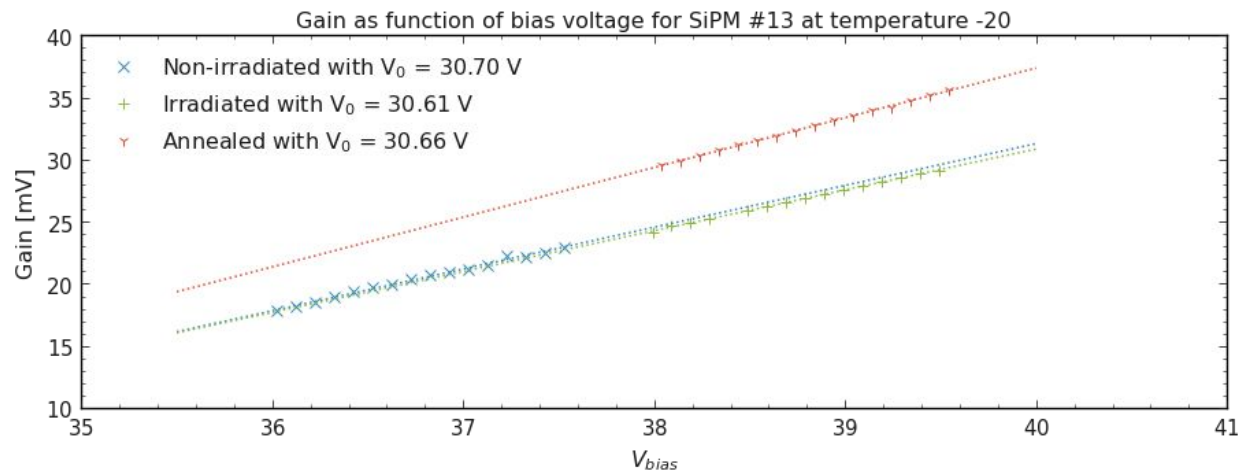
# Gain as function of bias voltage



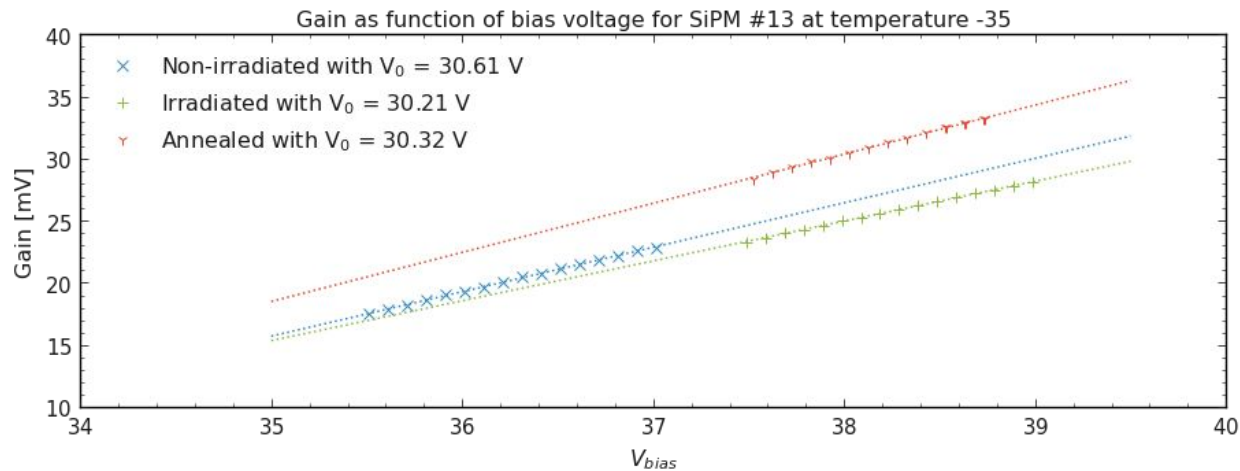
# Gain as function of bias voltage



# Gain as function of bias voltage

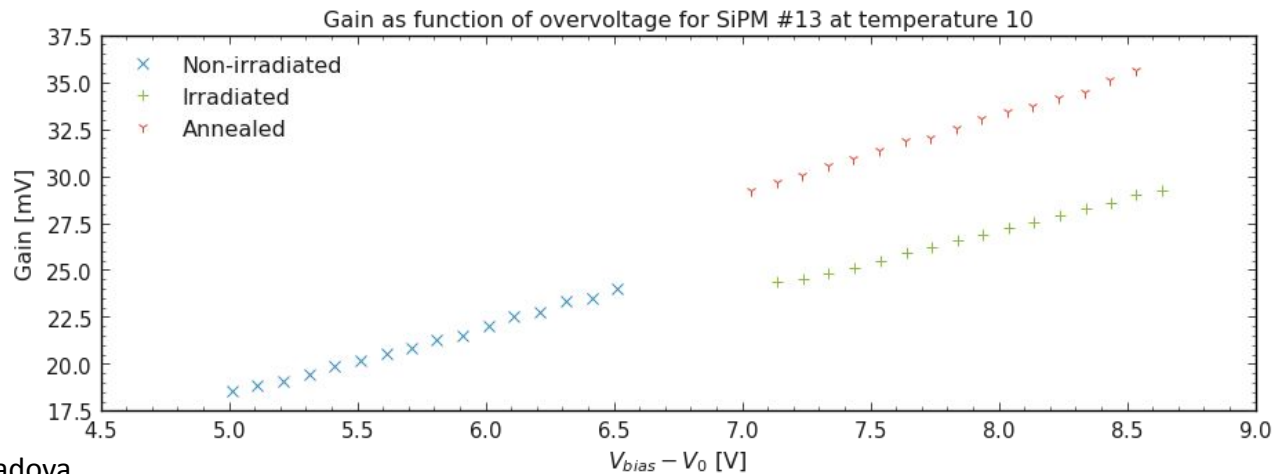
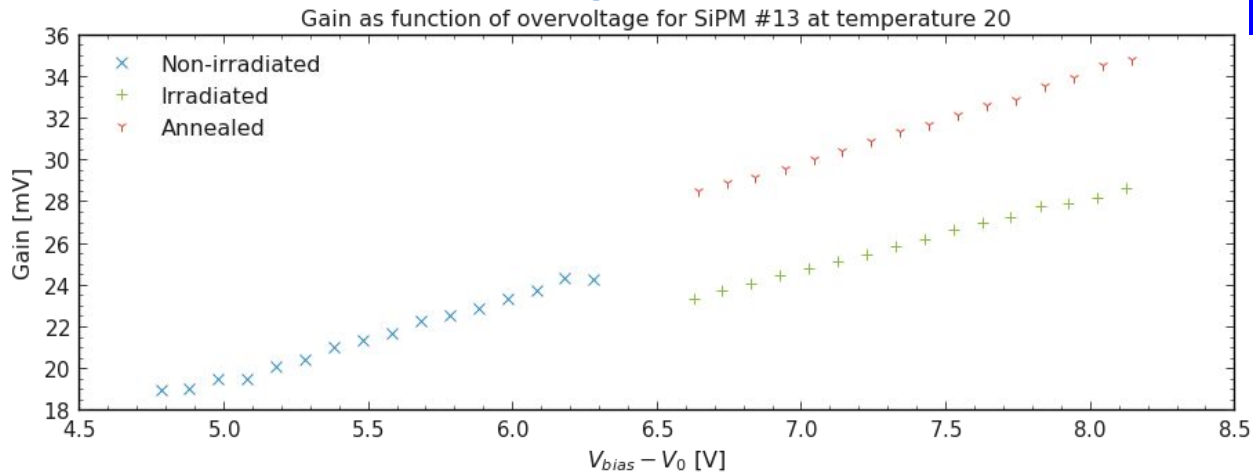


# Gain as function of bias voltage

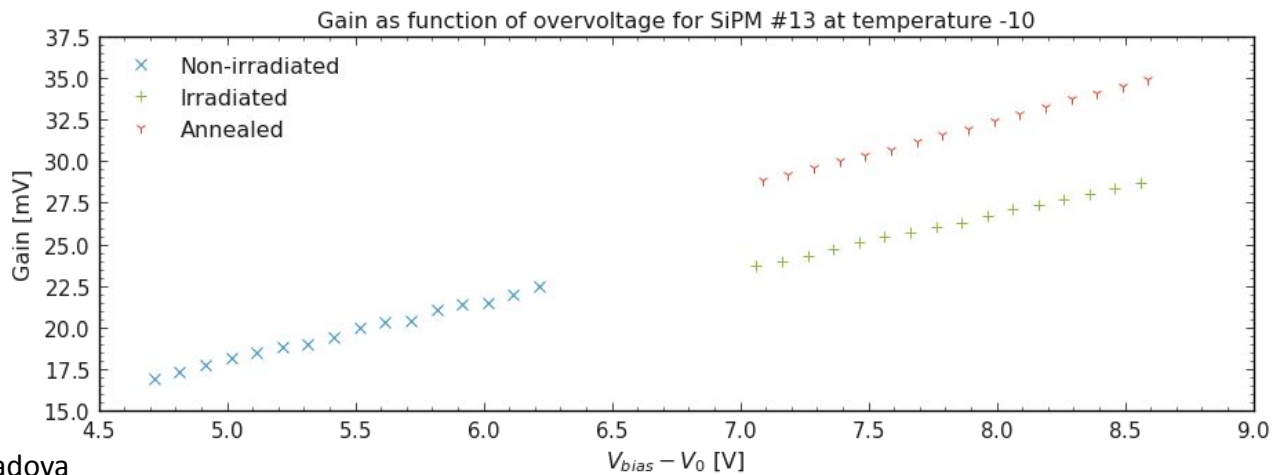
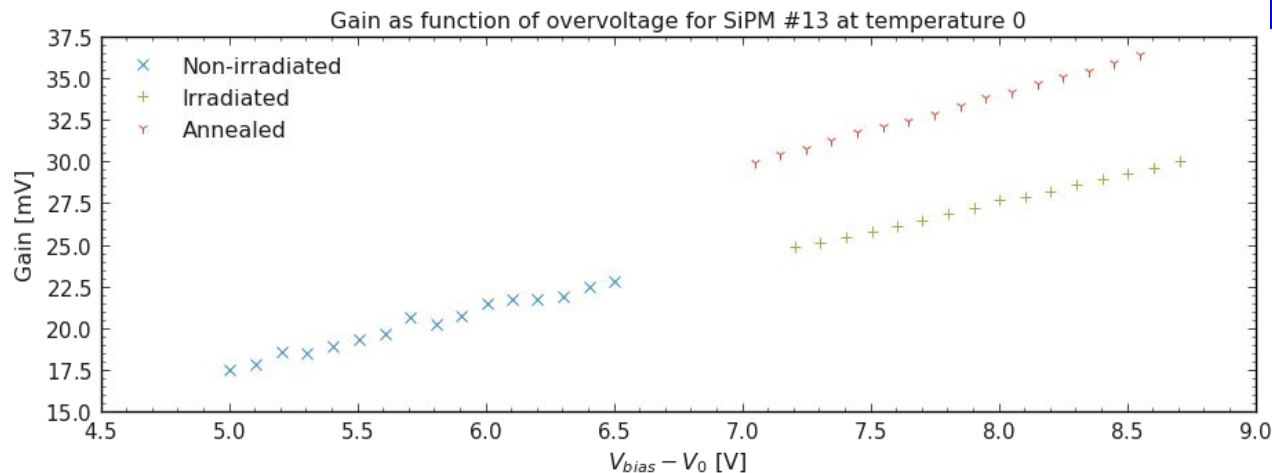


# Gain as function of overvoltage for SiPM #13

# Gain as function of overvoltage

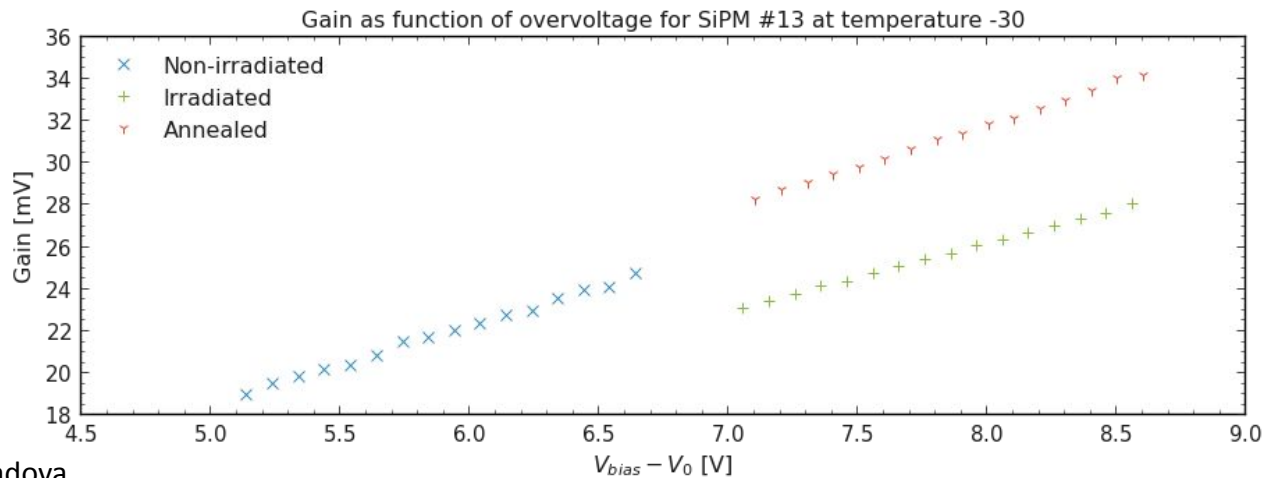
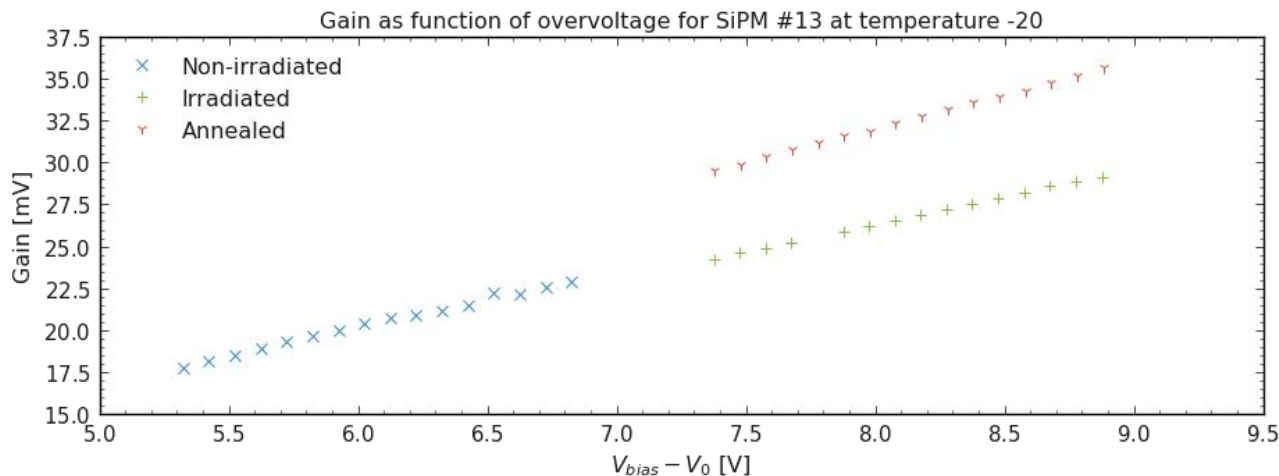


# Gain as function of overvoltage

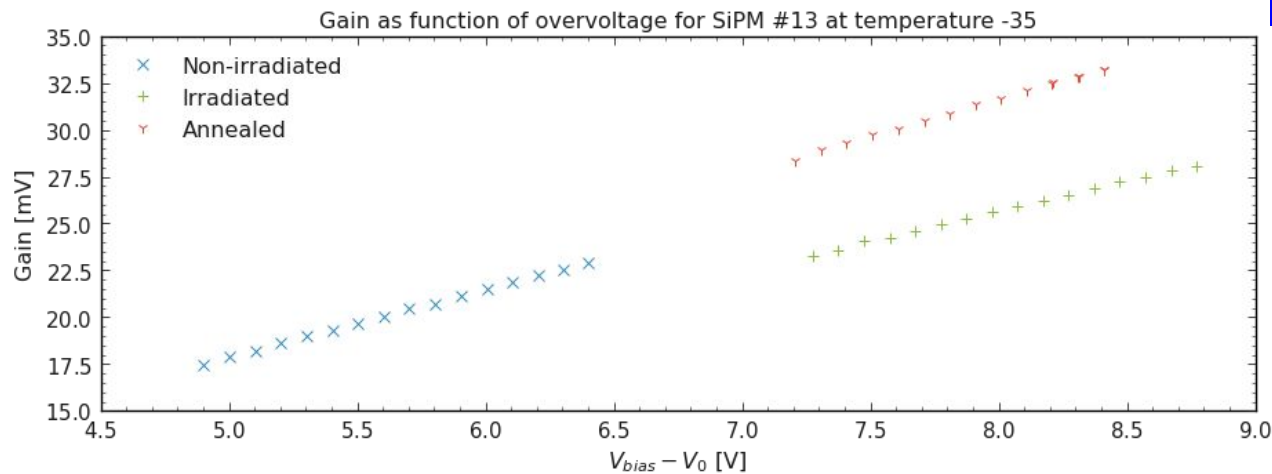




# Gain as function of overvoltage



# Gain as function of overvoltage

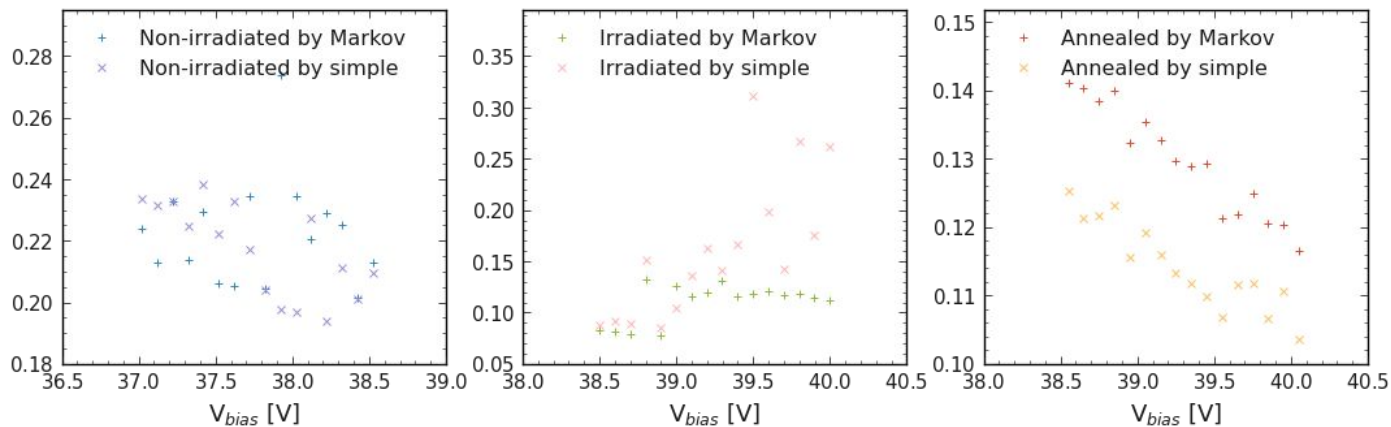


# Time resolution for first photon peak for SiPM #13

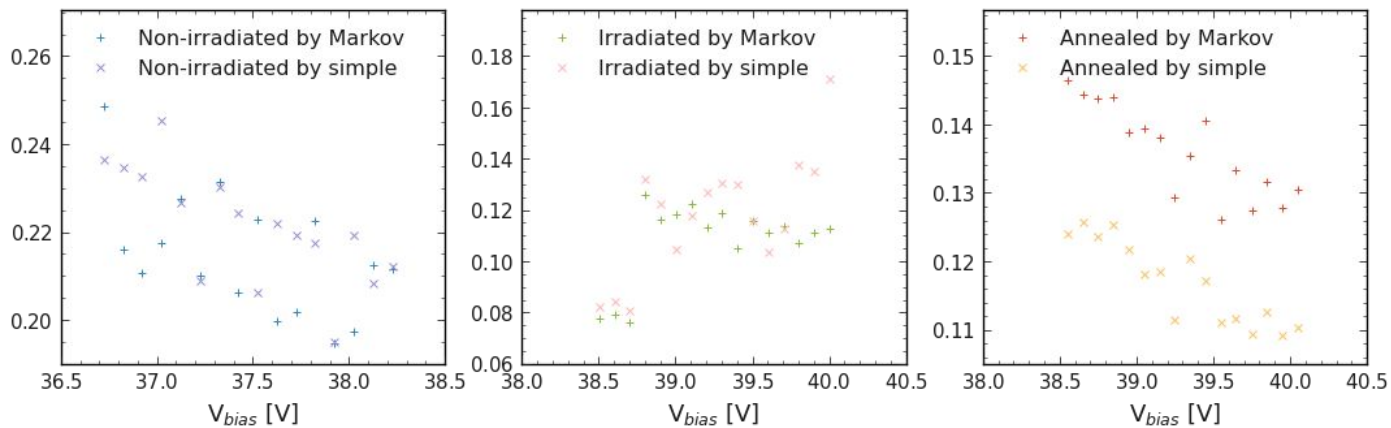
# Time resolution for first photon peak



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



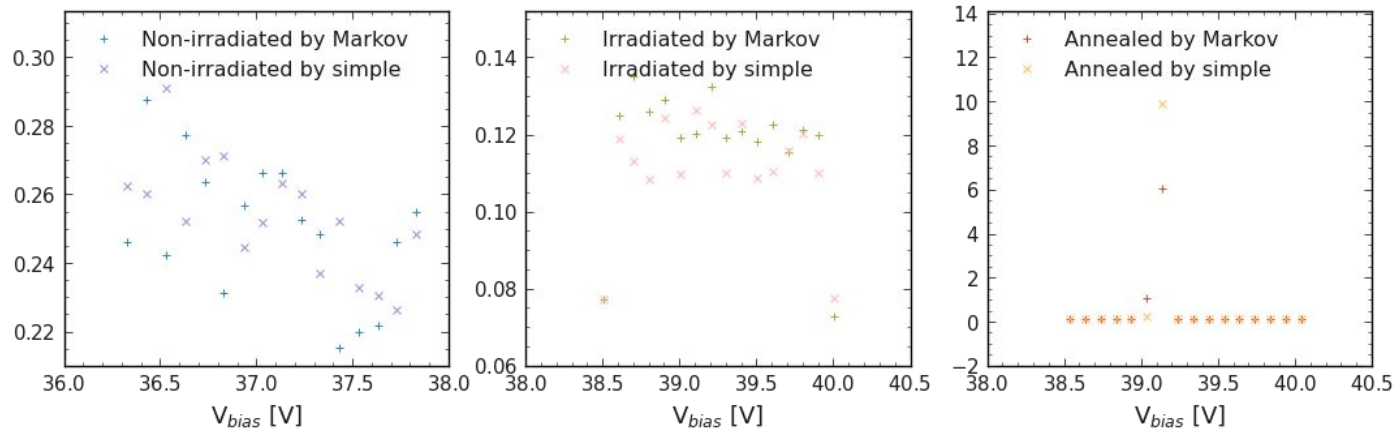
Time resolution of first peak for SiPM #13 at 10°



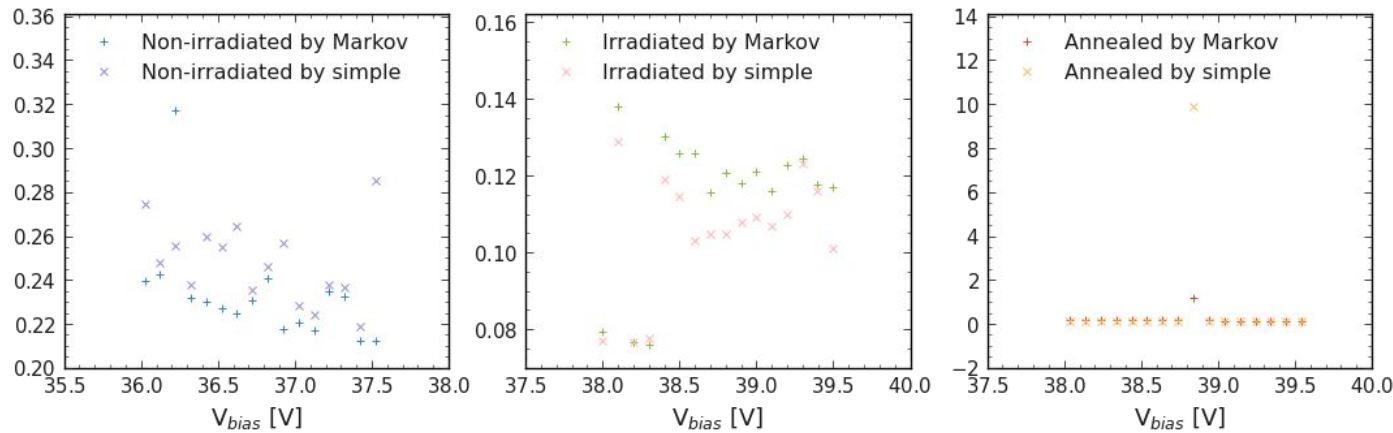
# Time resolution for first photon peak



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



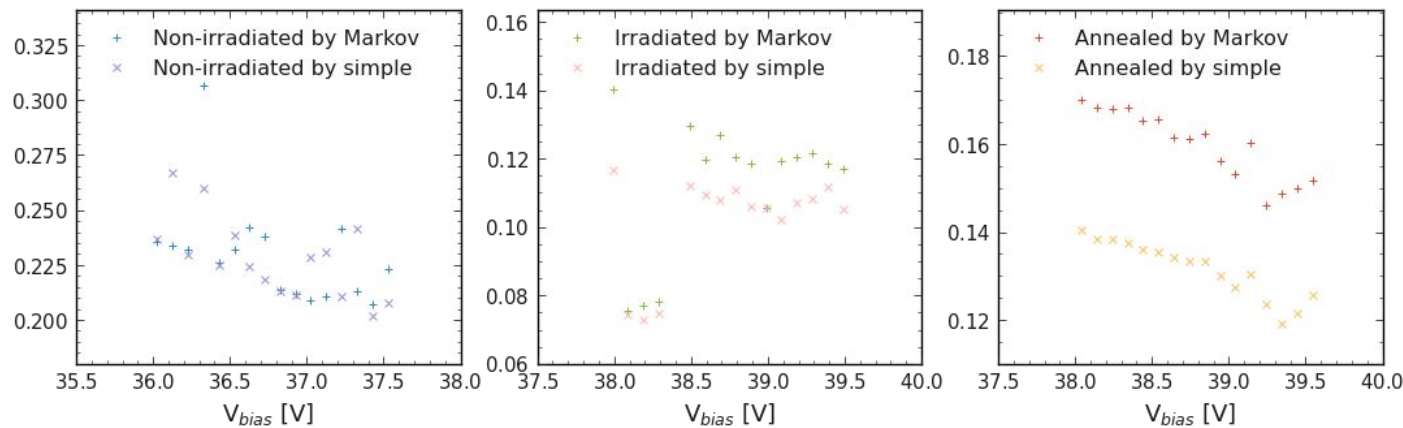
Time resolution of first peak for SiPM #13 at -10°



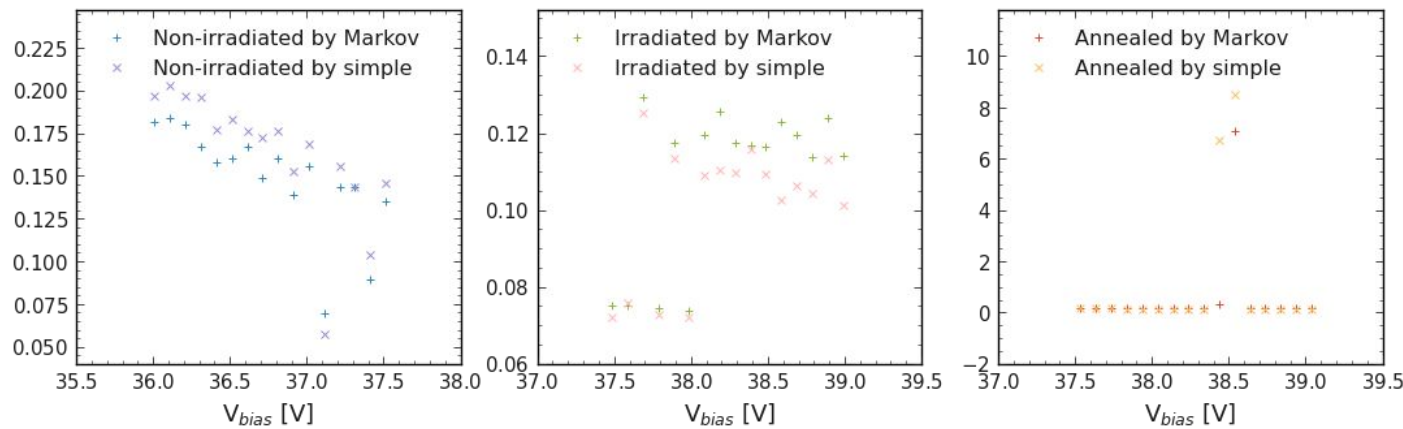
# Time resolution for first photon peak



Time resolution of first peak for SiPM #13 at  $-20^\circ$



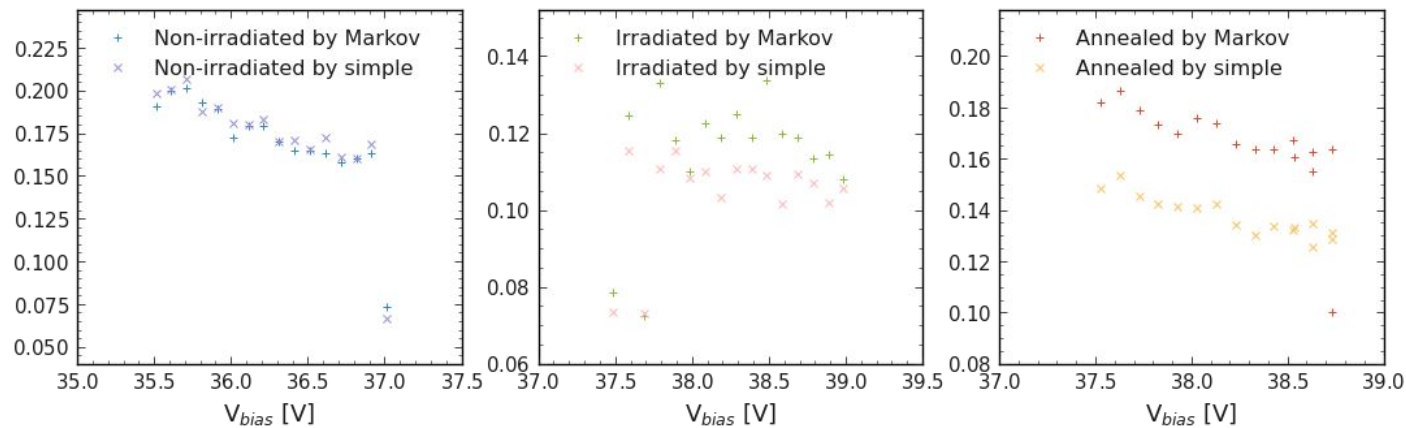
Time resolution of first peak for SiPM #13 at  $-30^\circ$



# Time resolution for first photon peak



Time resolution of first peak for SiPM #13 at  $-35^\circ$



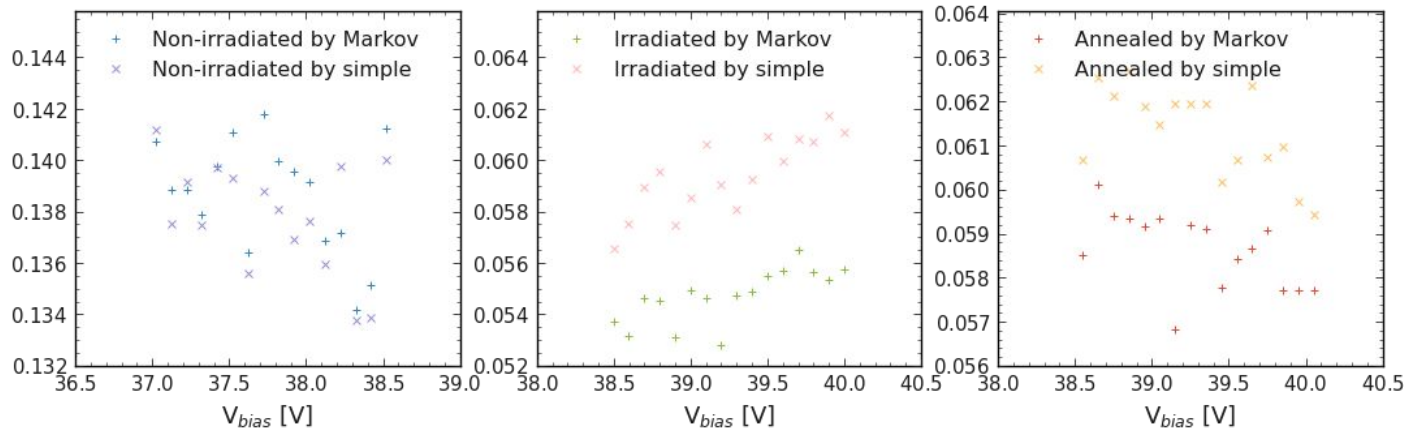
# Time resolution for other photon peaks for SiPM #13



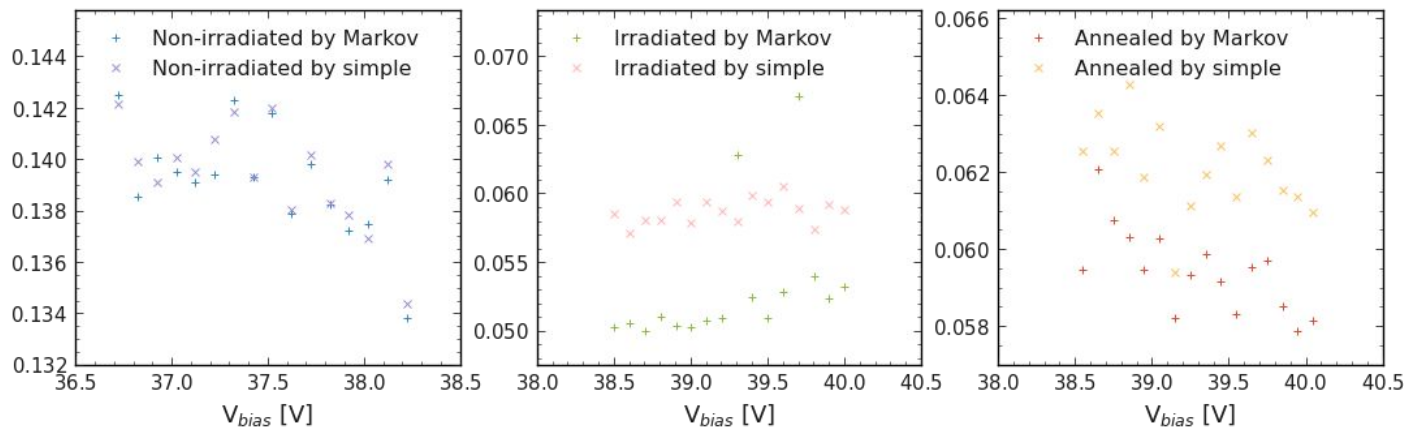
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #13 at 20°



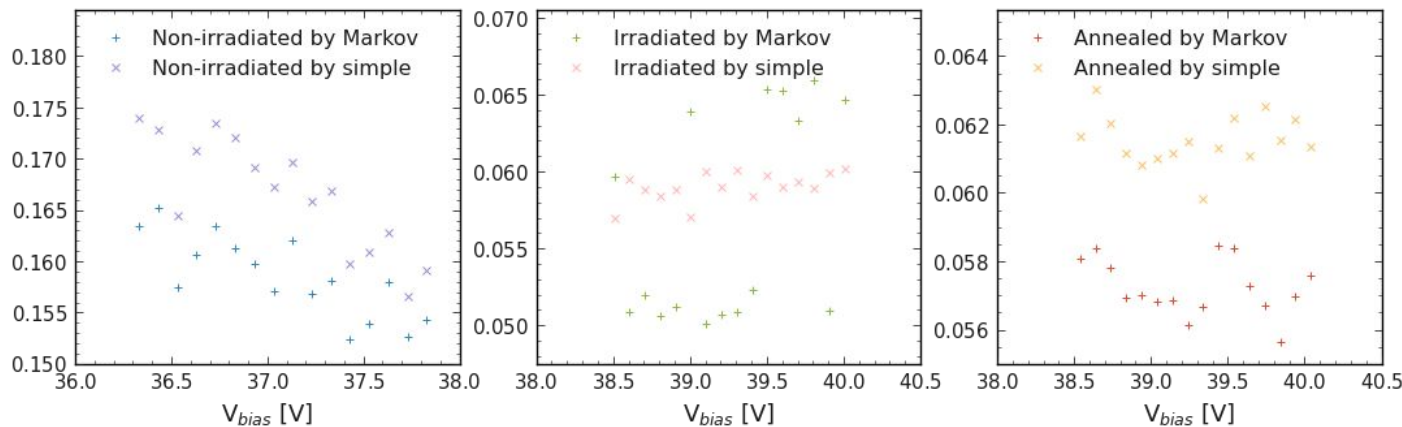
Time resolution of other peaks for SiPM #13 at 10°



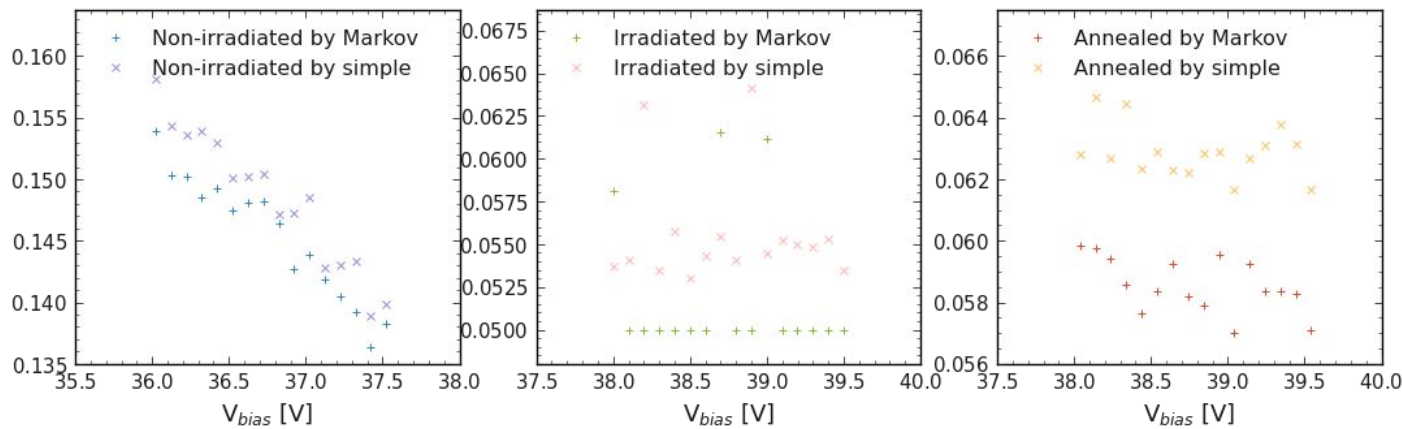
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #13 at 0°



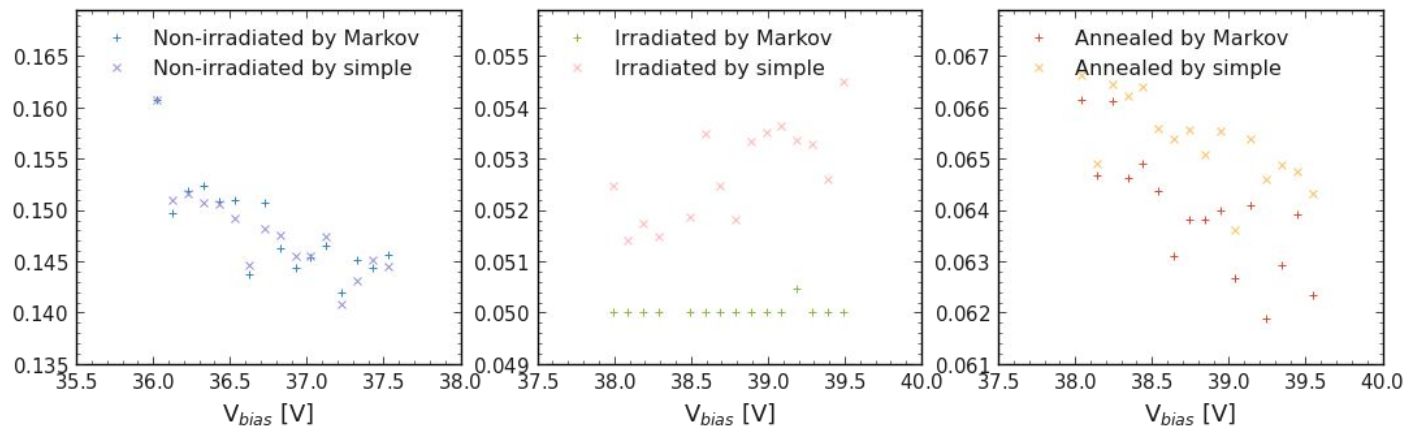
Time resolution of other peaks for SiPM #13 at -10°



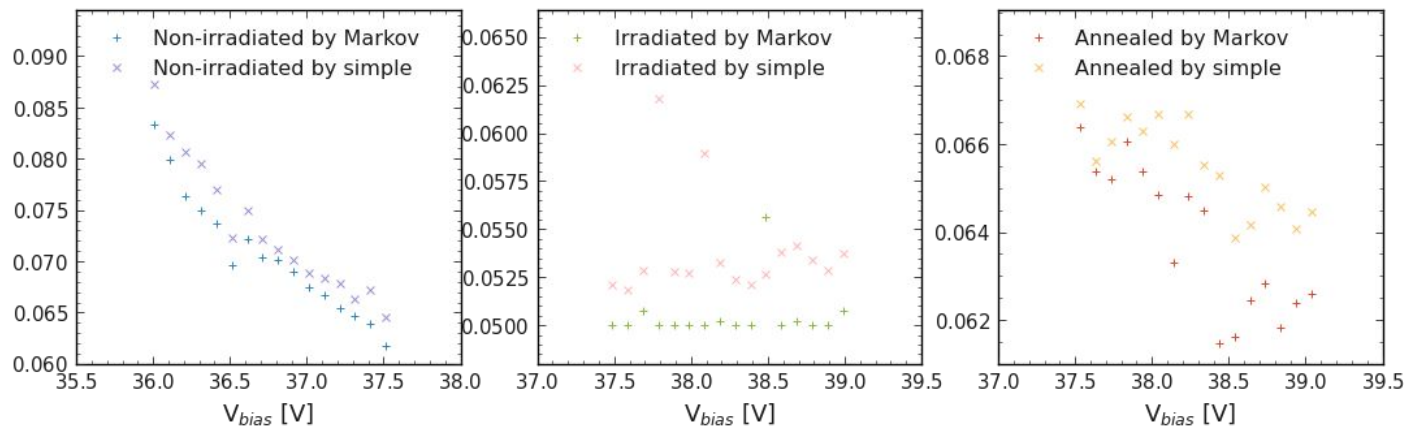
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #13 at  $-20^\circ$



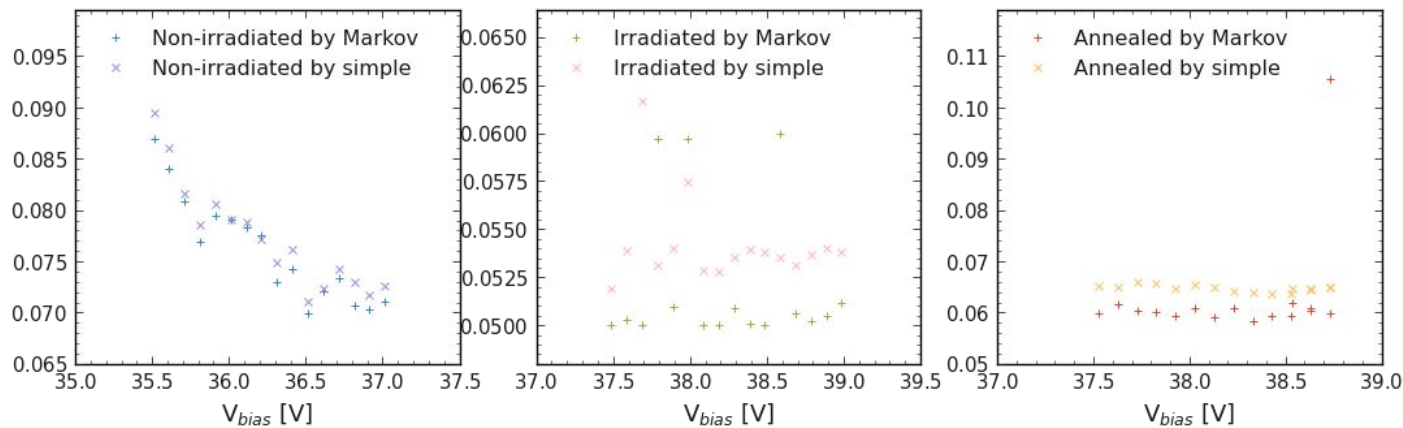
Time resolution of other peaks for SiPM #13 at  $-30^\circ$



# Time resolution for other photon peaks

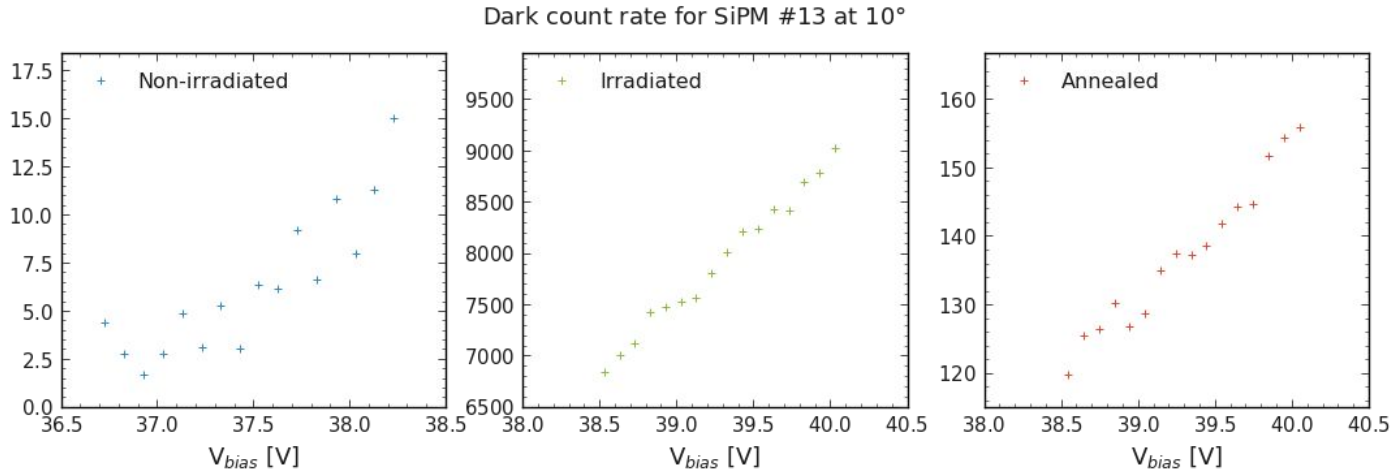
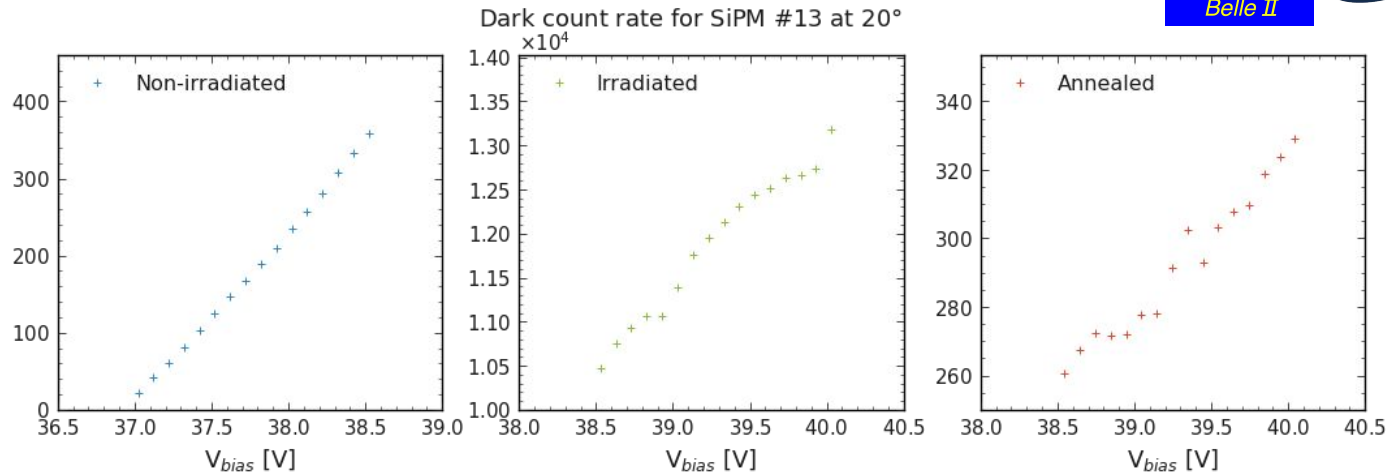


Time resolution of other peaks for SiPM #13 at  $-35^\circ$



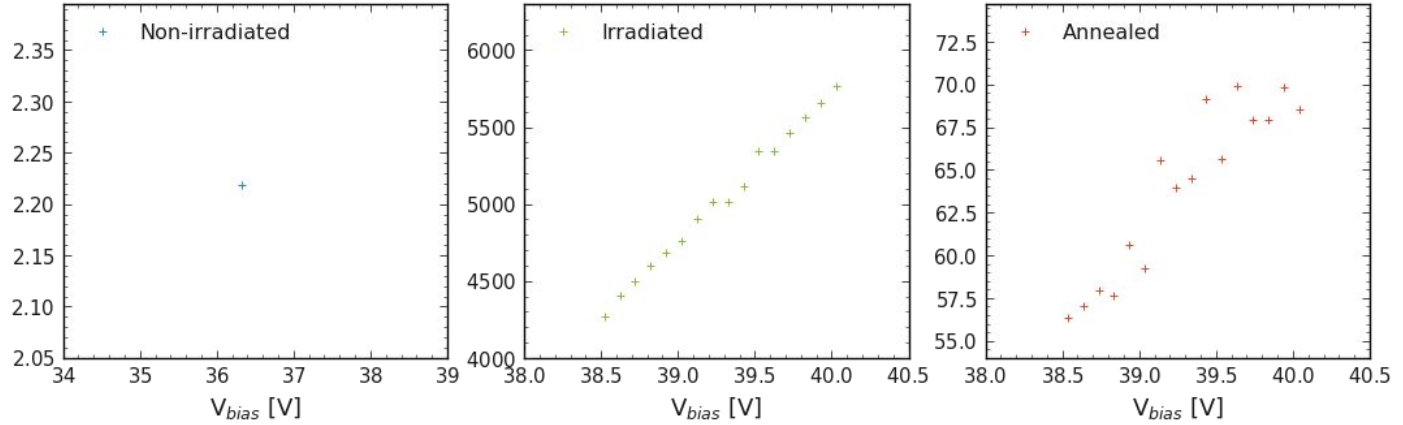
# Dark count rate for SiPM #13

# Dark count rate

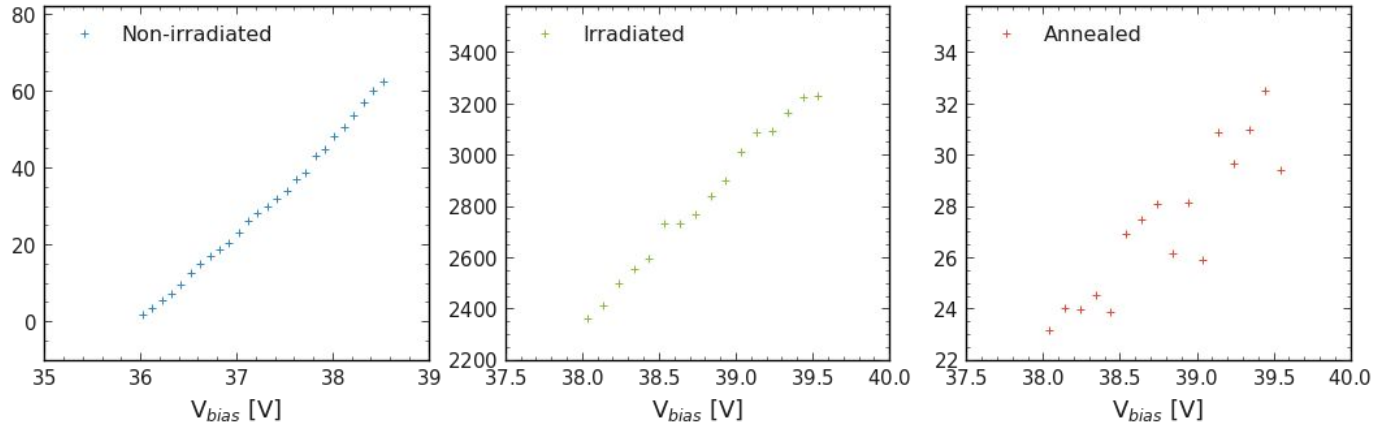


# Dark count rate

Dark count rate for SiPM #13 at 0°

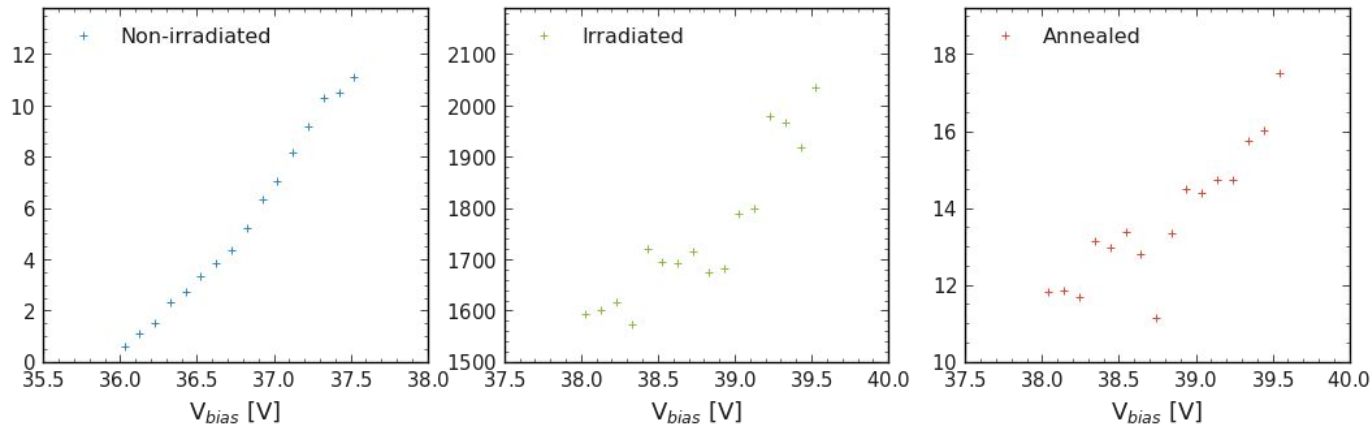


Dark count rate for SiPM #13 at -10°

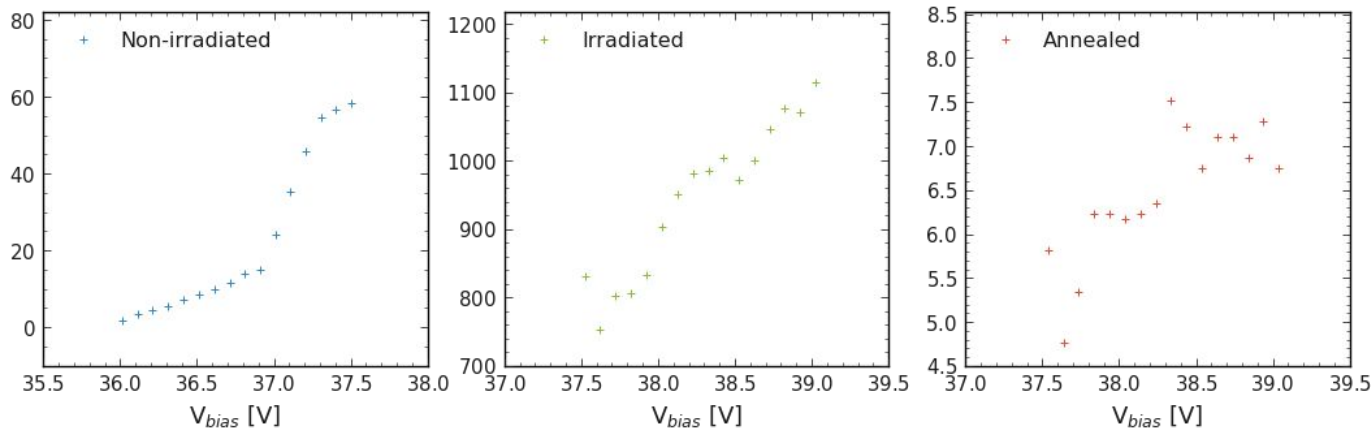


# Dark count rate

Dark count rate for SiPM #13 at  $-20^\circ$



Dark count rate for SiPM #13 at  $-30^\circ$

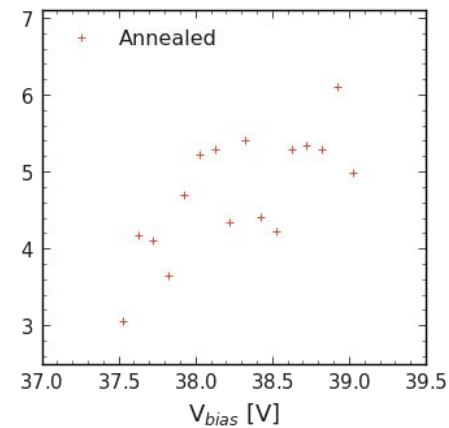
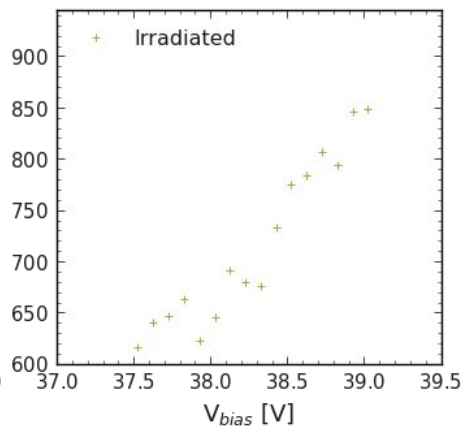
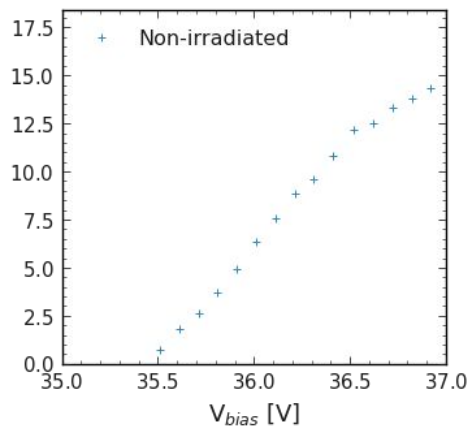




# Dark count rate



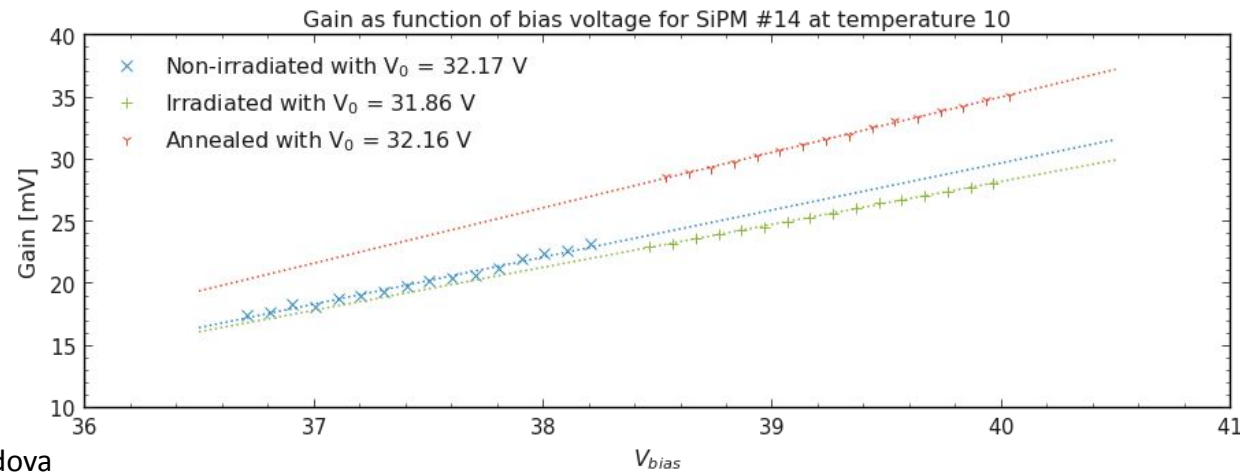
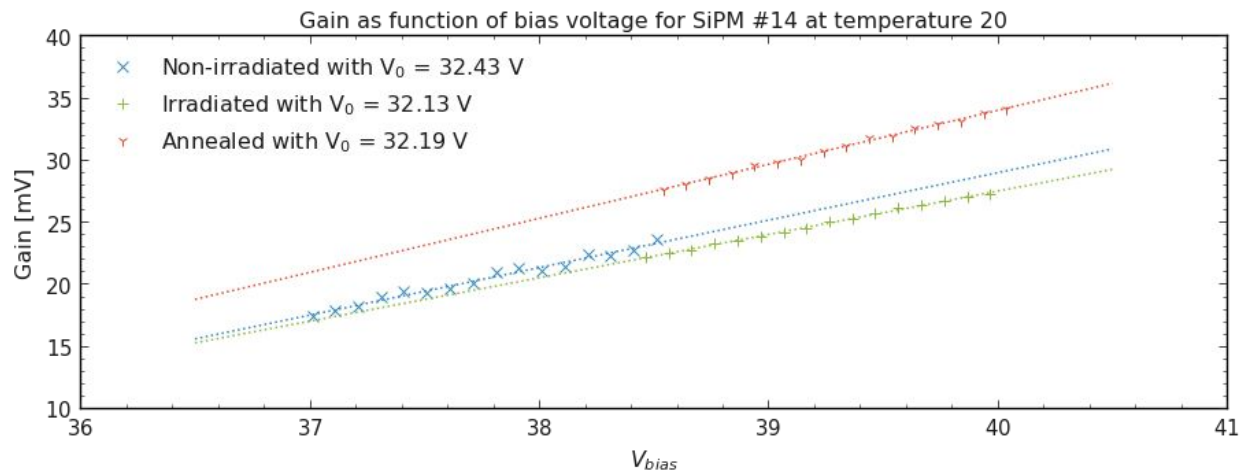
Dark count rate for SiPM #13 at  $-35^\circ$



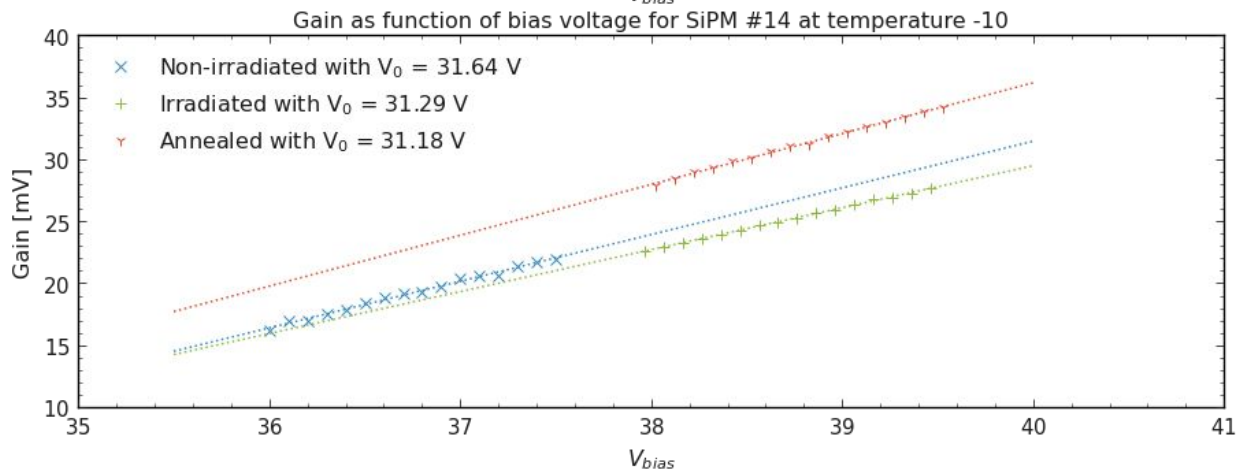
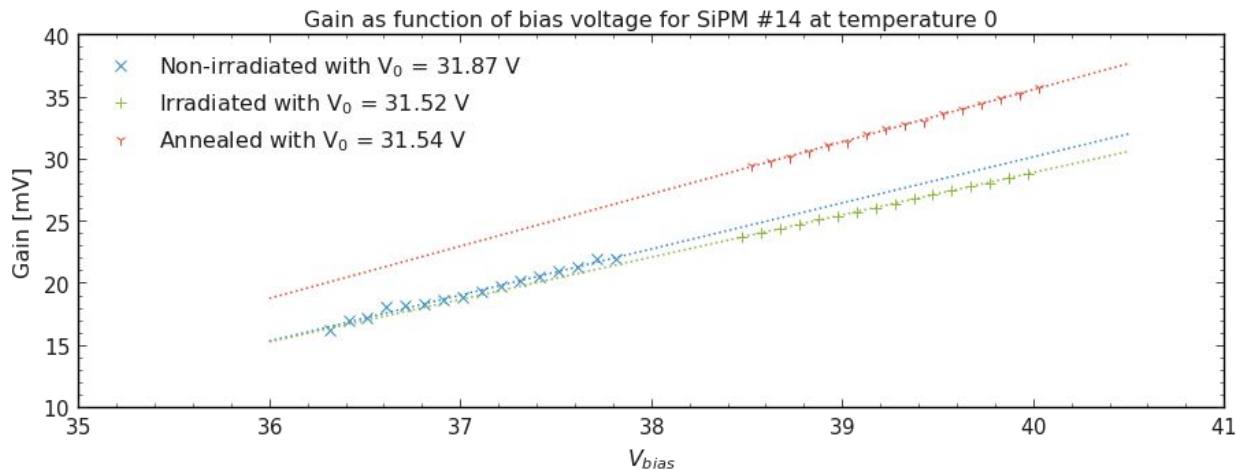
# SIMP #14

# Gain as function of bias voltage for SiPM #14

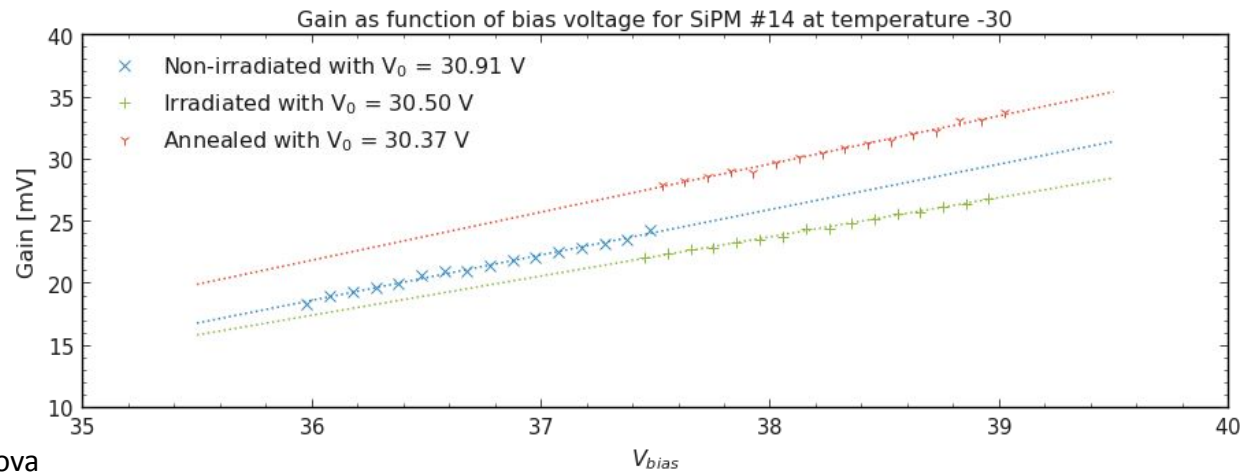
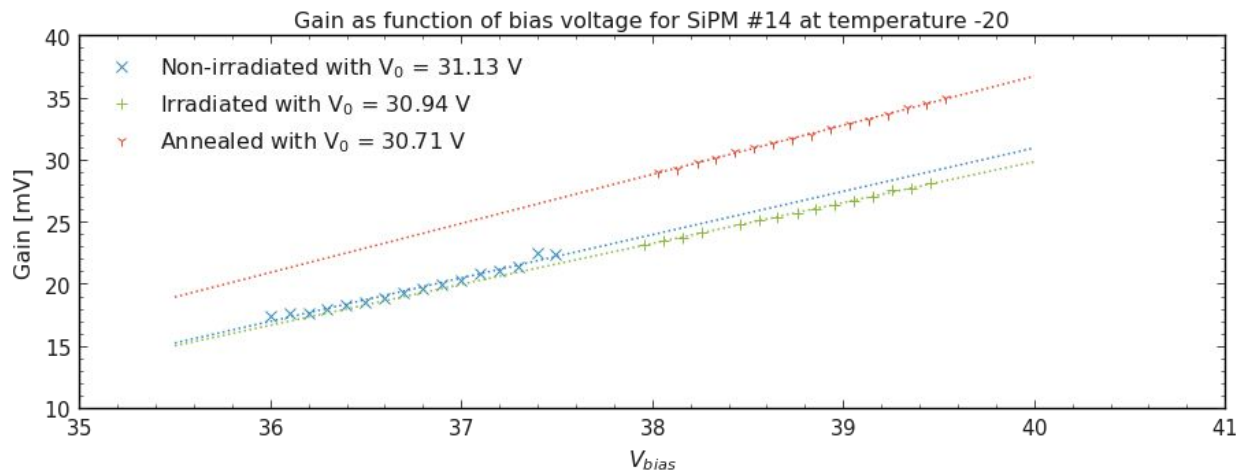
# Gain as function of bias voltage



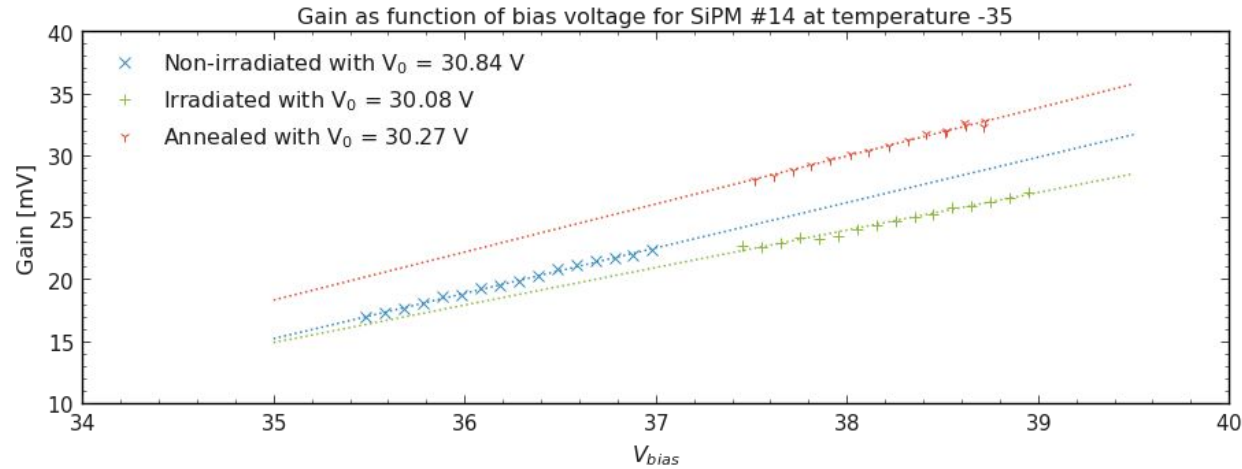
# Gain as function of bias voltage



# Gain as function of bias voltage



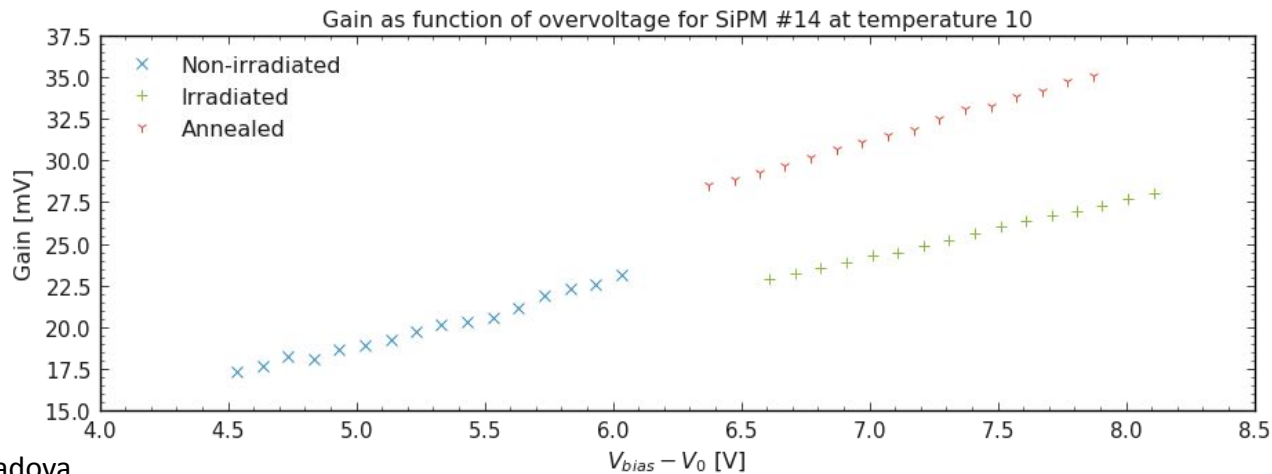
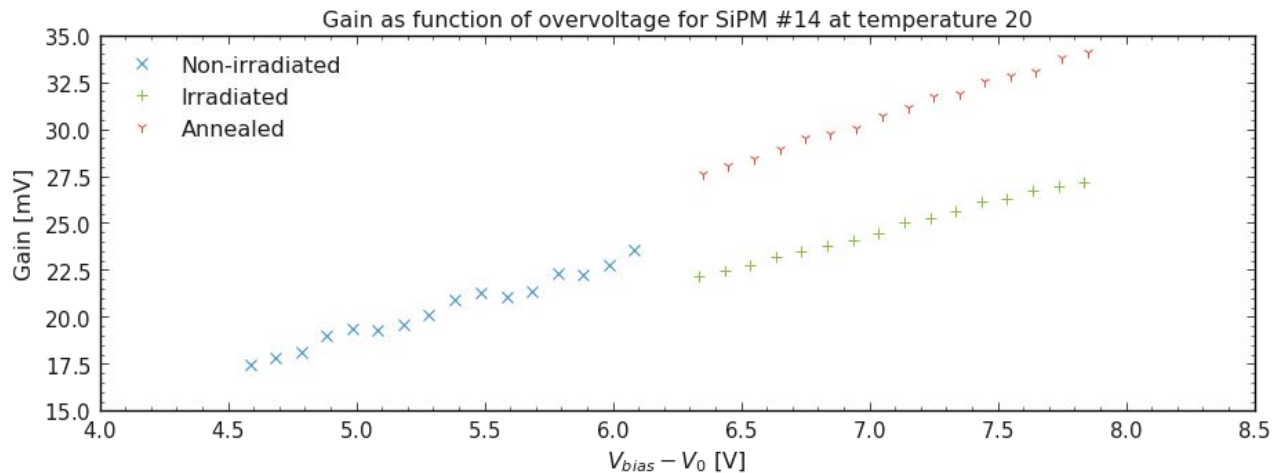
# Gain as function of bias voltage



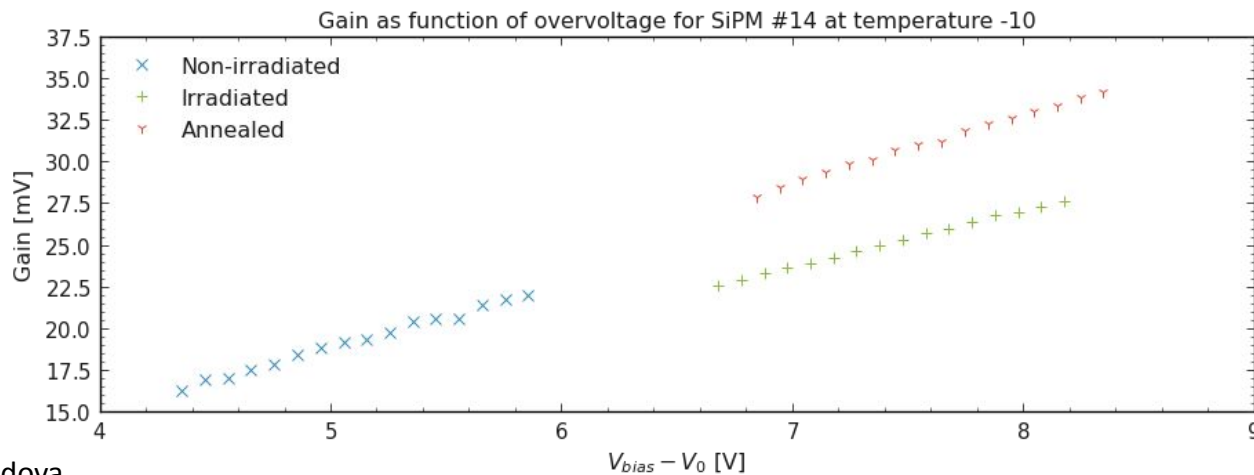
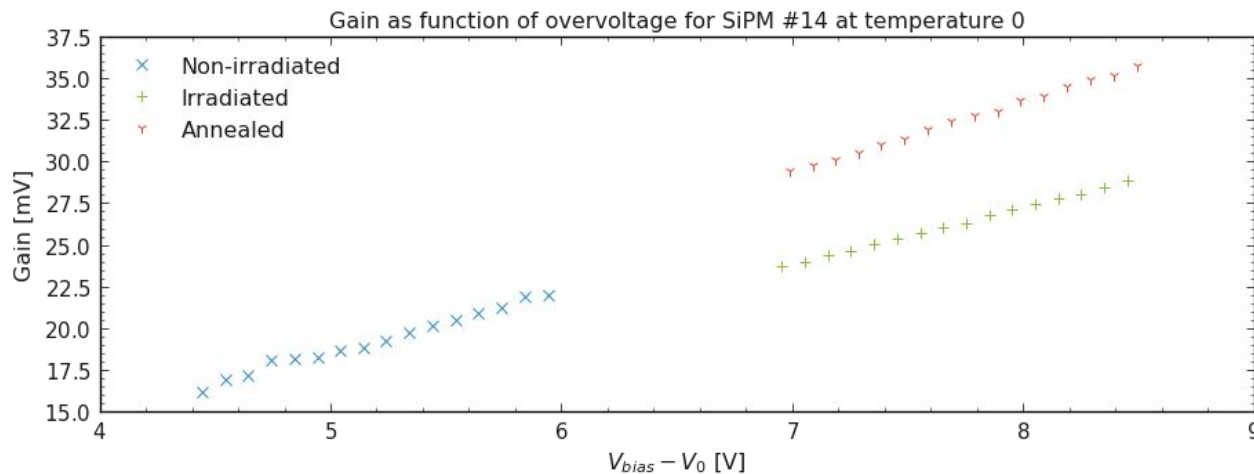
# Gain as function of overvoltage for SiPM #14



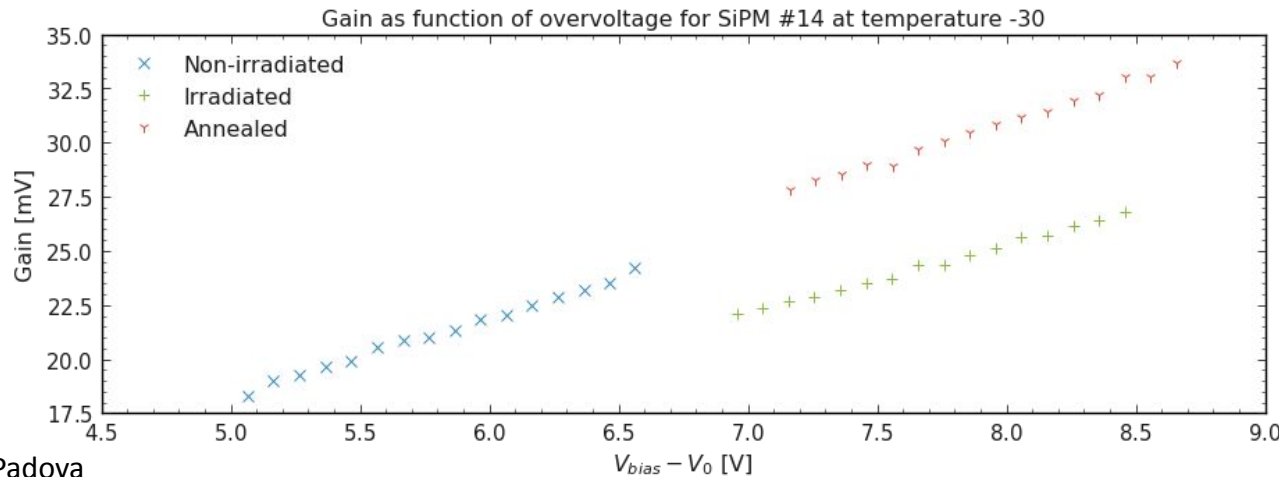
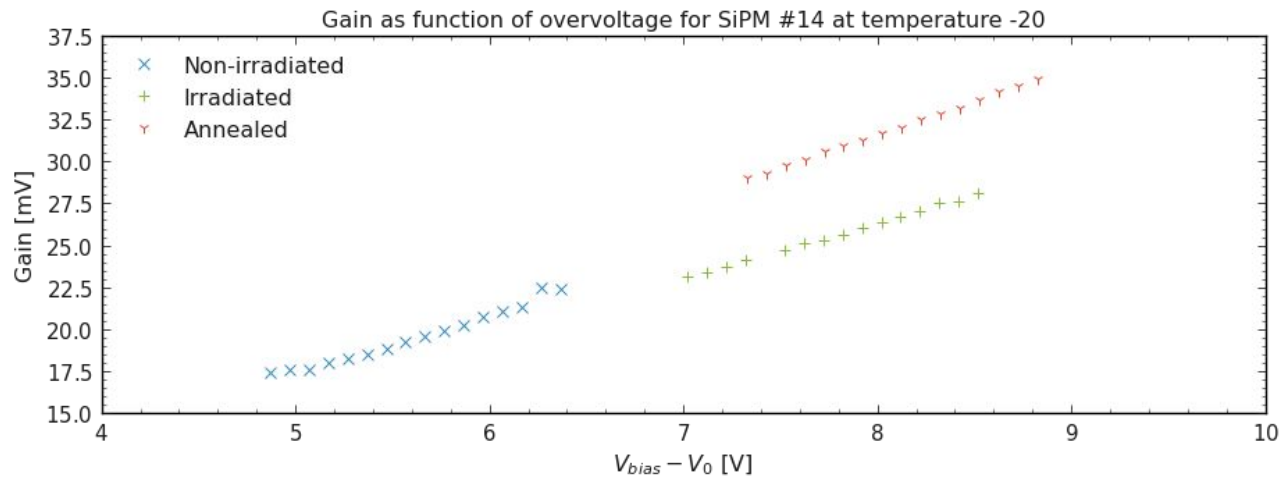
# Gain as function of overvoltage



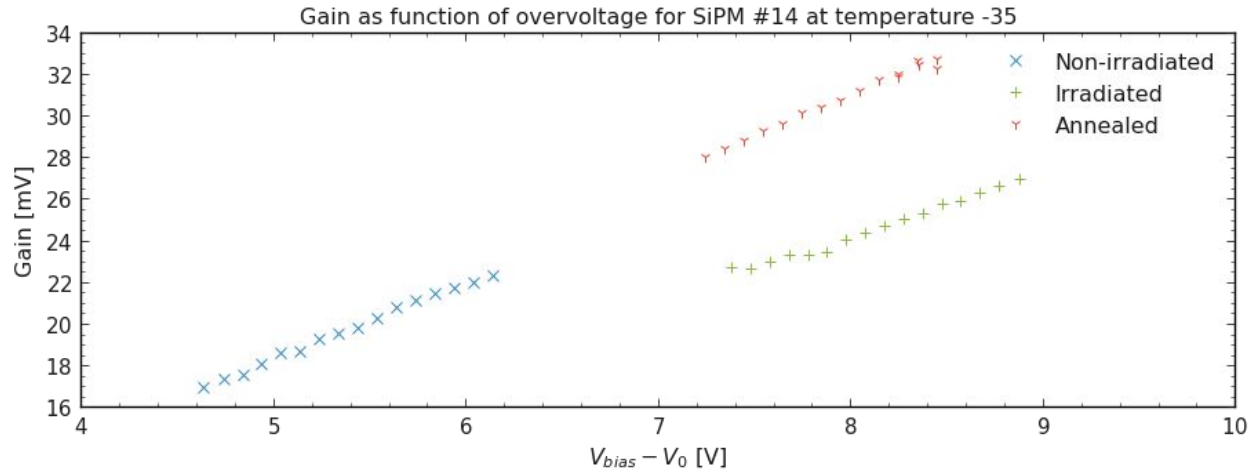
# Gain as function of overvoltage



# Gain as function of overvoltage



# Gain as function of overvoltage

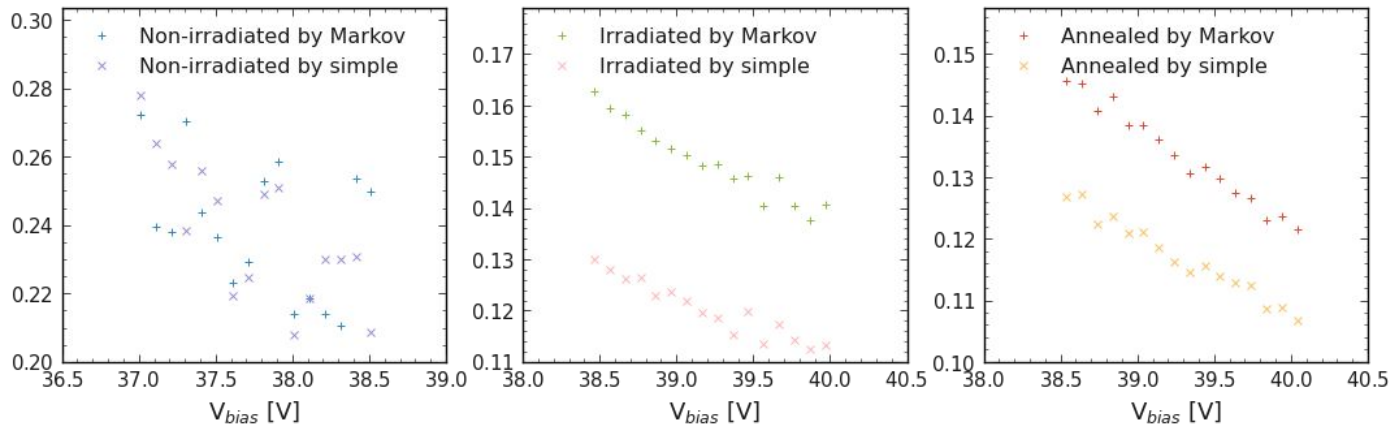


# Time resolution for first photon peak for SiPM #14

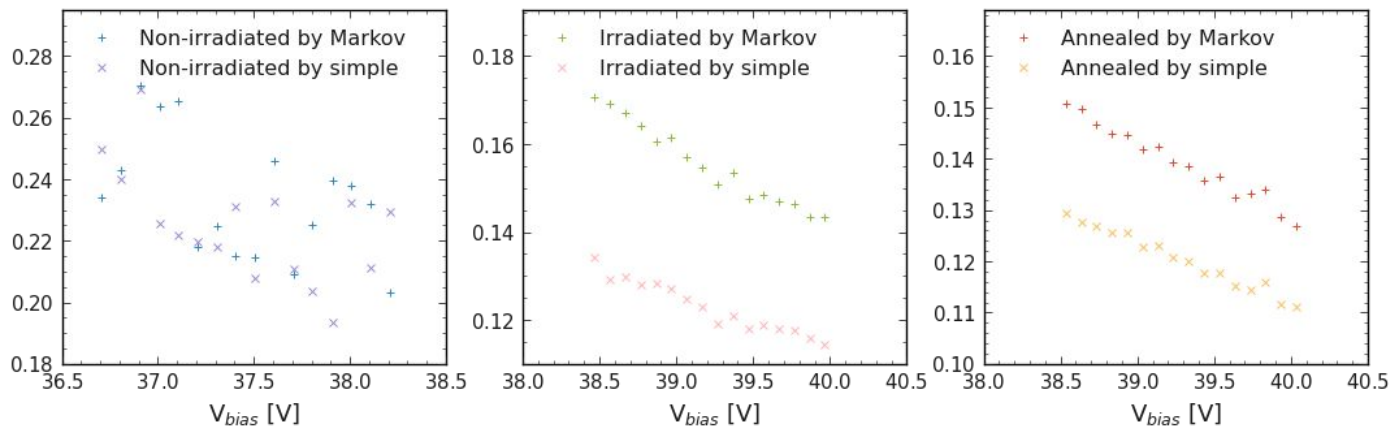
# Time resolution for first photon peak



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



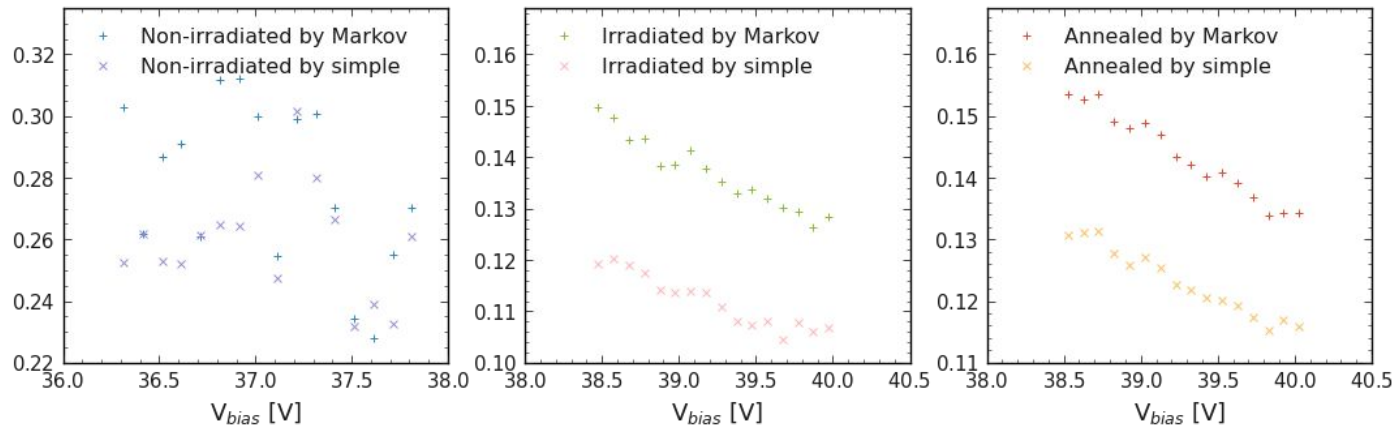
Time resolution of first peak for SiPM #14 at 10°



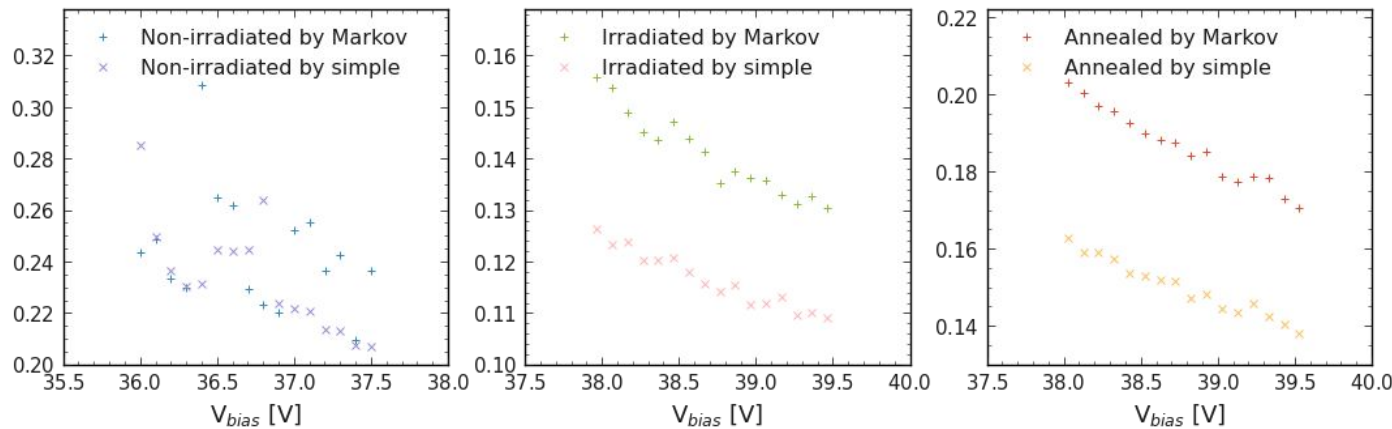
# Time resolution for first photon peak



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



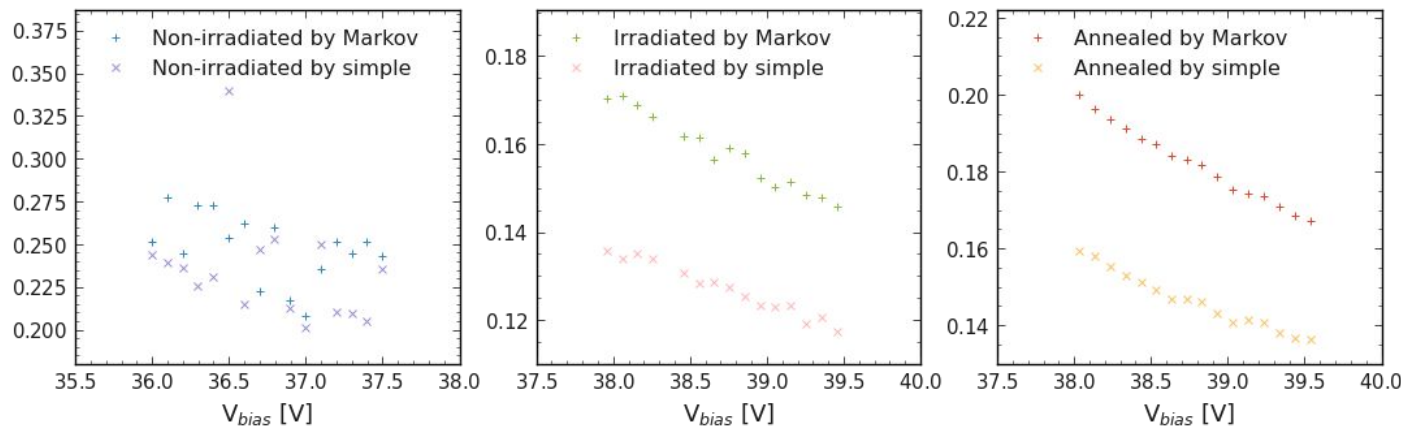
Time resolution of first peak for SiPM #14 at -10°



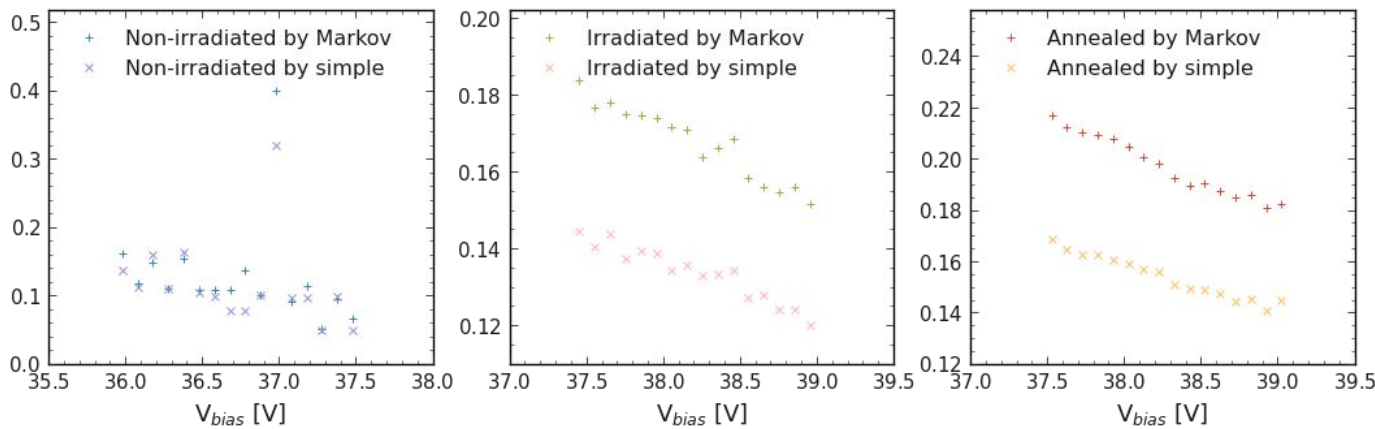
# Time resolution for first photon peak



Time resolution of first peak for SiPM #14 at  $-20^\circ$



Time resolution of first peak for SiPM #14 at  $-30^\circ$

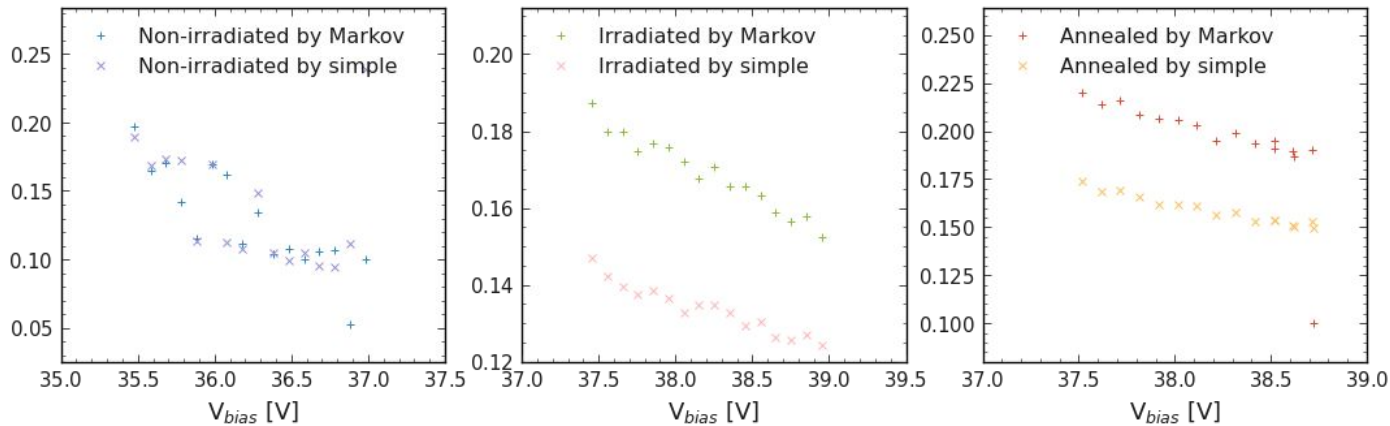




# Time resolution for first photon peak



Time resolution of first peak for SiPM #14 at  $-35^\circ$

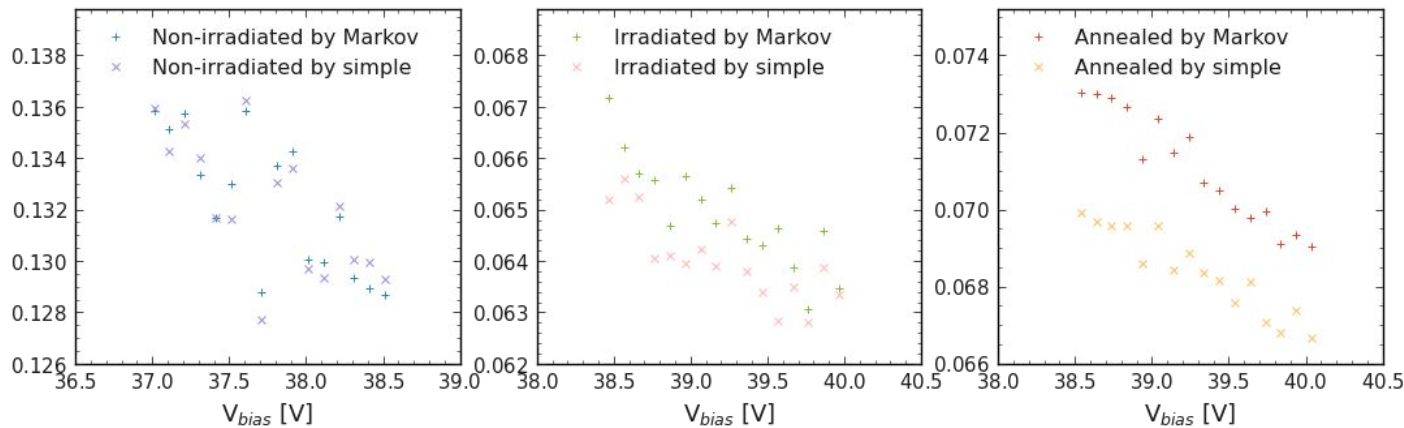


# Time resolution for other photon peaks for SiPM #14

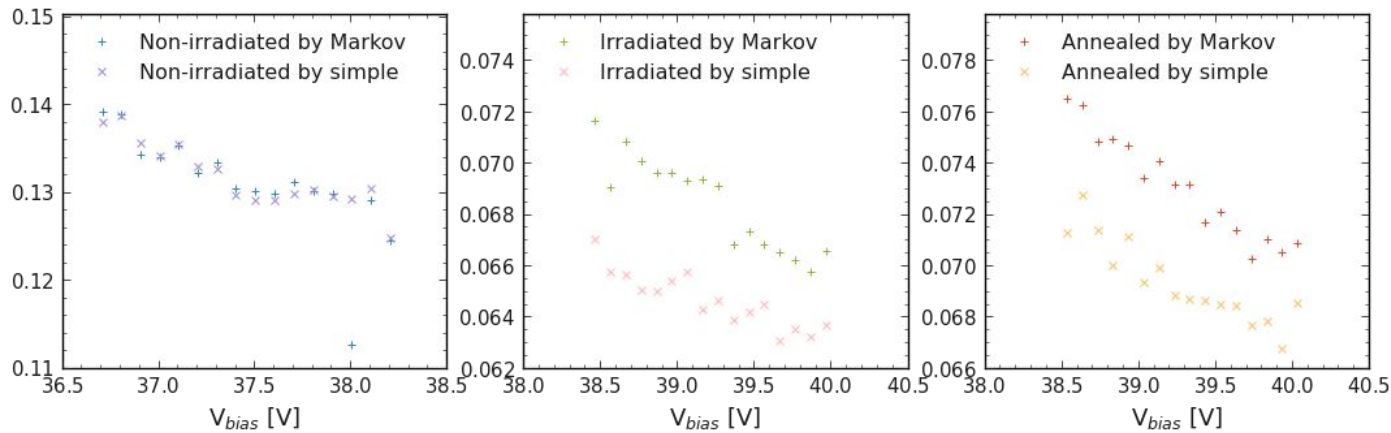
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #14 at 20°



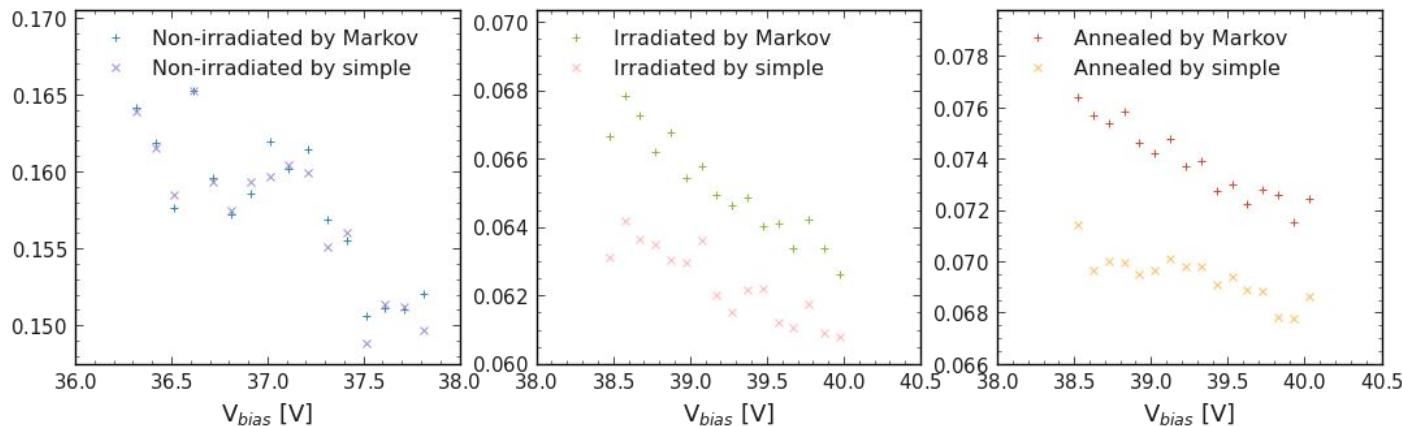
Time resolution of other peaks for SiPM #14 at 10°



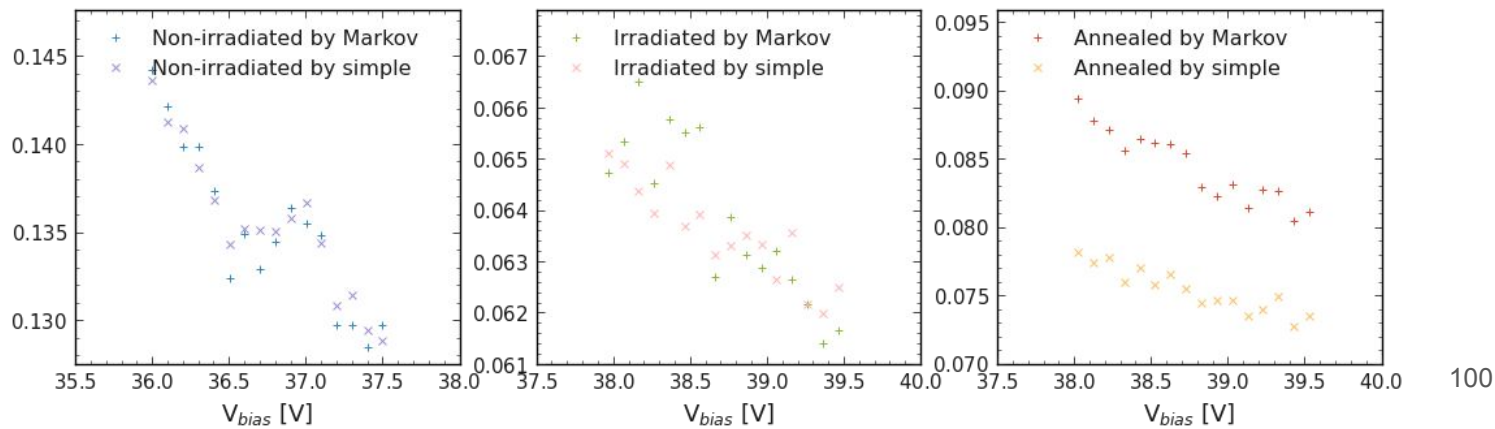
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #14 at 0°



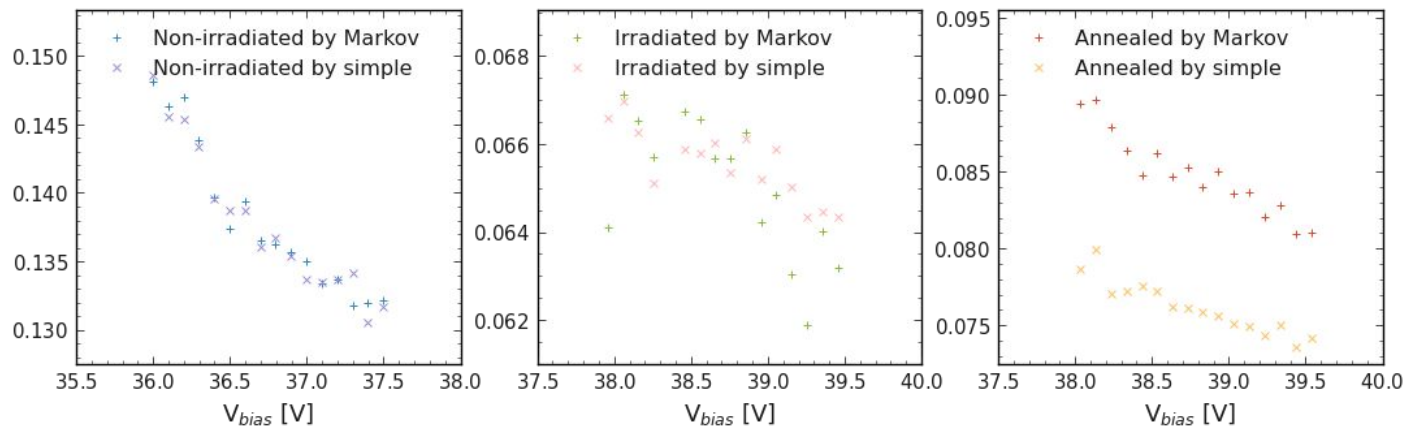
Time resolution of other peaks for SiPM #14 at -10°



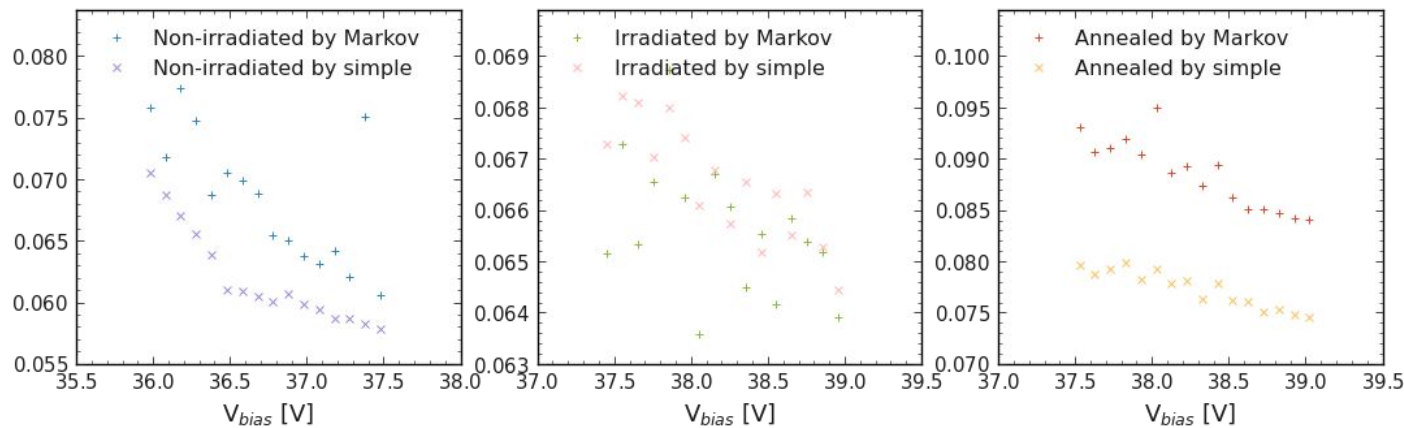
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #14 at  $-20^\circ$



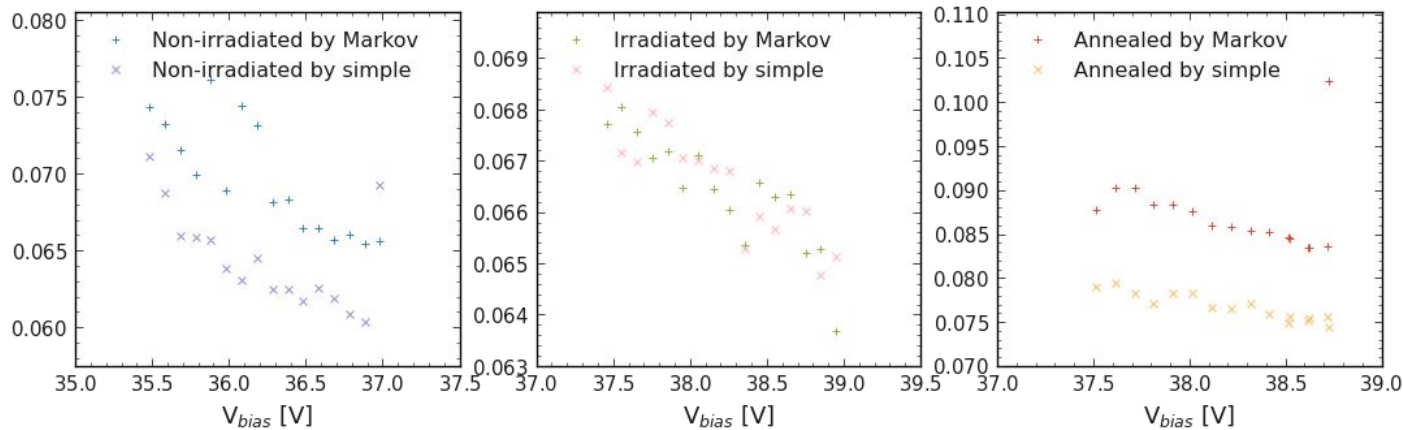
Time resolution of other peaks for SiPM #14 at  $-30^\circ$



# Time resolution for other photon peaks



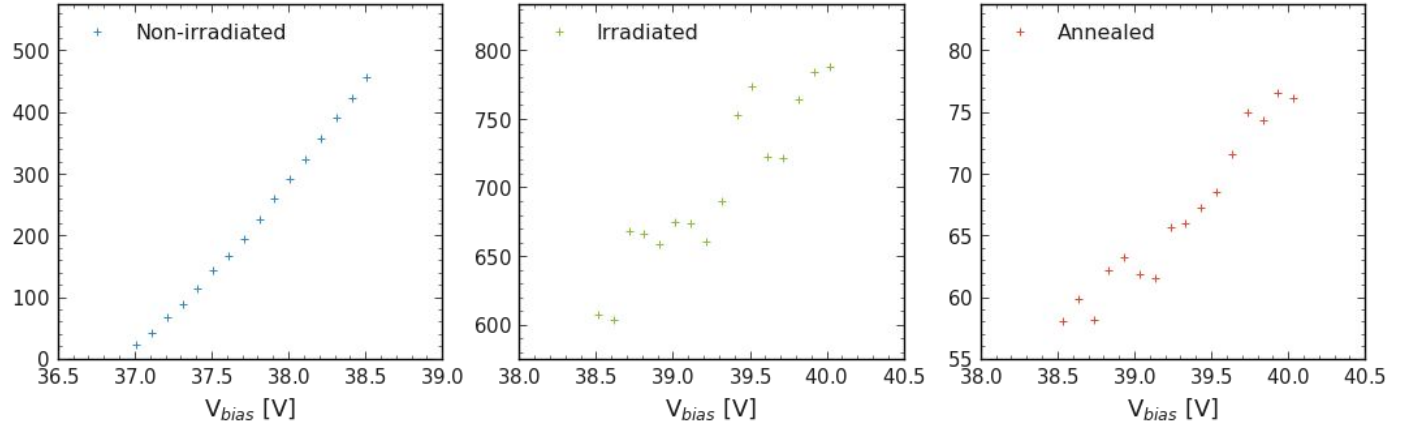
Time resolution of other peaks for SiPM #14 at  $-35^\circ$



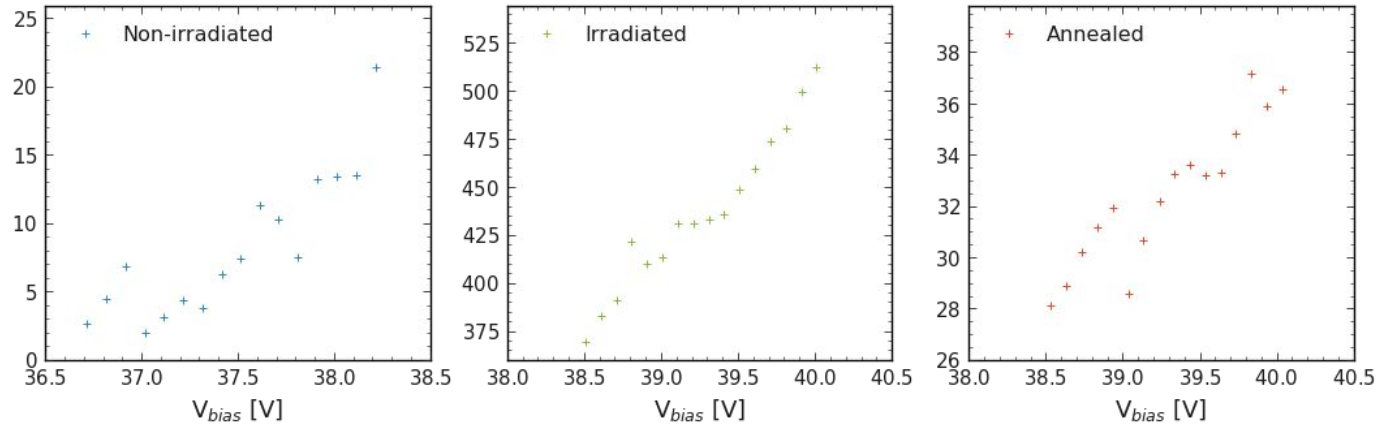
# Dark count rate for SiPM #14

# Dark count rate

Dark count rate for SiPM #14 at 20°



Dark count rate for SiPM #14 at 10°

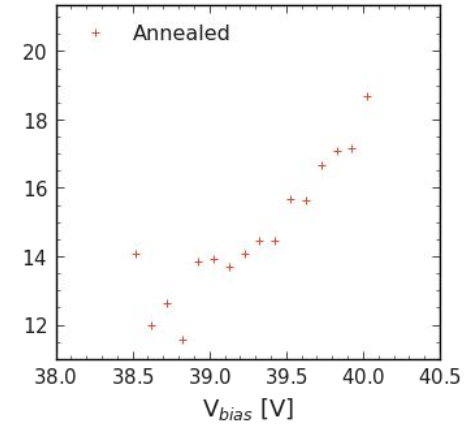
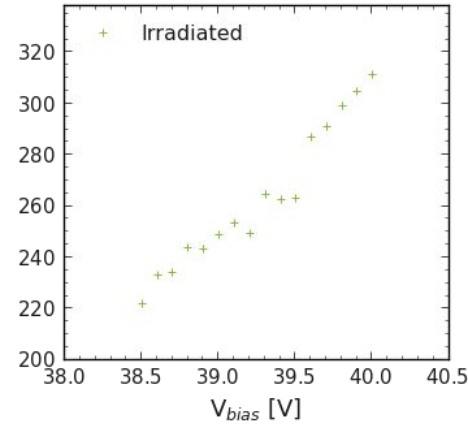
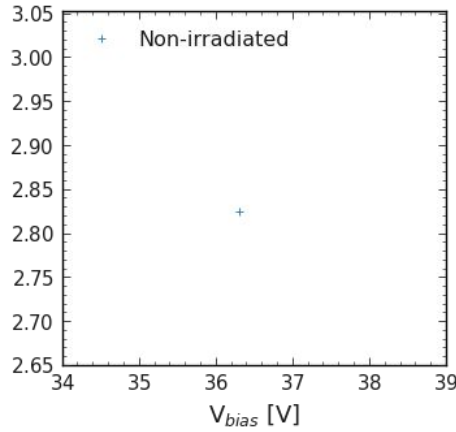




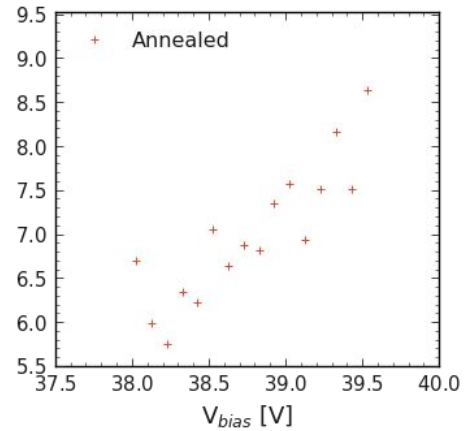
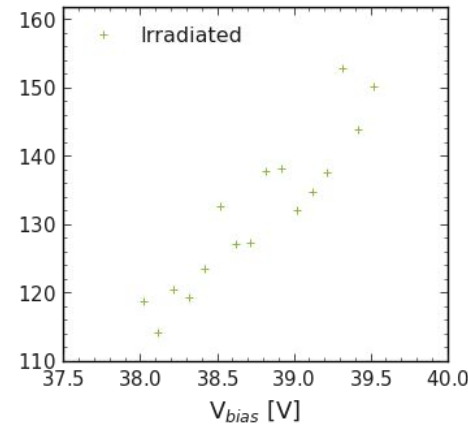
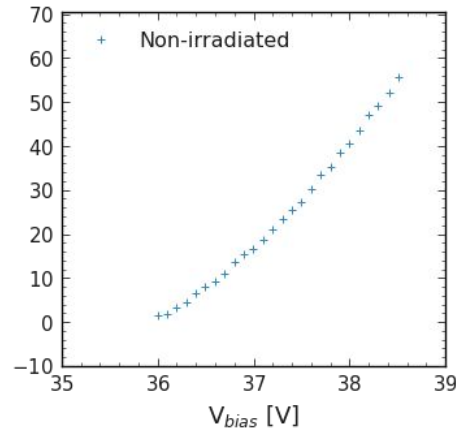
# Dark count rate



Dark count rate for SiPM #14 at 0°



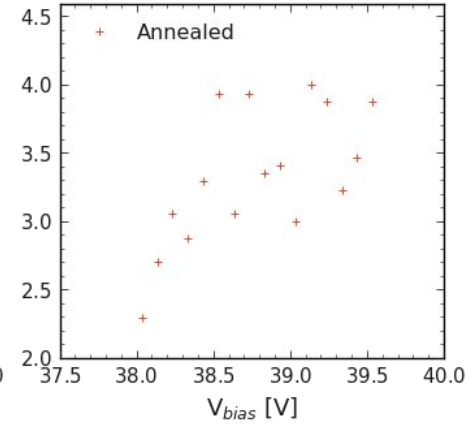
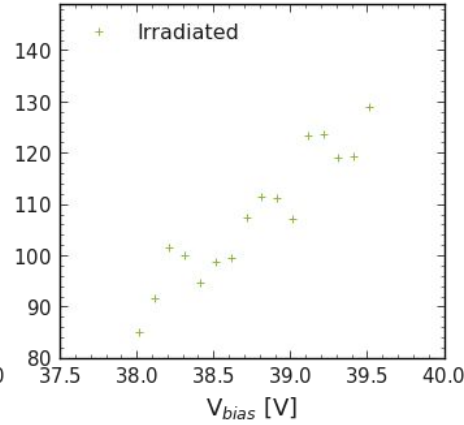
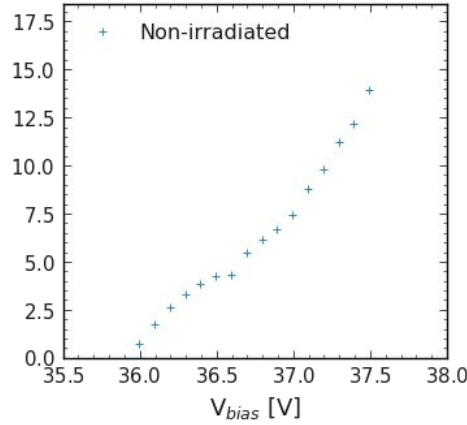
Dark count rate for SiPM #14 at -10°



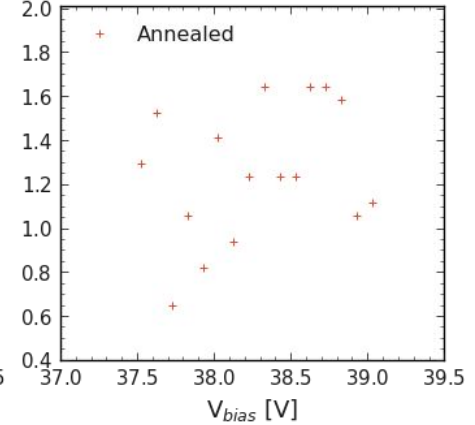
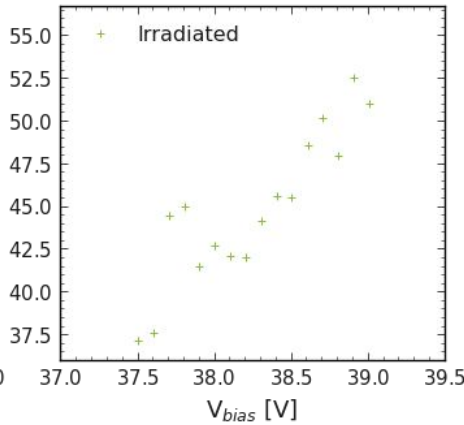
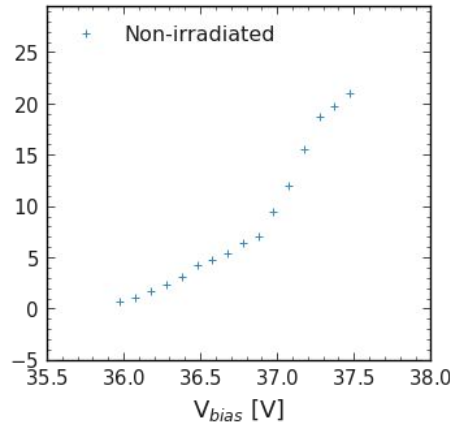
# Dark count rate



Dark count rate for SiPM #14 at  $-20^\circ$



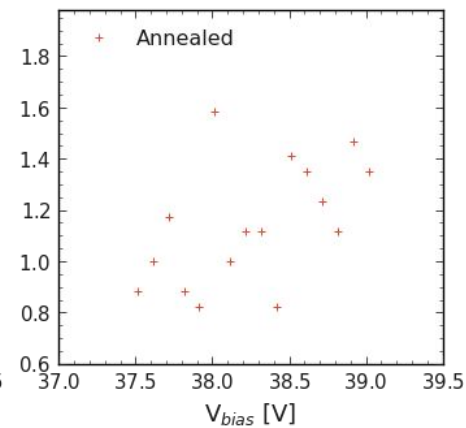
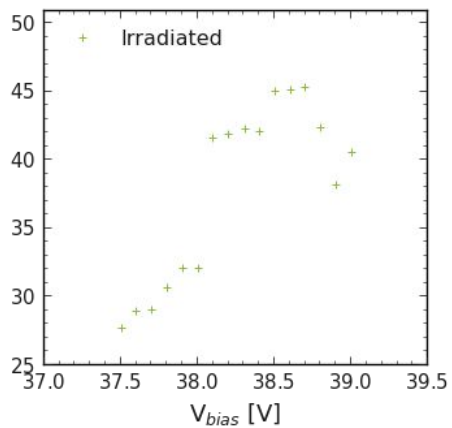
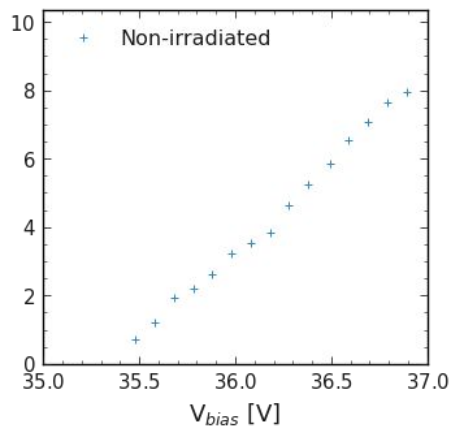
Dark count rate for SiPM #14 at  $-30^\circ$



# Dark count rate



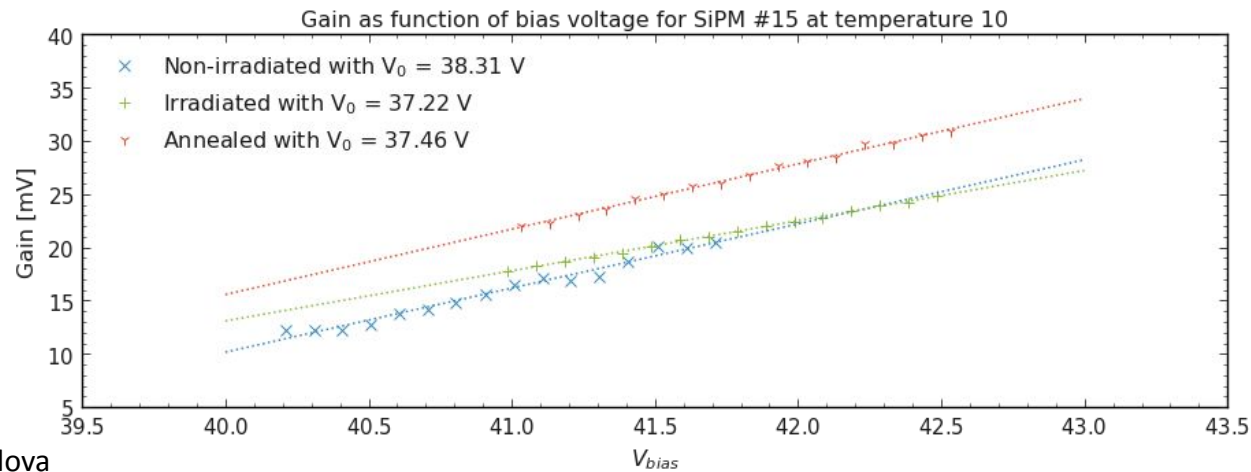
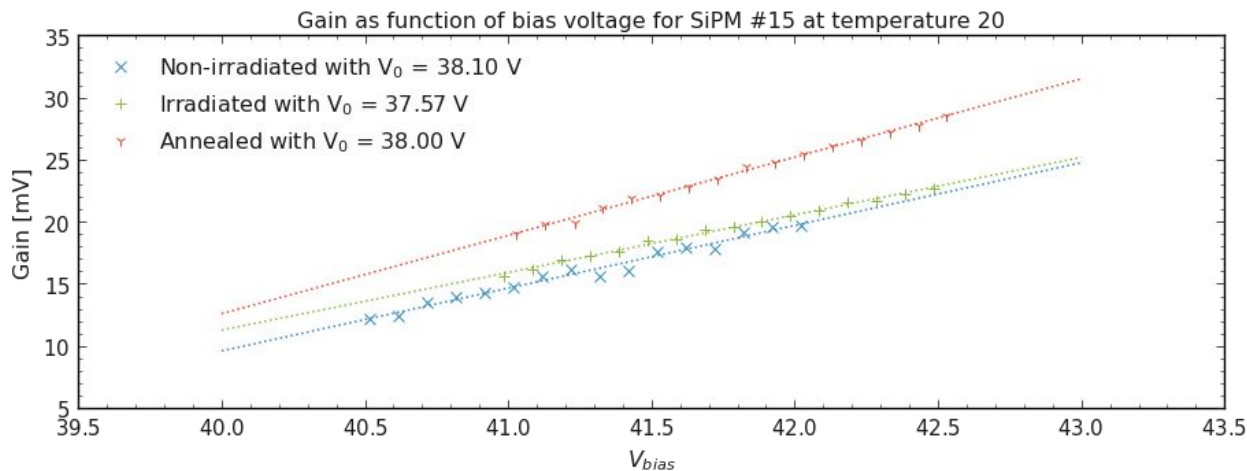
Dark count rate for SiPM #14 at  $-35^\circ$



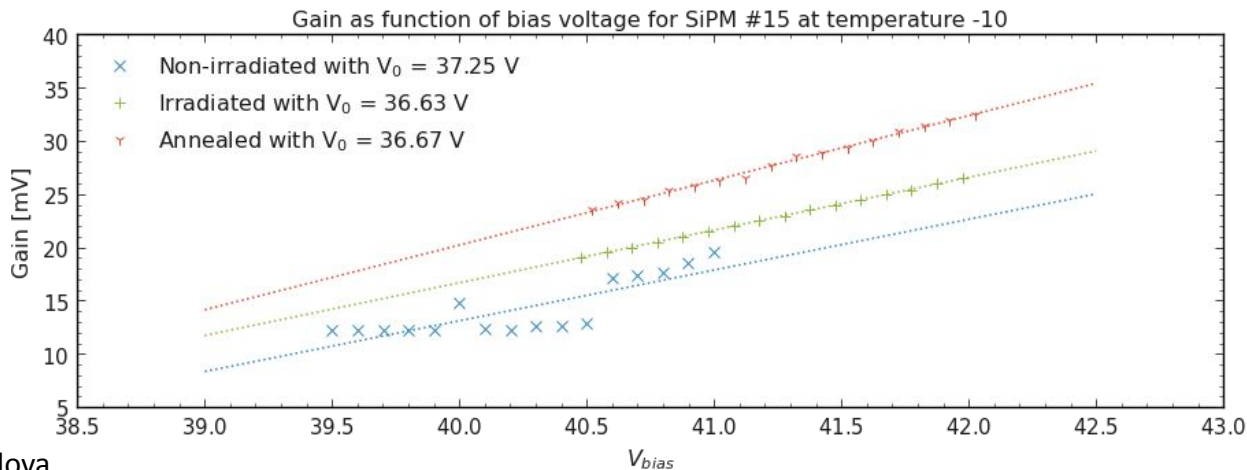
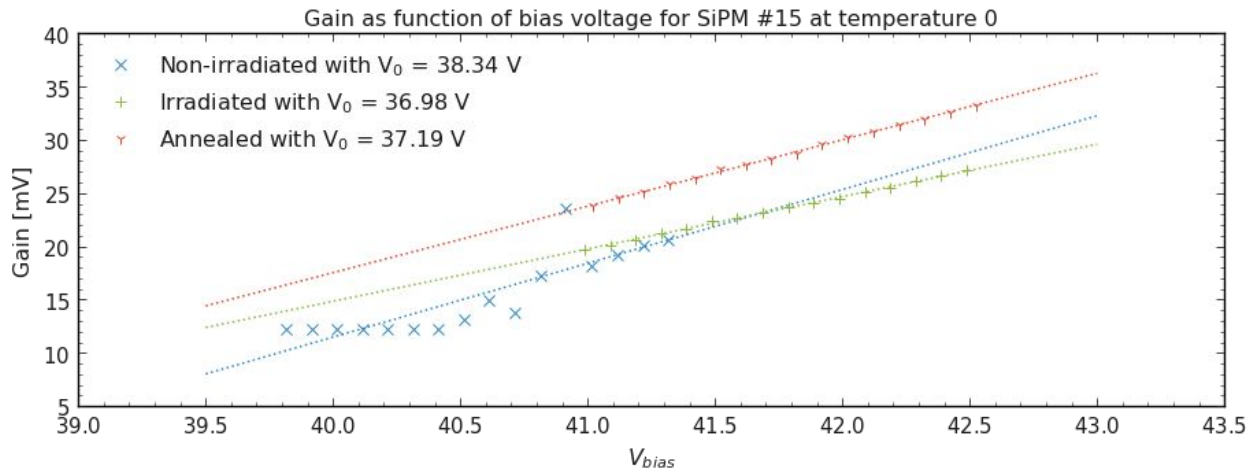
# SIMP #15

# Gain as function of bias voltage for SiPM #15

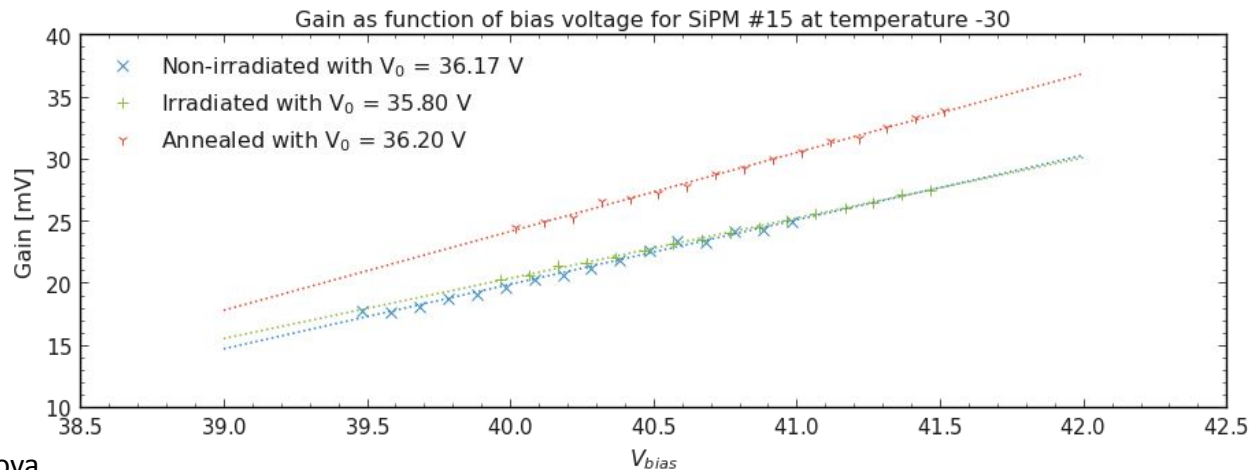
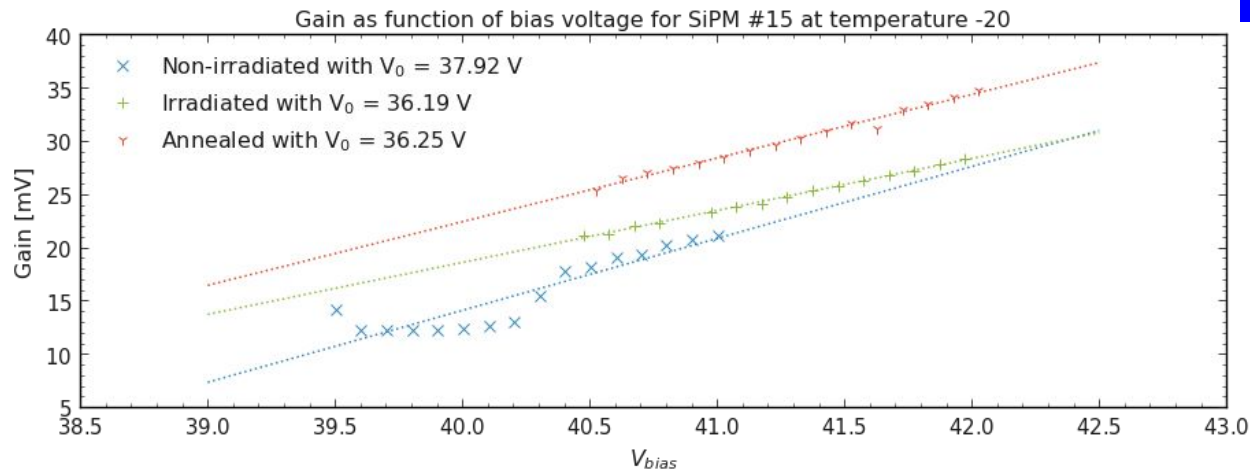
# Gain as function of bias voltage



# Gain as function of bias voltage

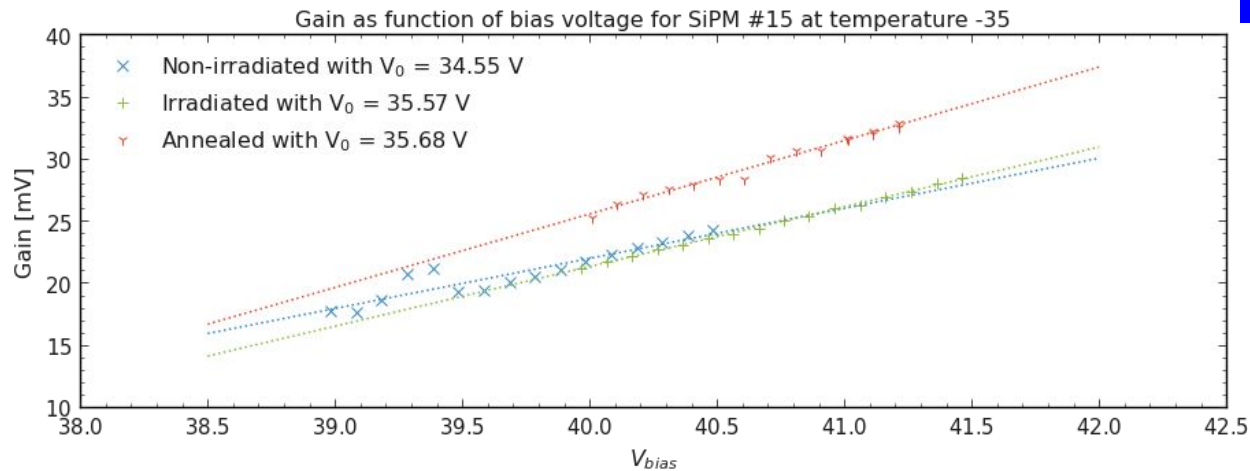


# Gain as function of bias voltage



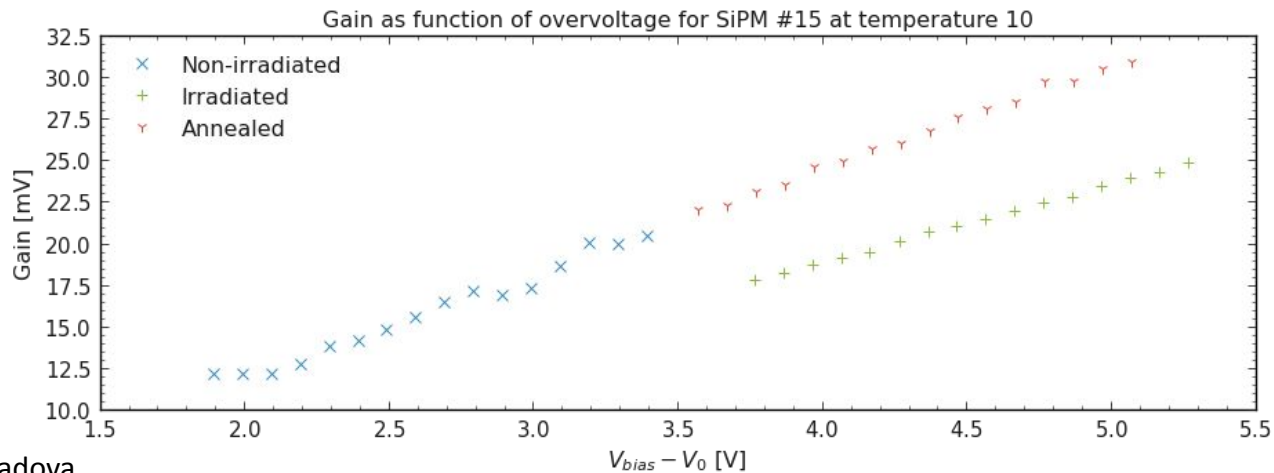
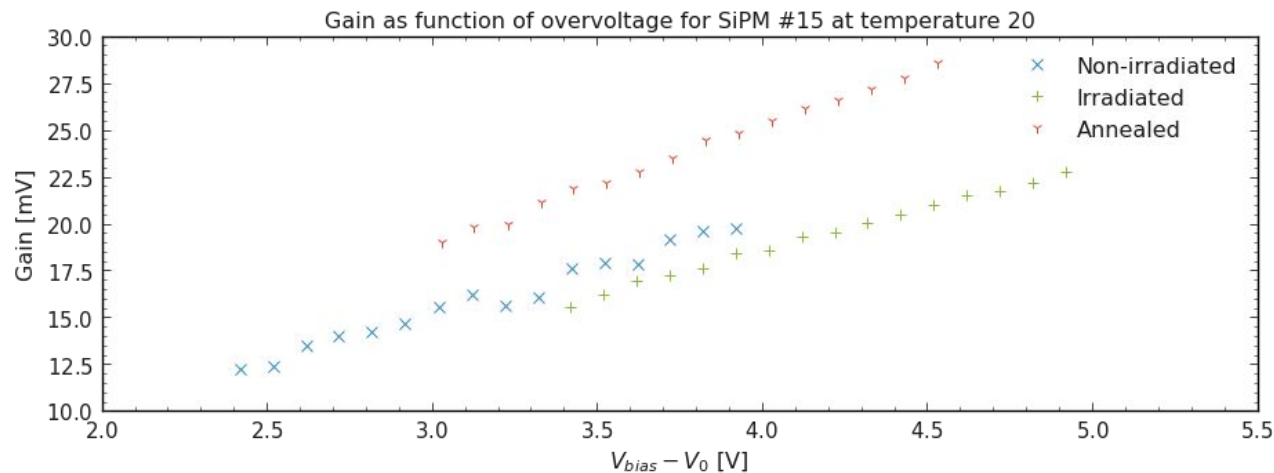


# Gain as function of bias voltage

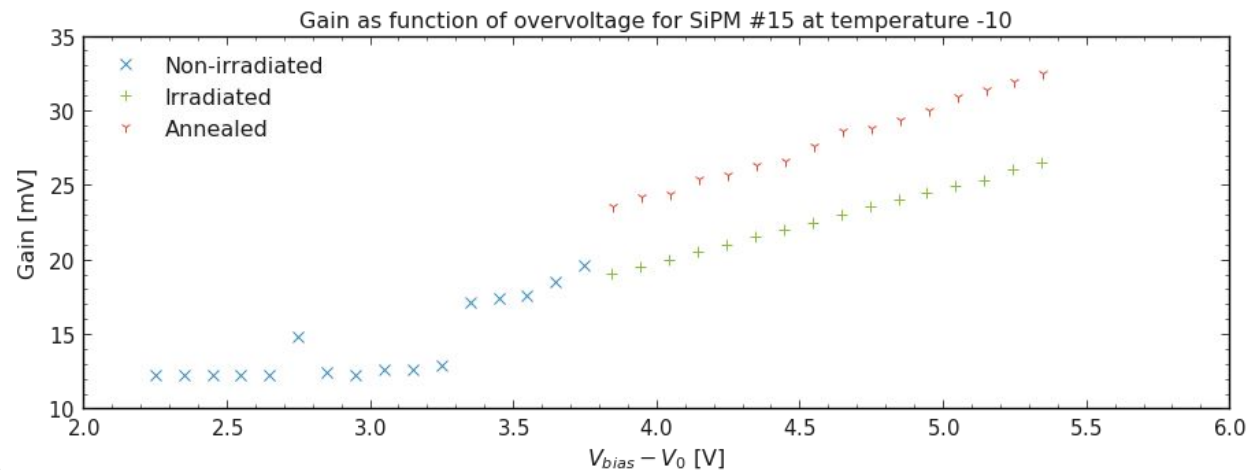
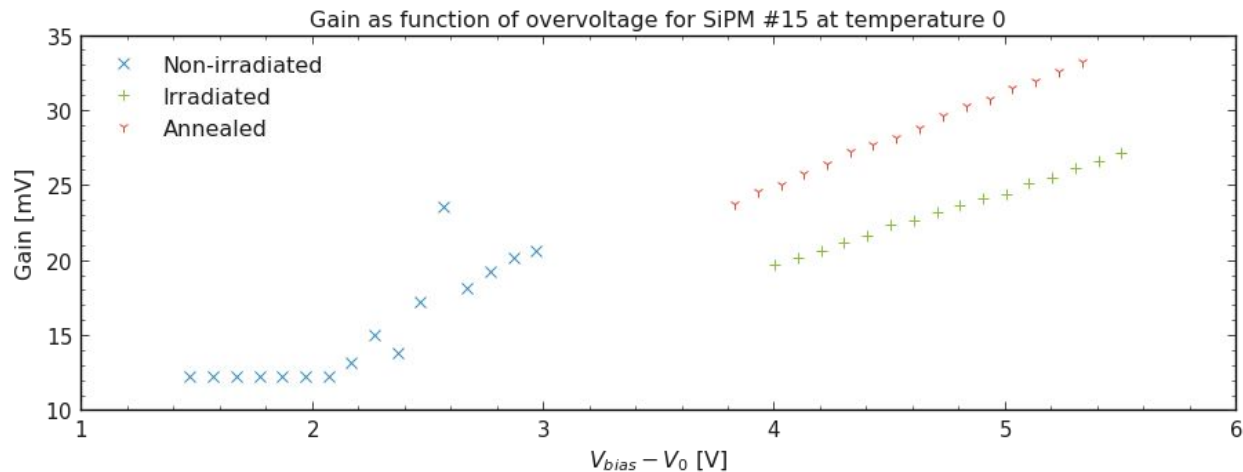


# Gain as function of overvoltage for SiPM #15

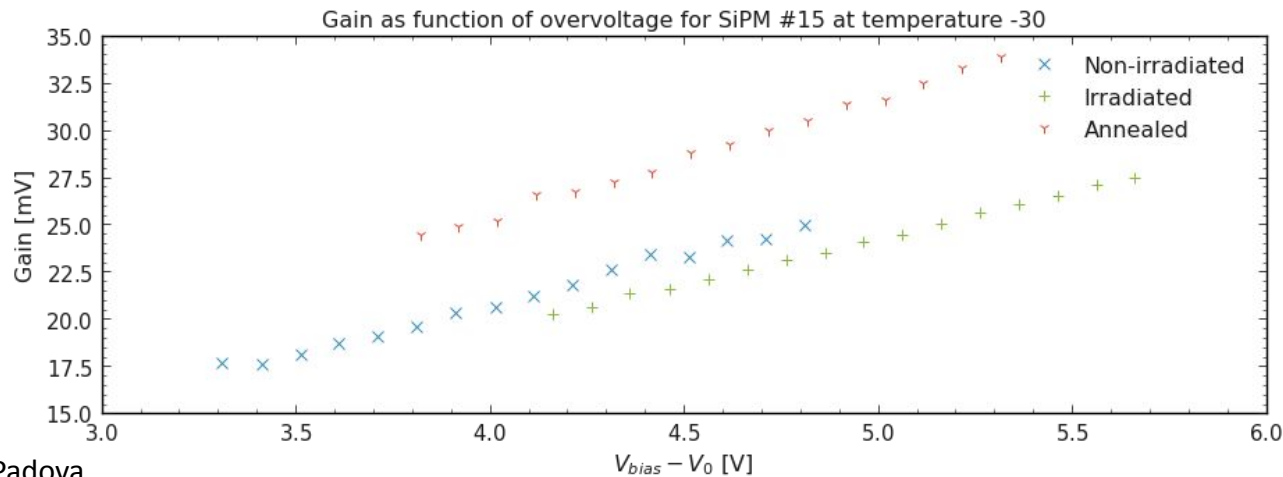
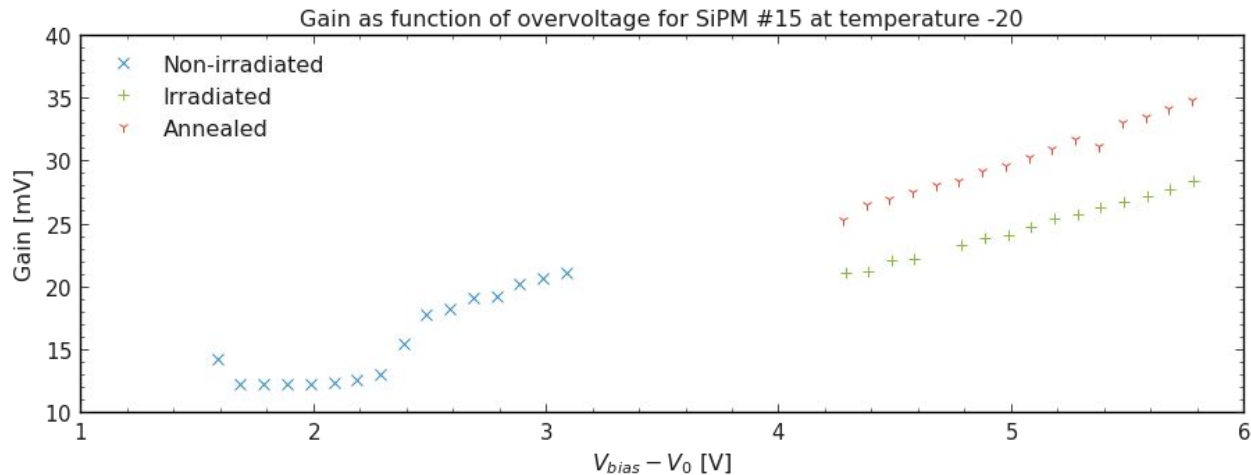
# Gain as function of overvoltage



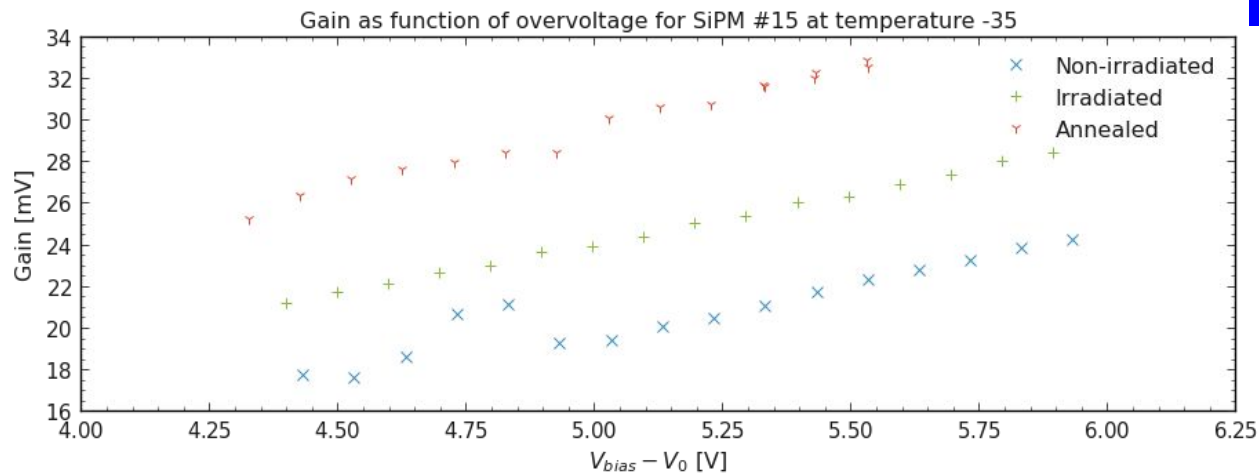
# Gain as function of overvoltage



# Gain as function of overvoltage



# Gain as function of overvoltage

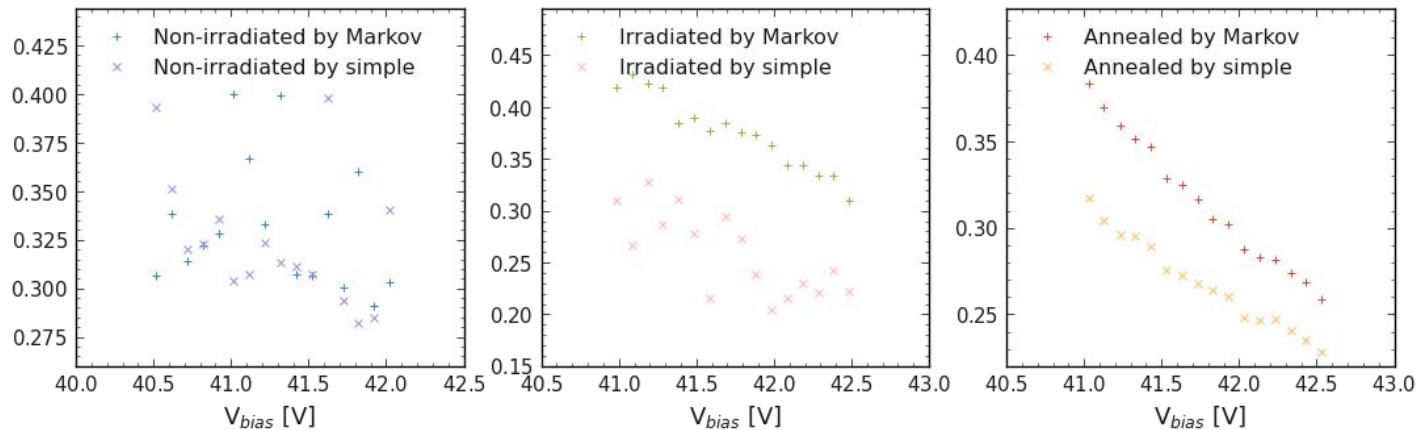


# Time resolution for first photon peak for SiPM #15

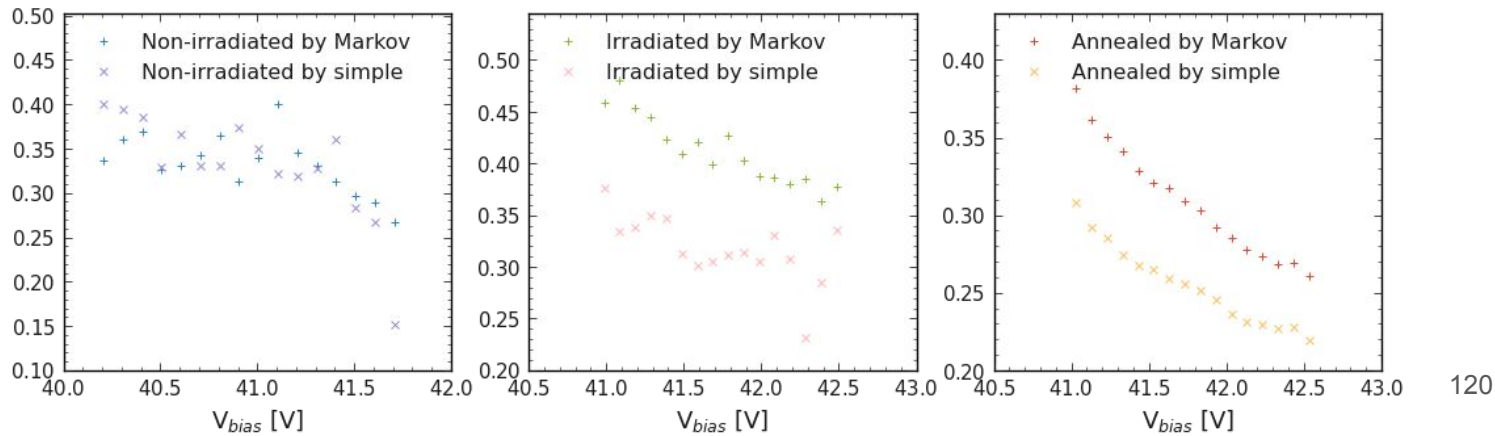
# Time resolution for first photon peak



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



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

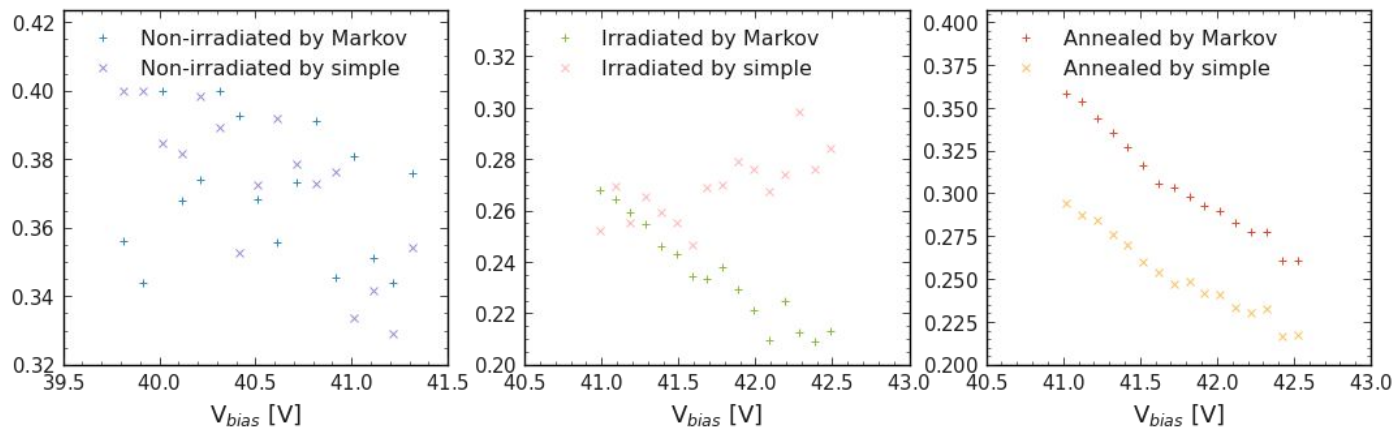




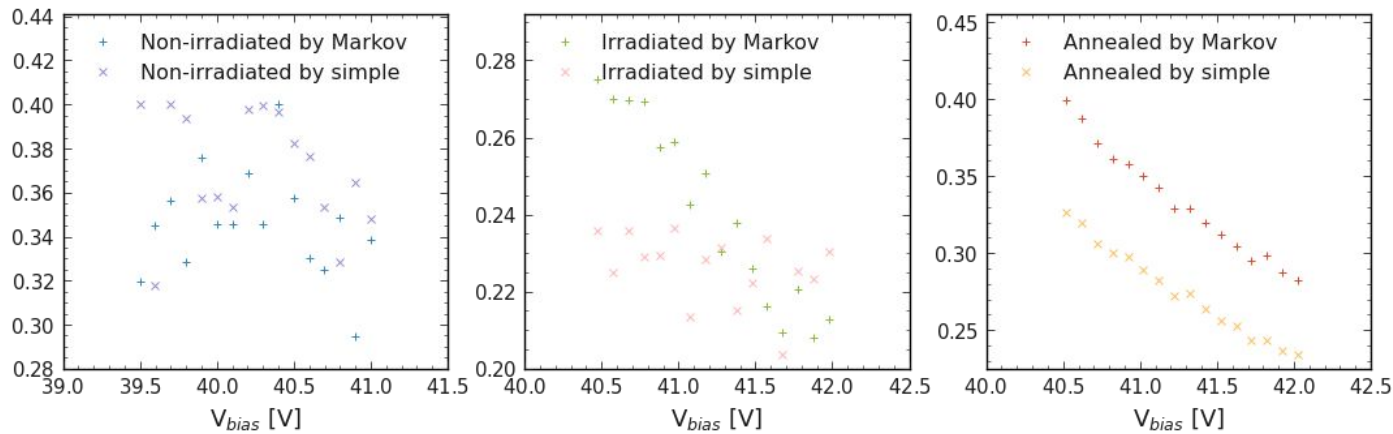
# Time resolution for first photon peak



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



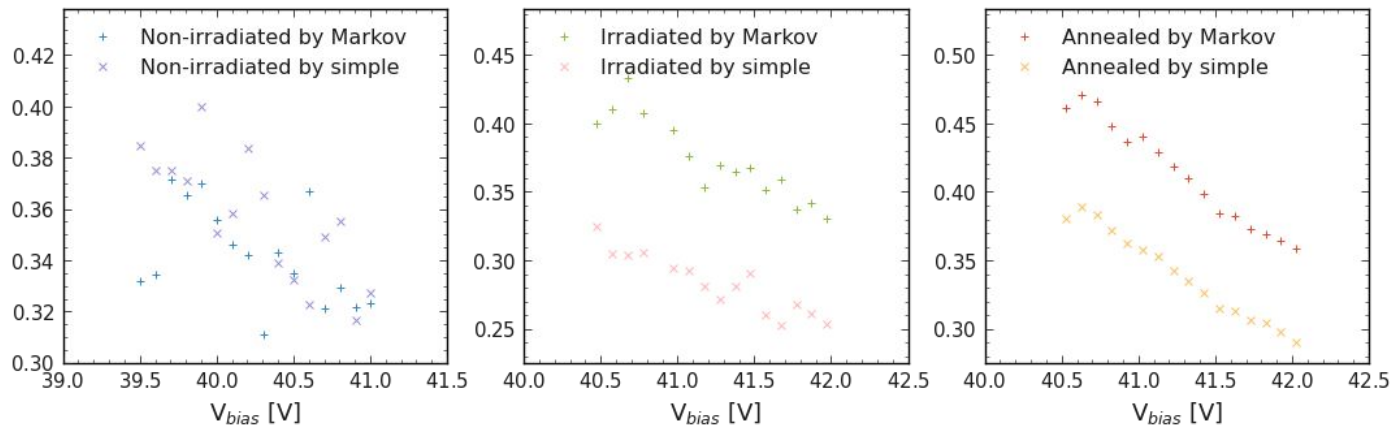
Time resolution of first peak for SiPM #15 at -10°



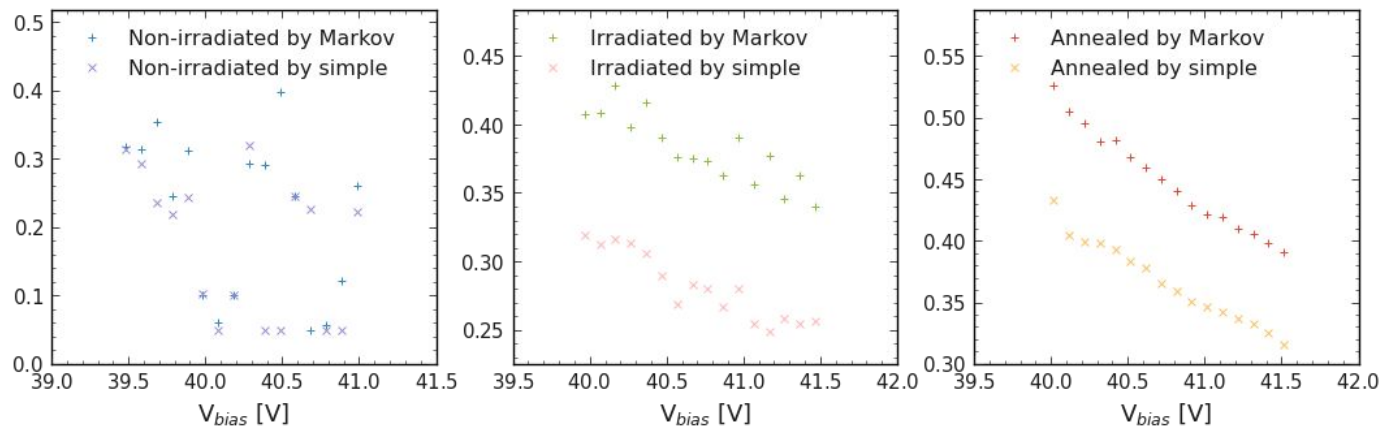
# Time resolution for first photon peak



Time resolution of first peak for SiPM #15 at  $-20^\circ$



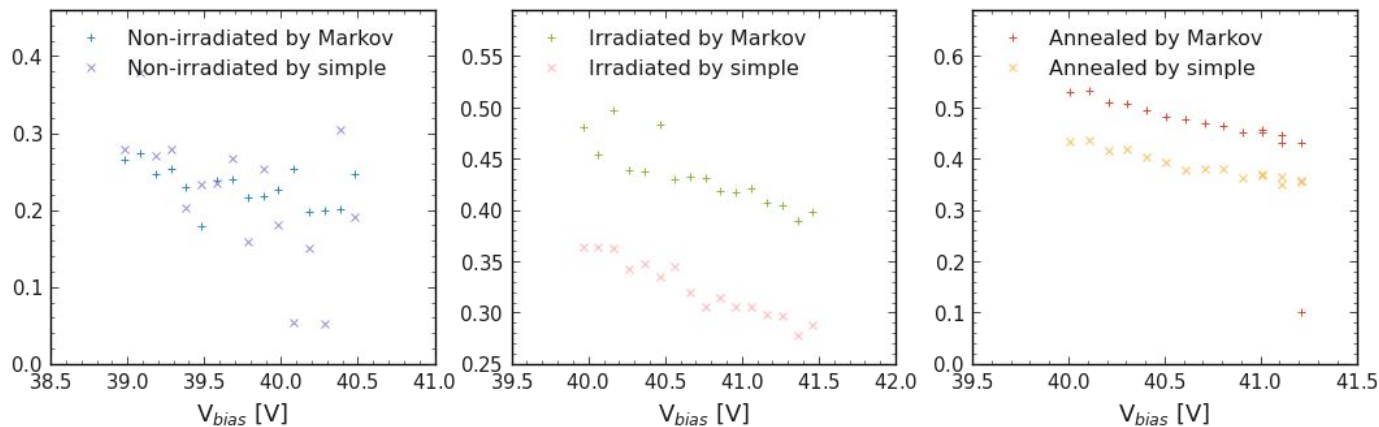
Time resolution of first peak for SiPM #15 at  $-30^\circ$



# Time resolution for first photon peak



Time resolution of first peak for SiPM #15 at  $-35^\circ$

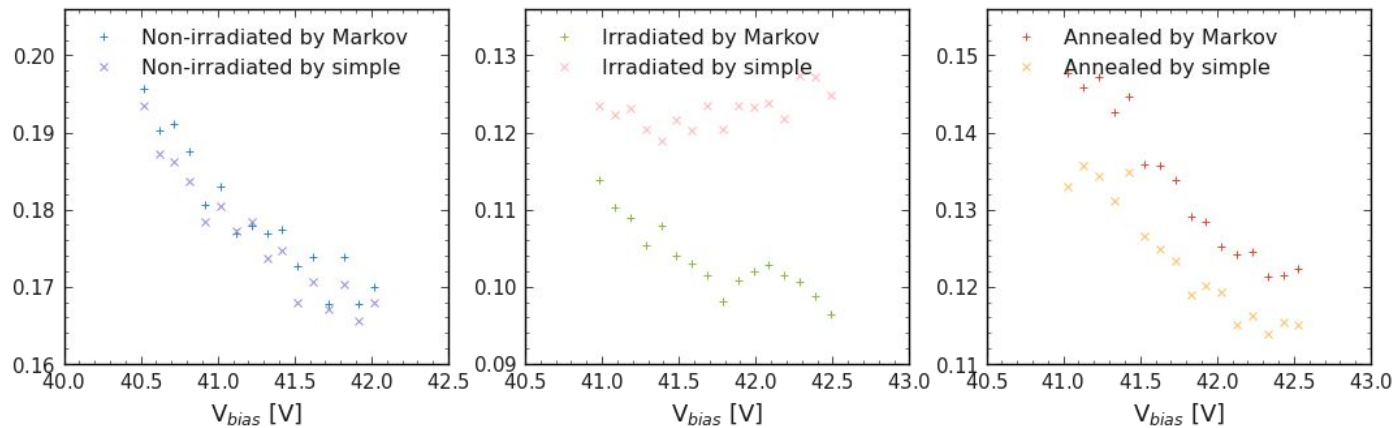


# Time resolution for other photon peaks for SiPM #15

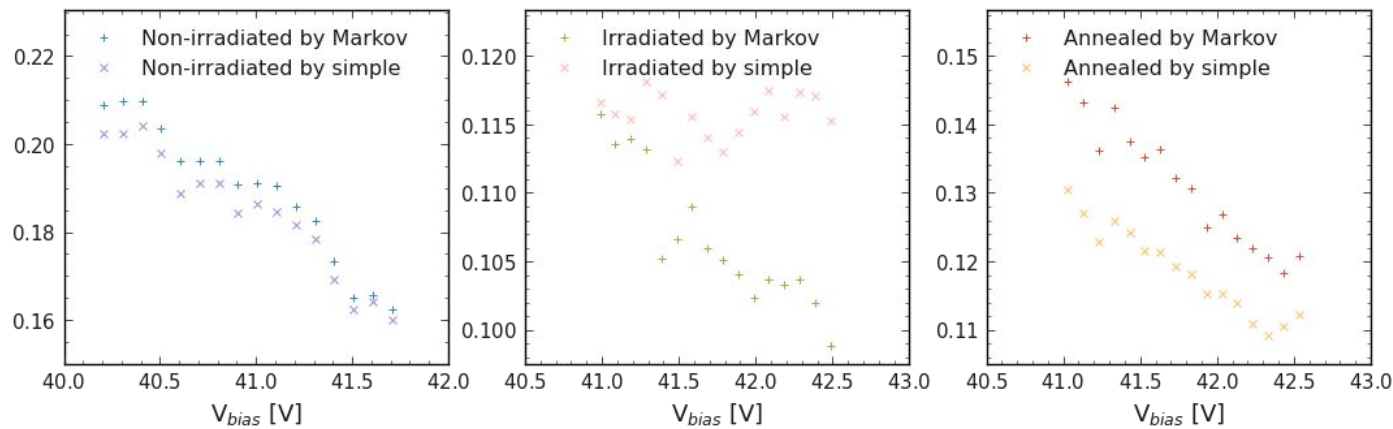
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #15 at 20°



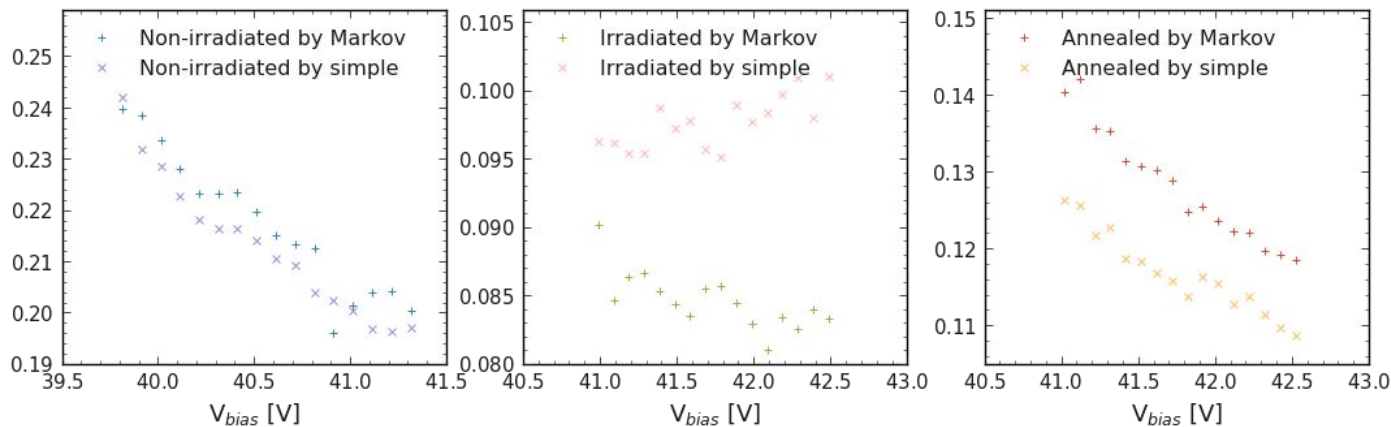
Time resolution of other peaks for SiPM #15 at 10°



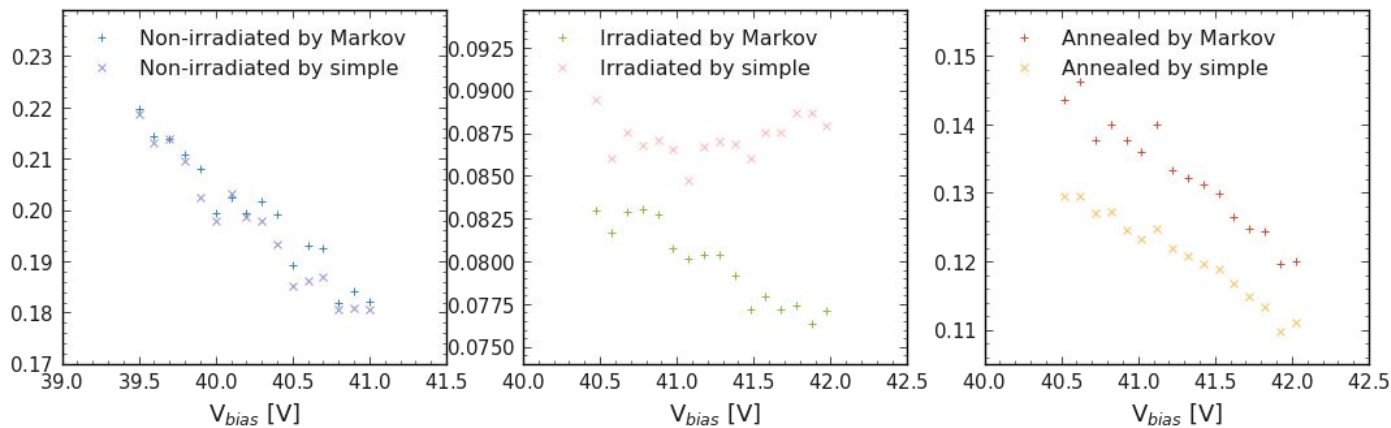
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #15 at 0°



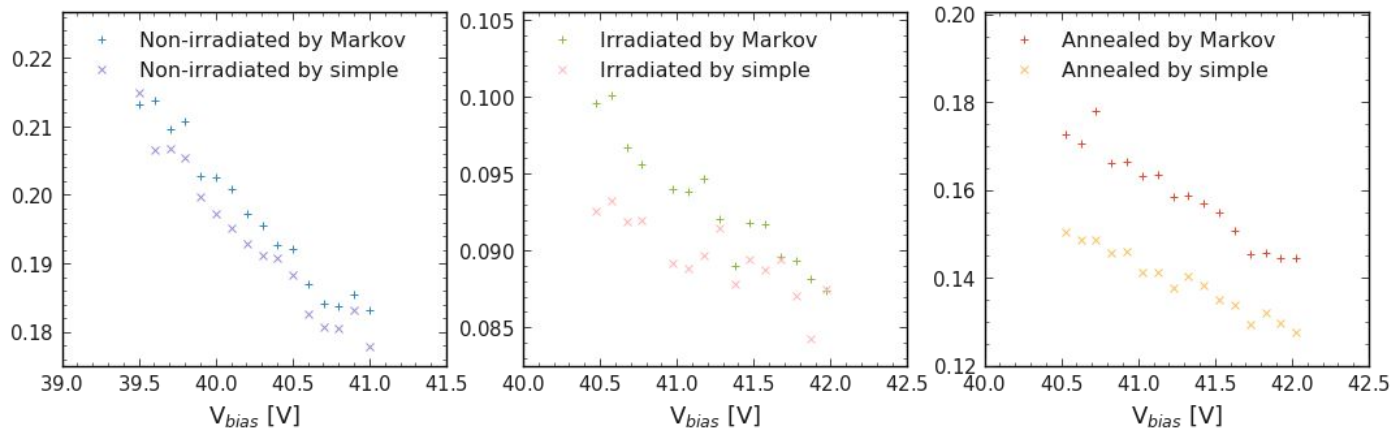
Time resolution of other peaks for SiPM #15 at -10°



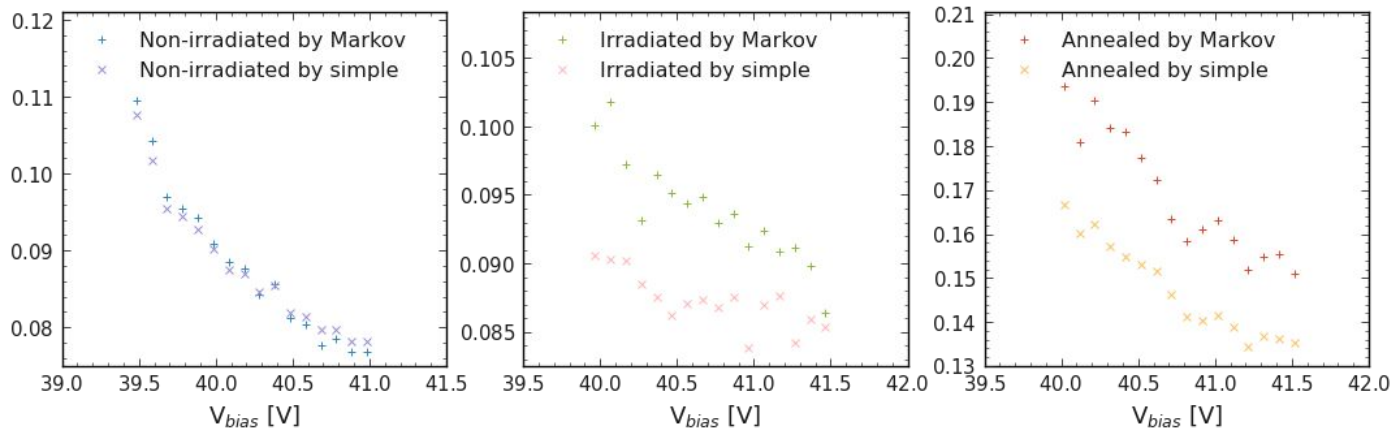
# Time resolution for other photon peaks



Time resolution of other peaks for SiPM #15 at  $-20^\circ$



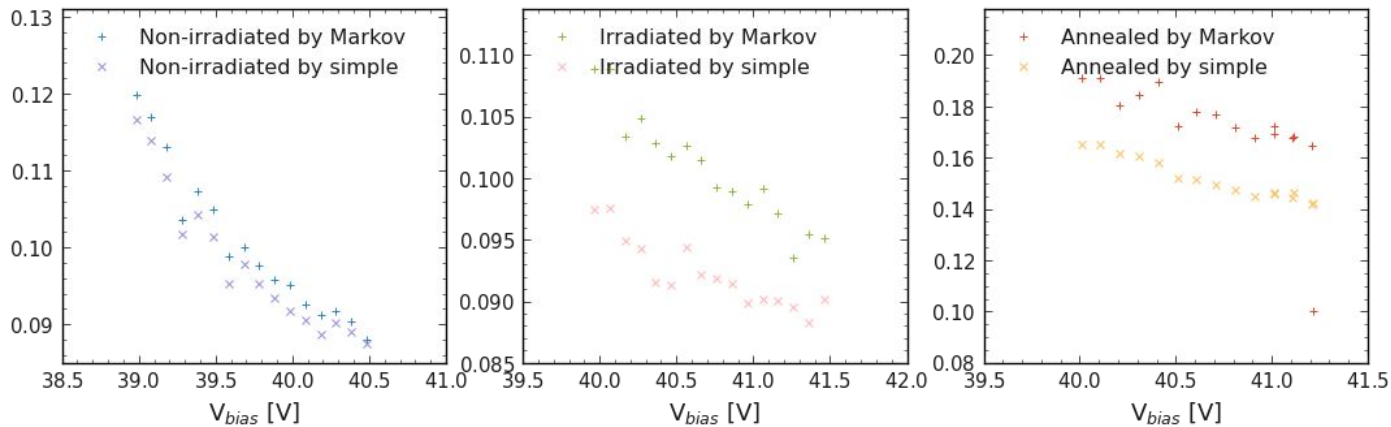
Time resolution of other peaks for SiPM #15 at  $-30^\circ$



# Time resolution for other photon peaks



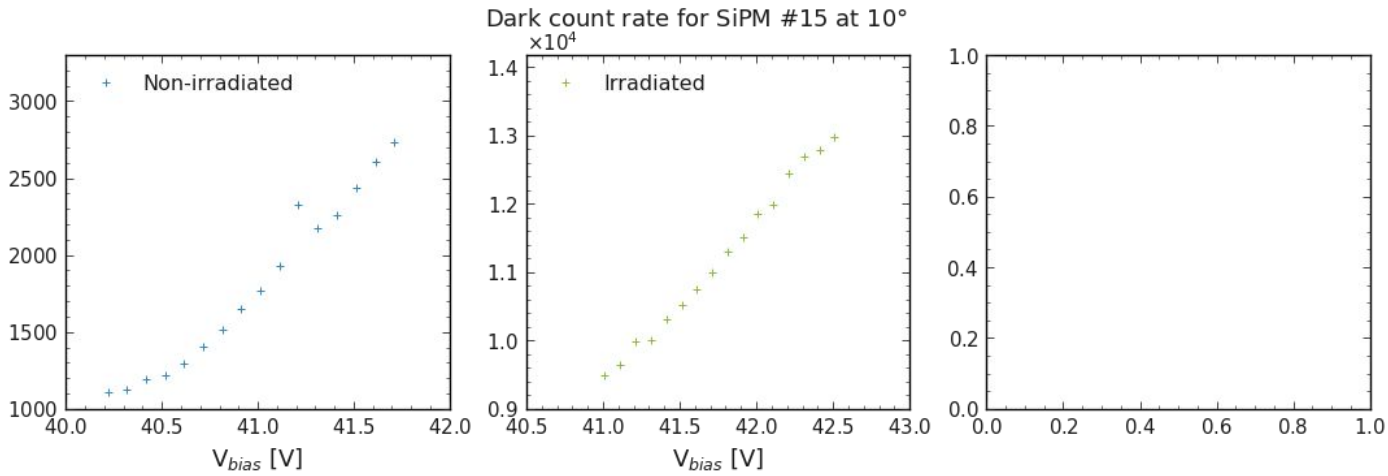
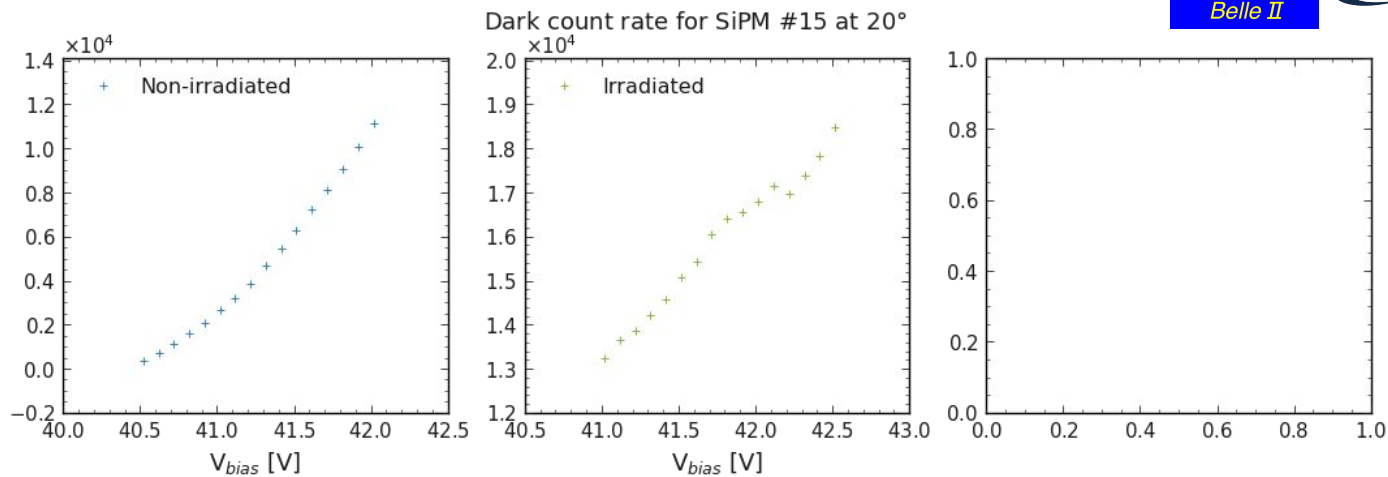
Time resolution of other peaks for SiPM #15 at  $-35^\circ$





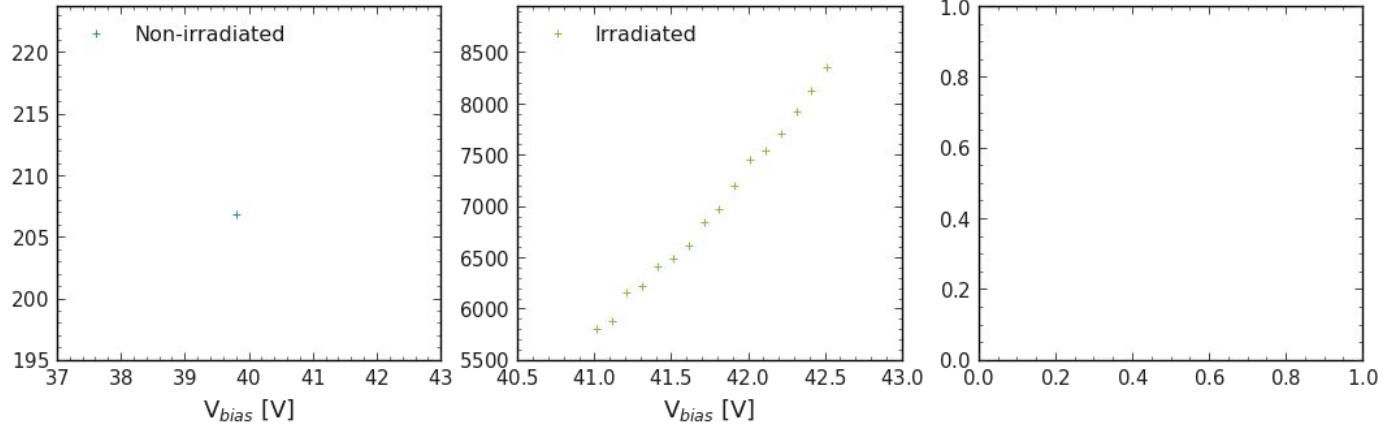
# Dark count rate for SiPM #15

# Dark count rate

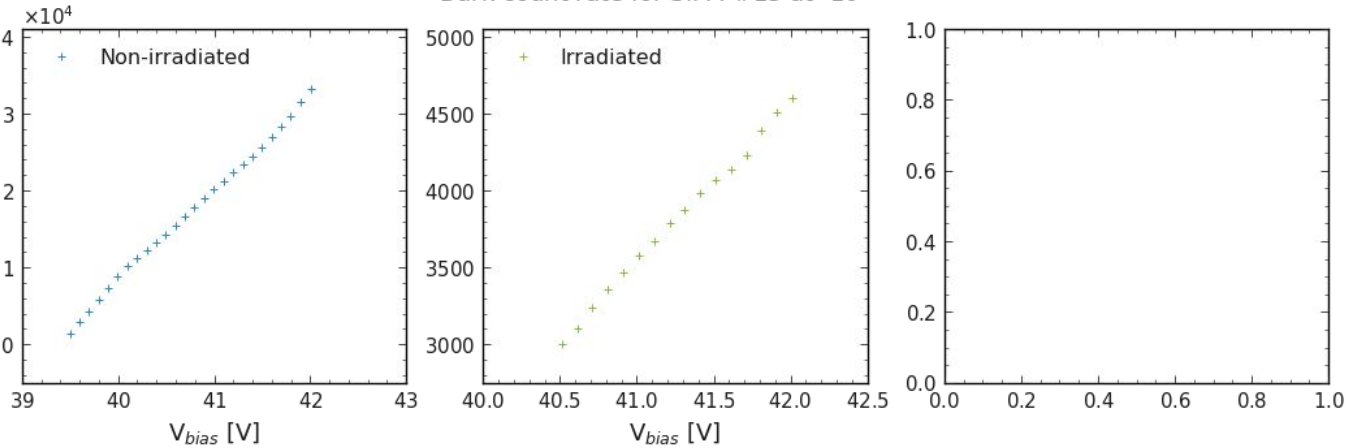


# Dark count rate

Dark count rate for SiPM #15 at 0°



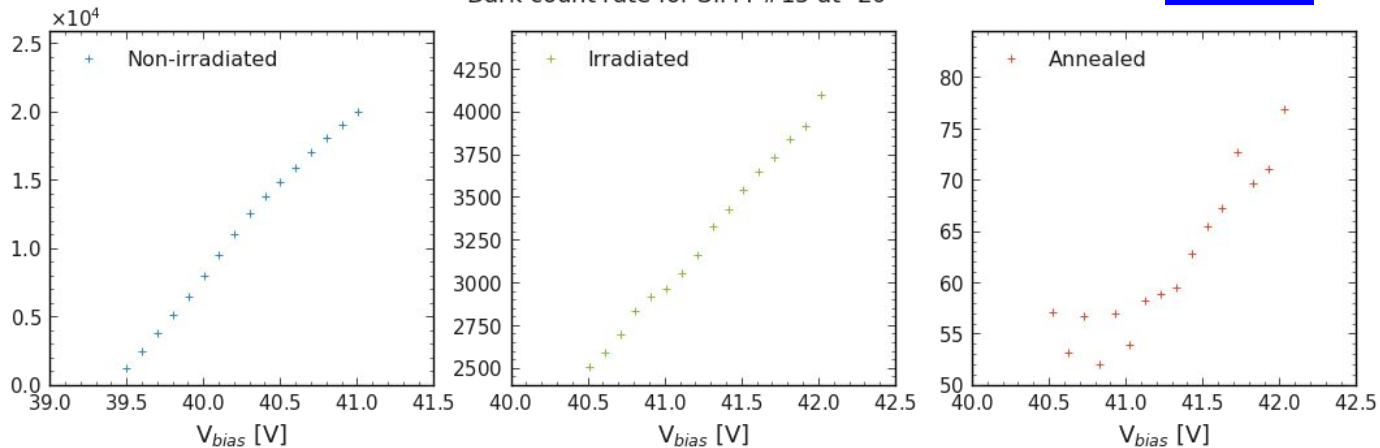
Dark count rate for SiPM #15 at -10°



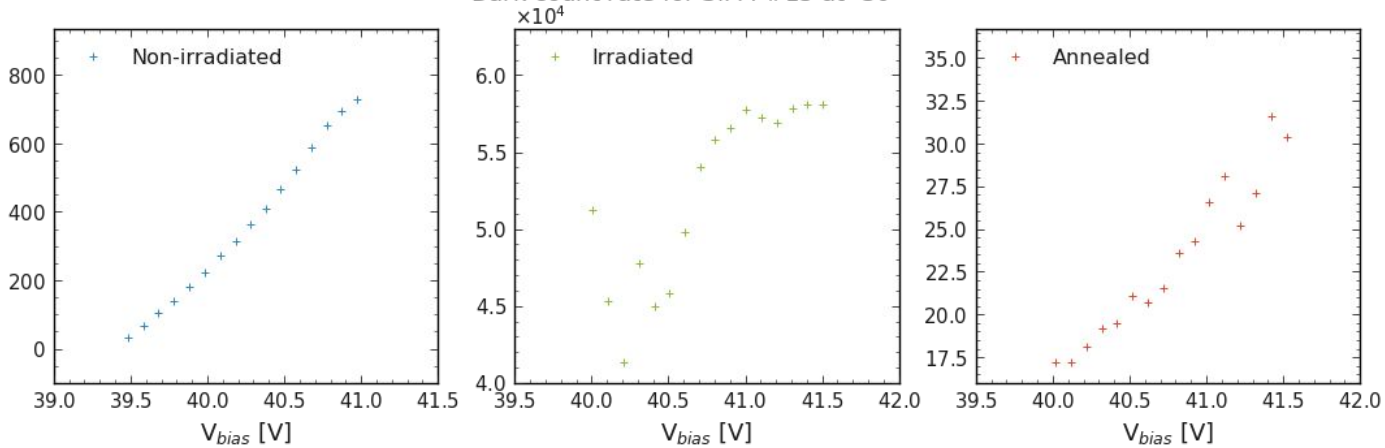
# Dark count rate



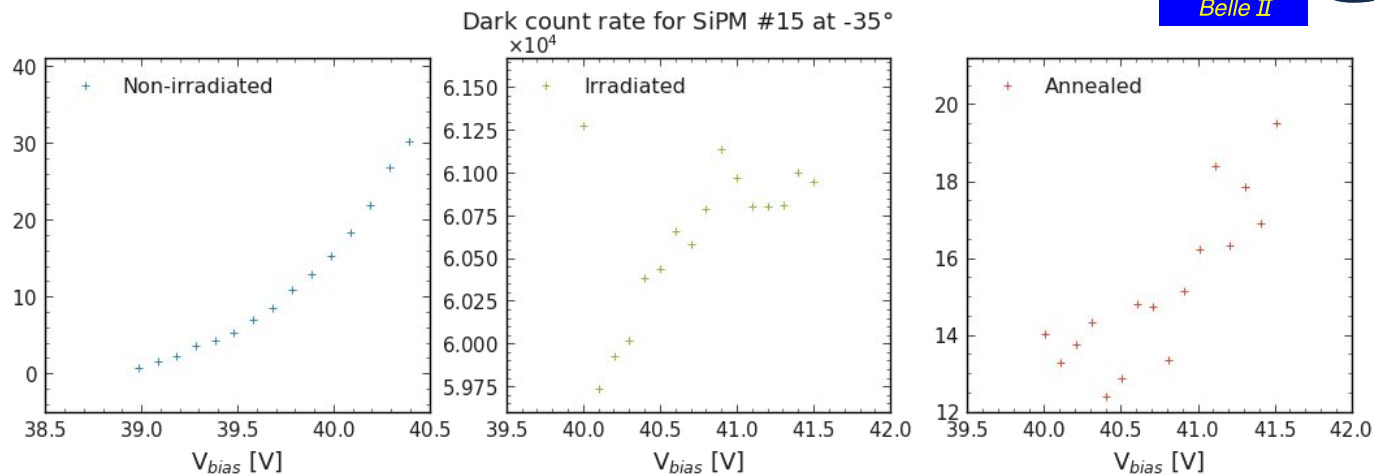
Dark count rate for SiPM #15 at  $-20^\circ$



Dark count rate for SiPM #15 at  $-30^\circ$



# Dark count rate





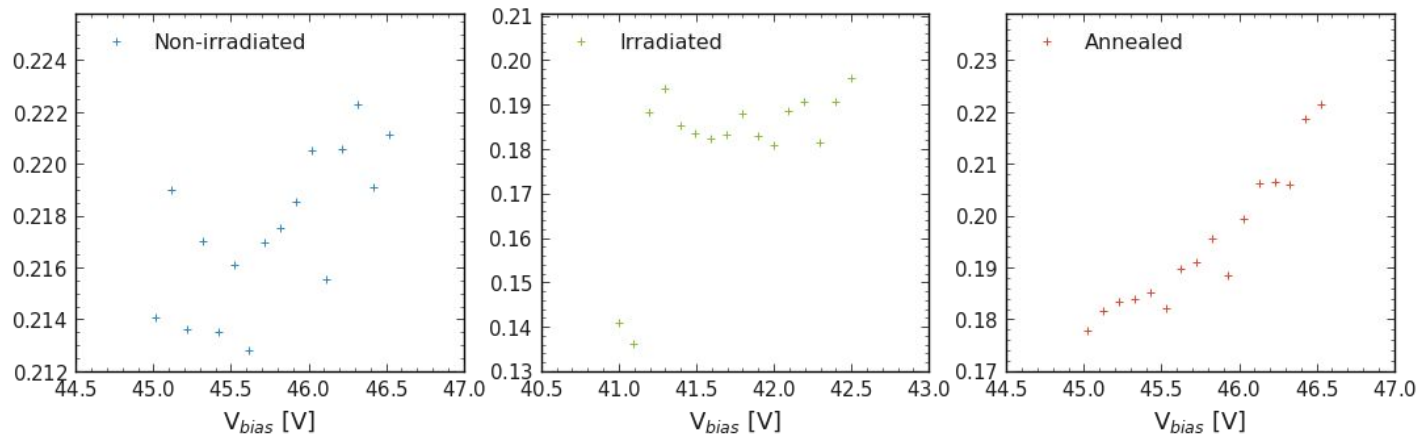
# SIMP #8

# Time resolution for all photon peaks for SiPM #8

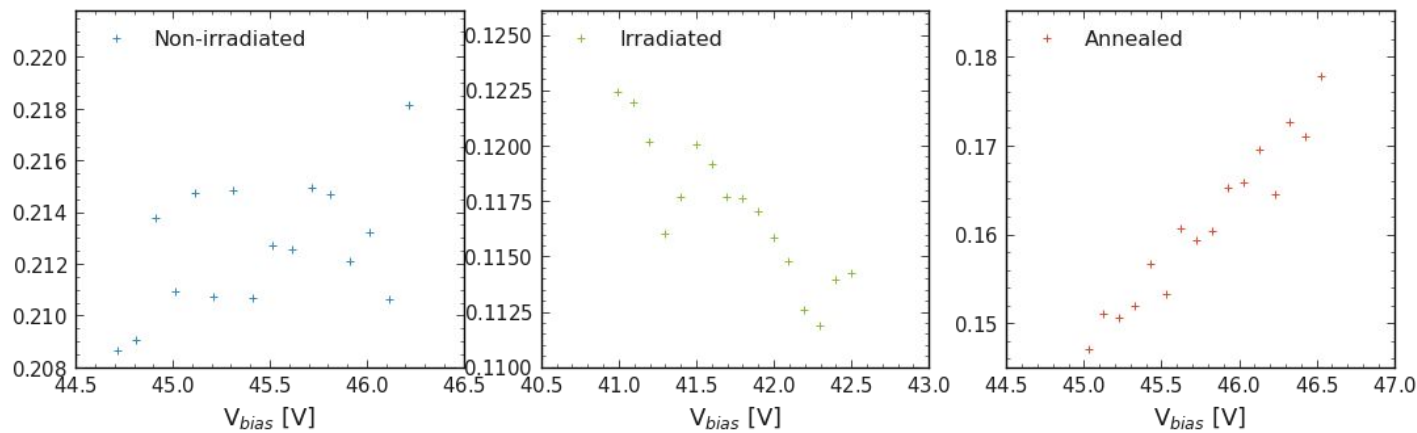
# Time resolution for first photon peak



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



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

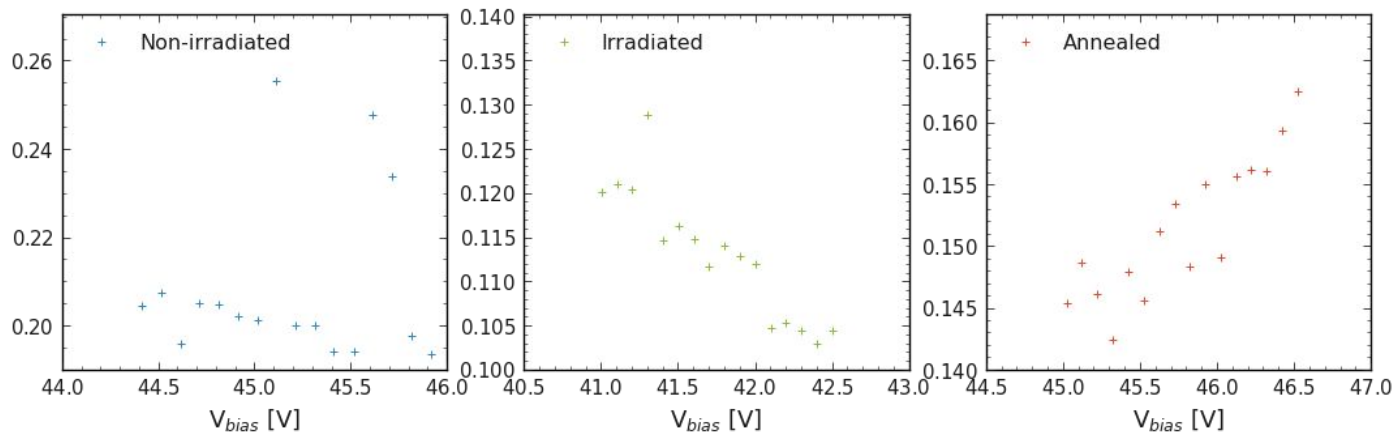




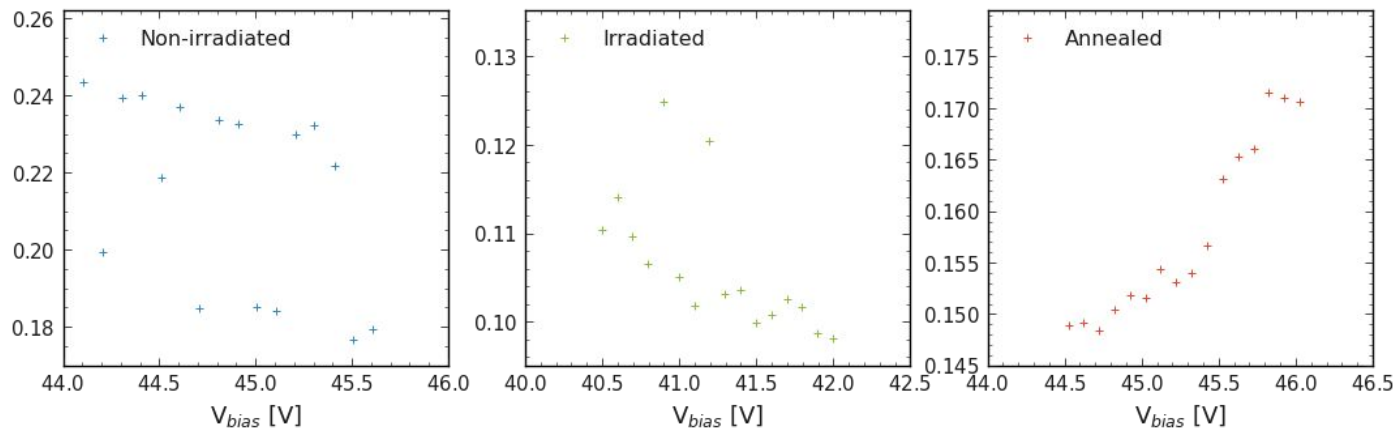
# Time resolution for first photon peak



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



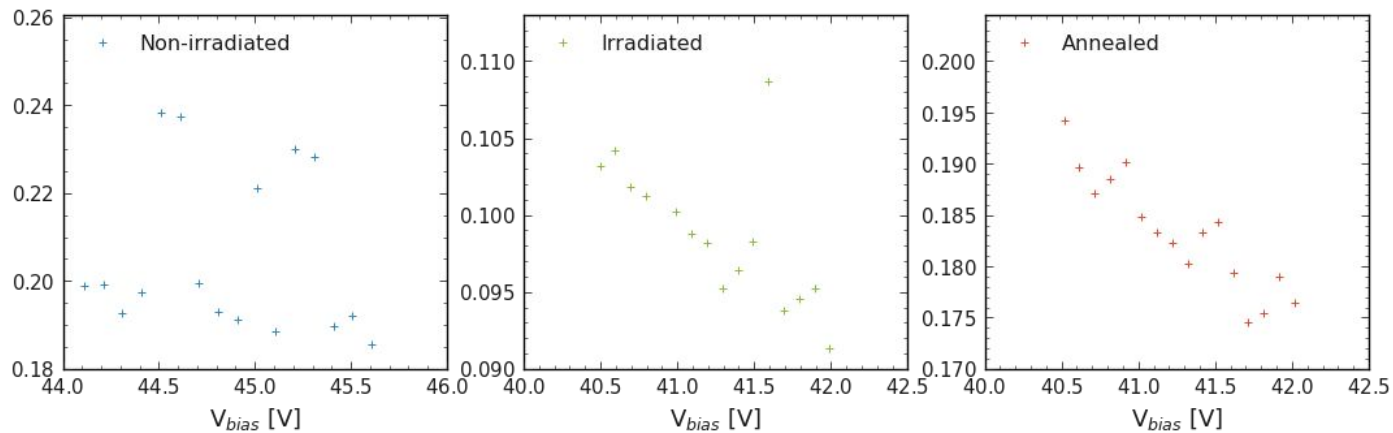
Time resolution of all peaks for SiPM #8 at -10°



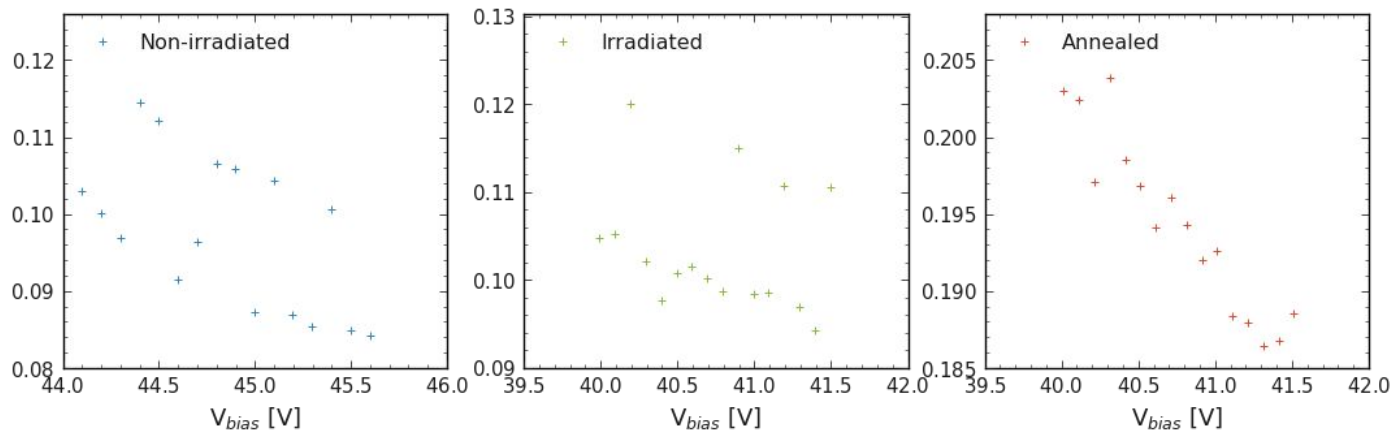
# Time resolution for first photon peak



Time resolution of all peaks for SiPM #8 at  $-20^\circ$



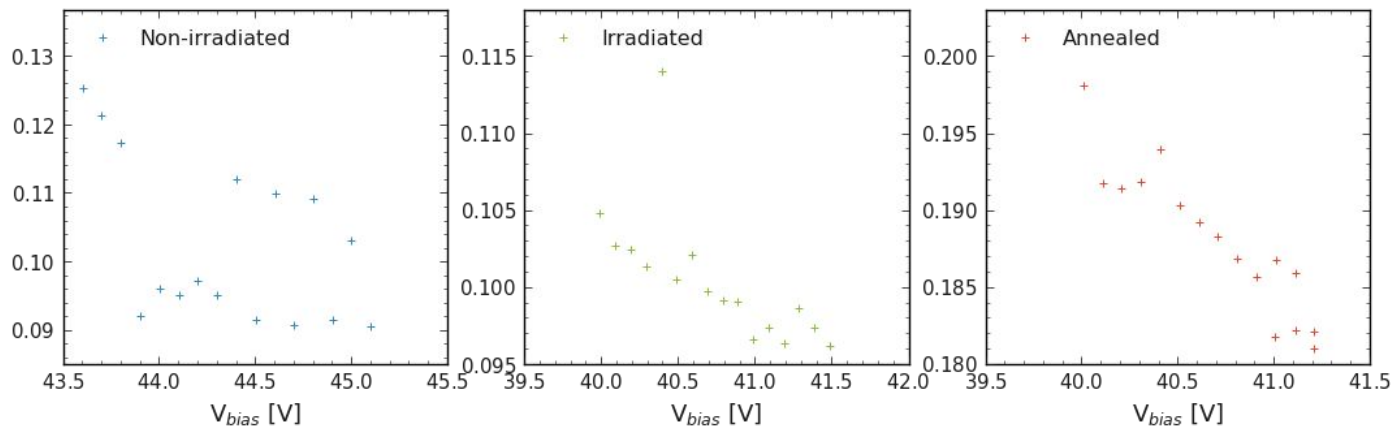
Time resolution of all peaks for SiPM #8 at  $-30^\circ$



# Time resolution for first photon peak

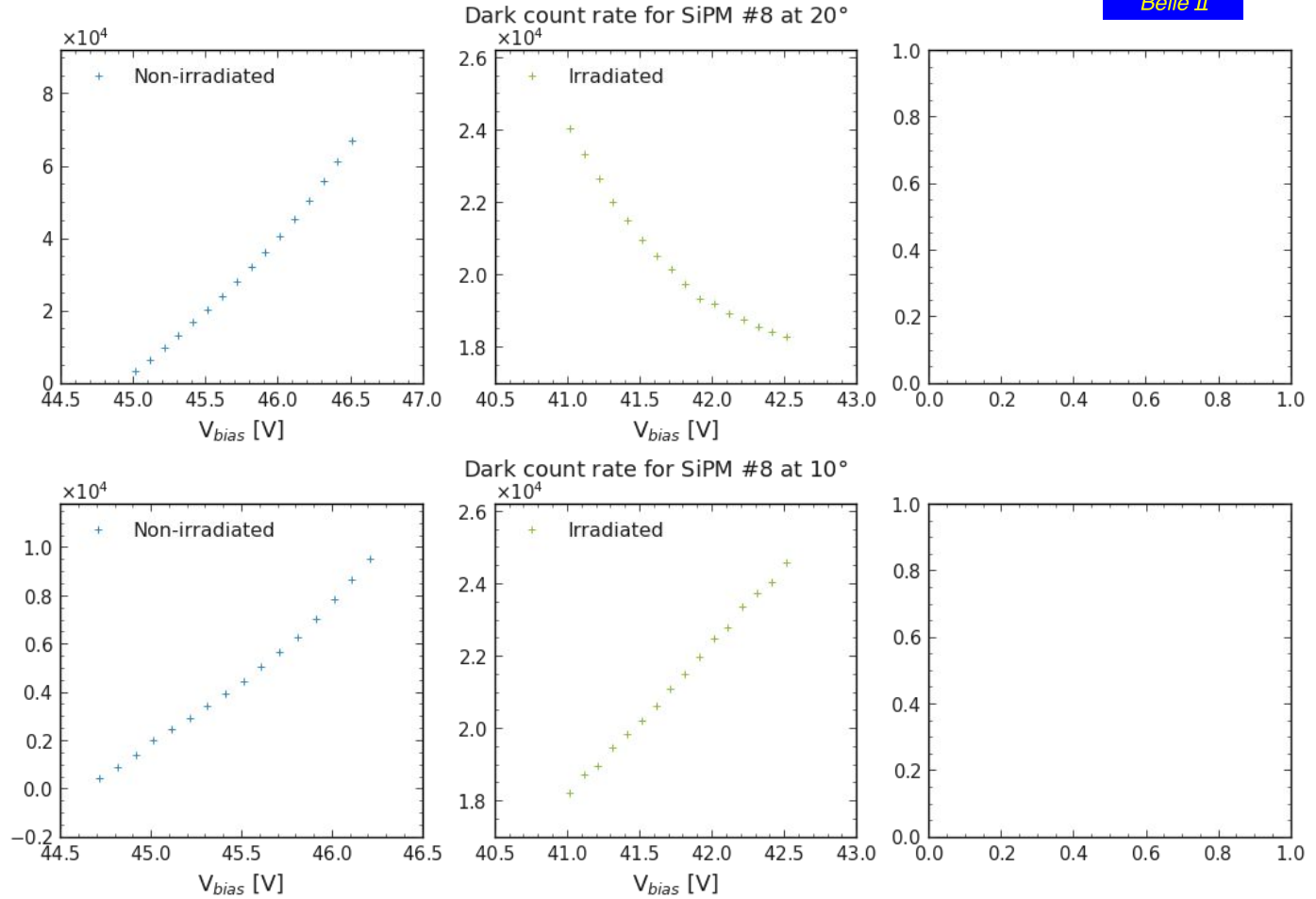


Time resolution of all peaks for SiPM #8 at  $-35^\circ$

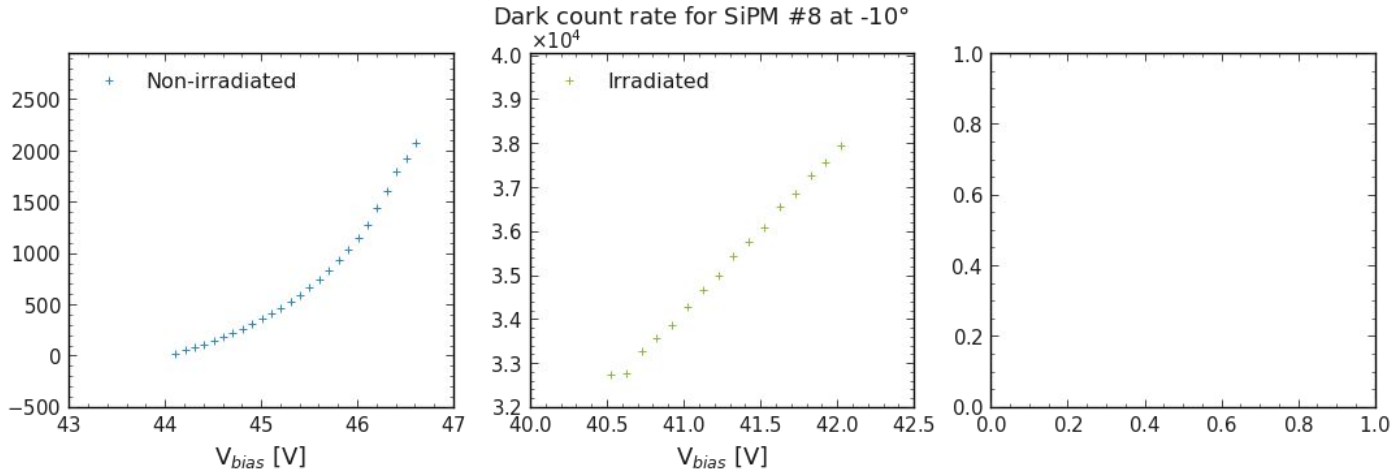
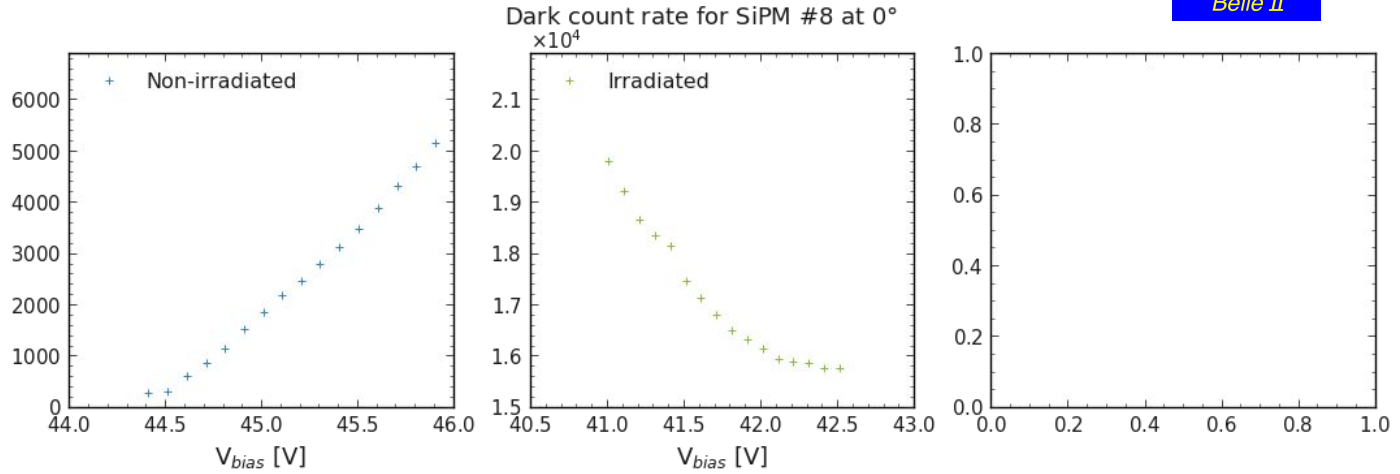


# Dark count rate for SiPM #8

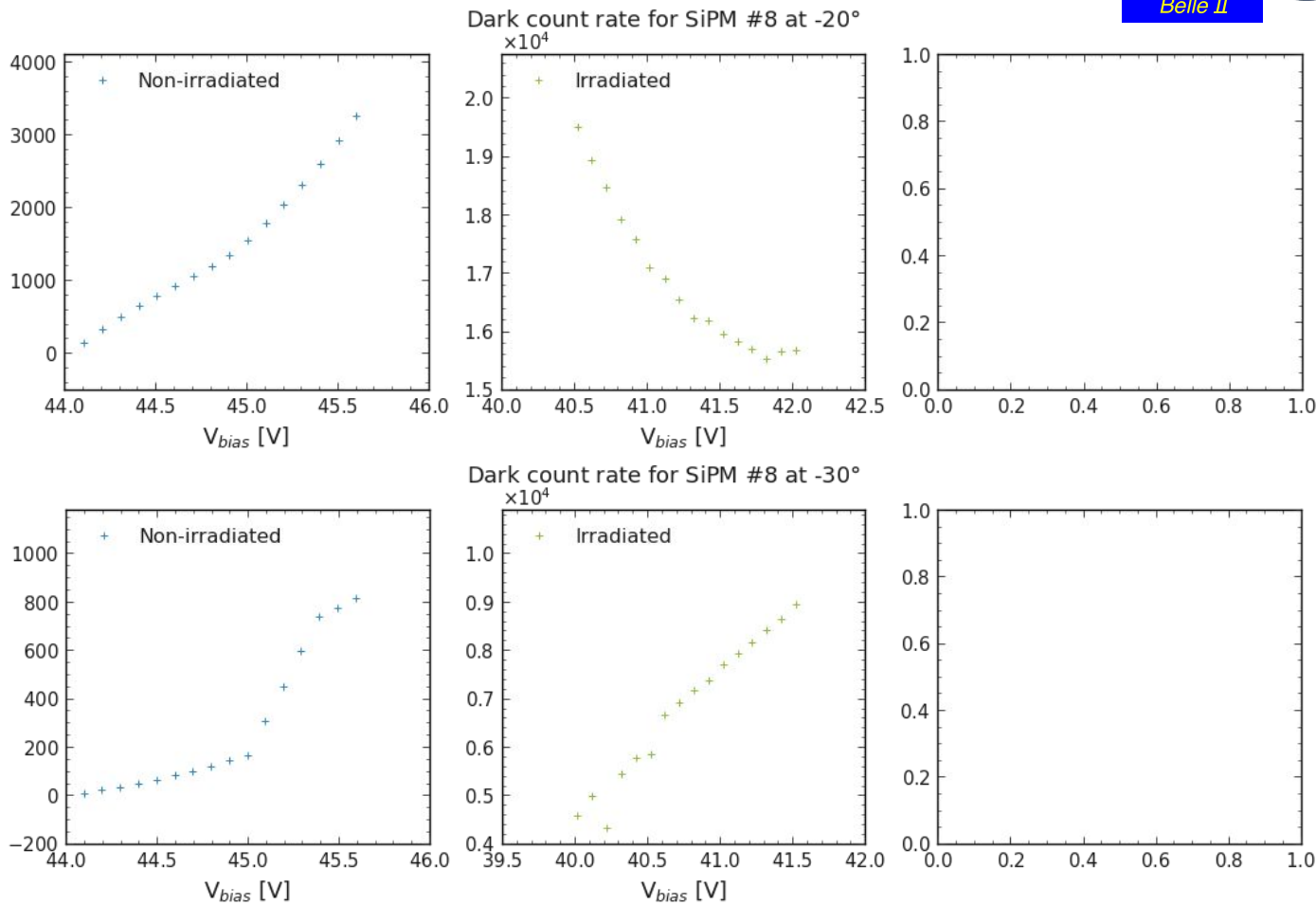
# Dark count rate



# Dark count rate



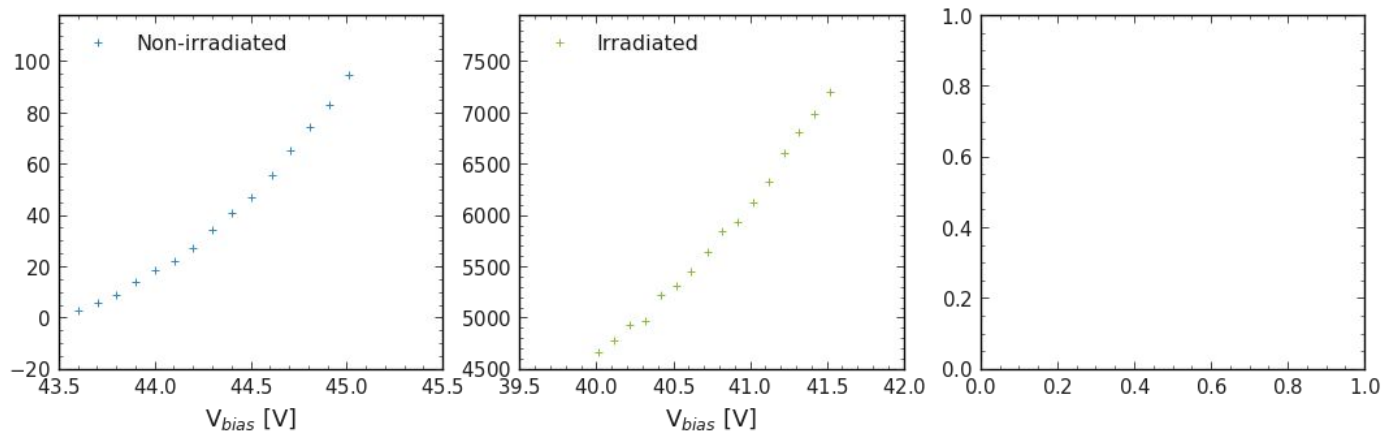
# Dark count rate



# Dark count rate



Dark count rate for SiPM #8 at -35°





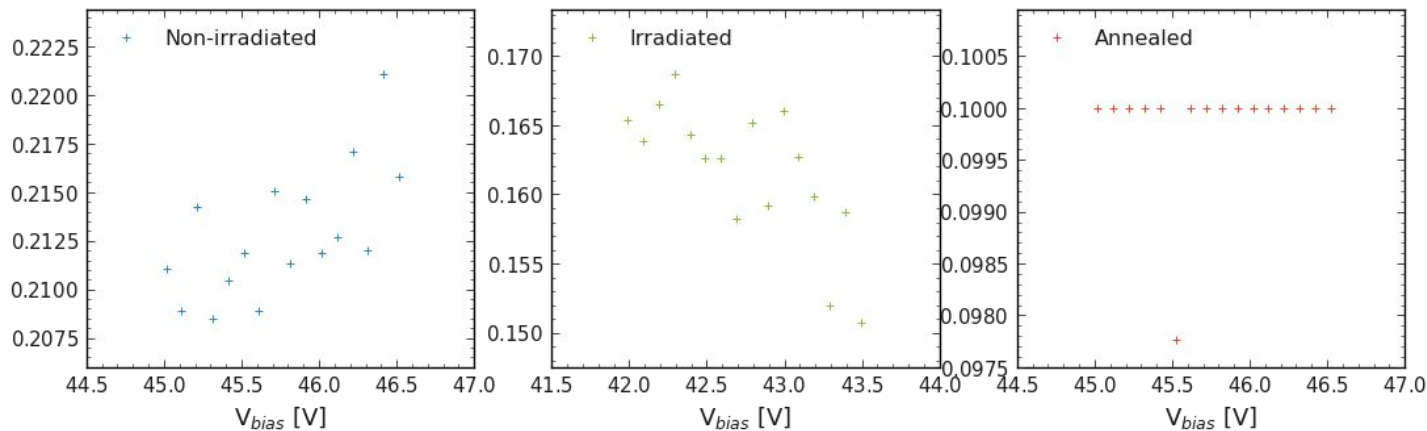
# SIMP #9

# Time resolution for all photon peaks for SiPM #9

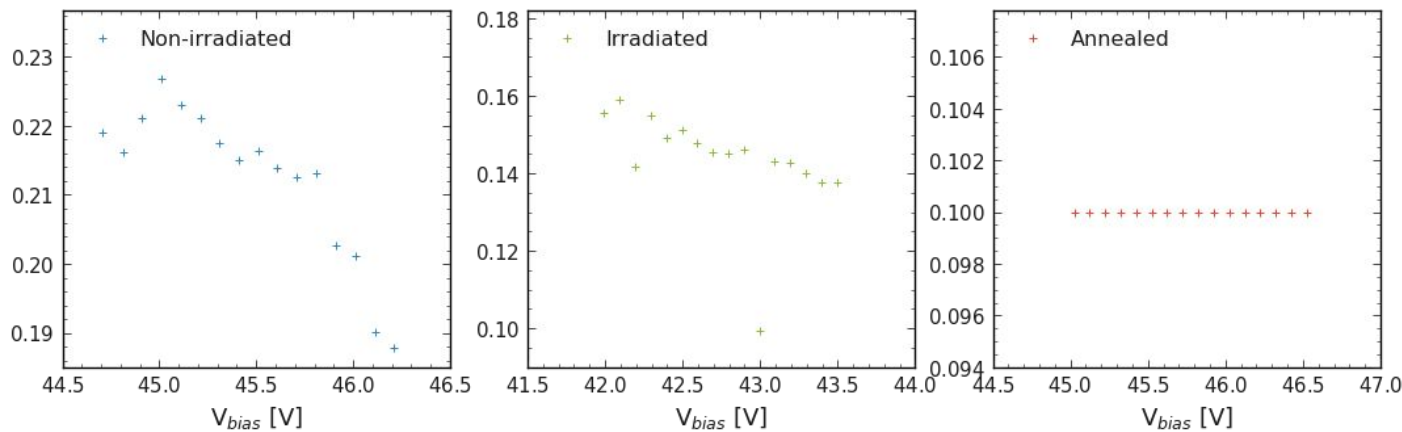
# Time resolution for first photon peak



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



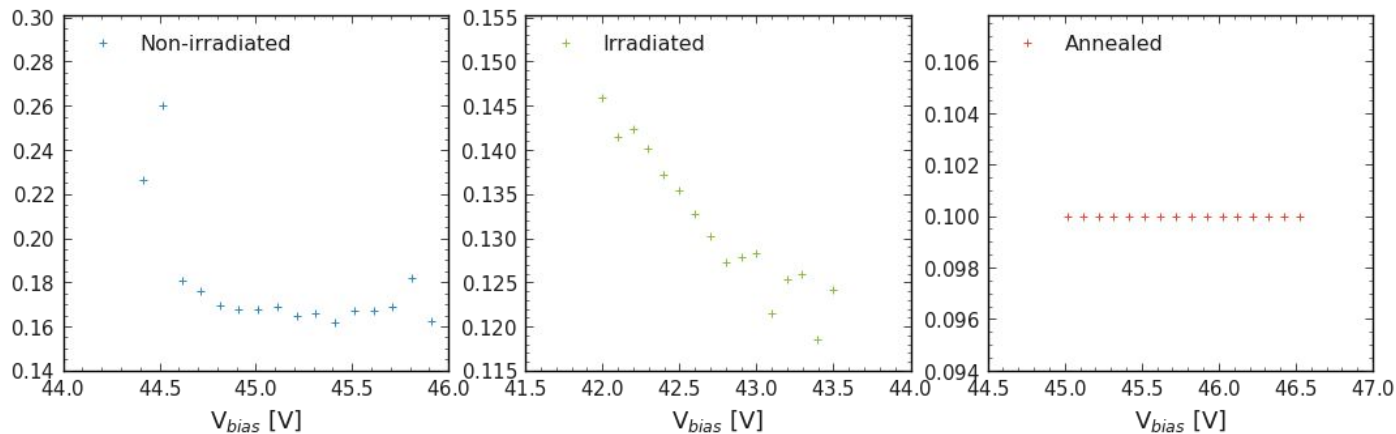
Time resolution of all peaks for SiPM #9 at 10°



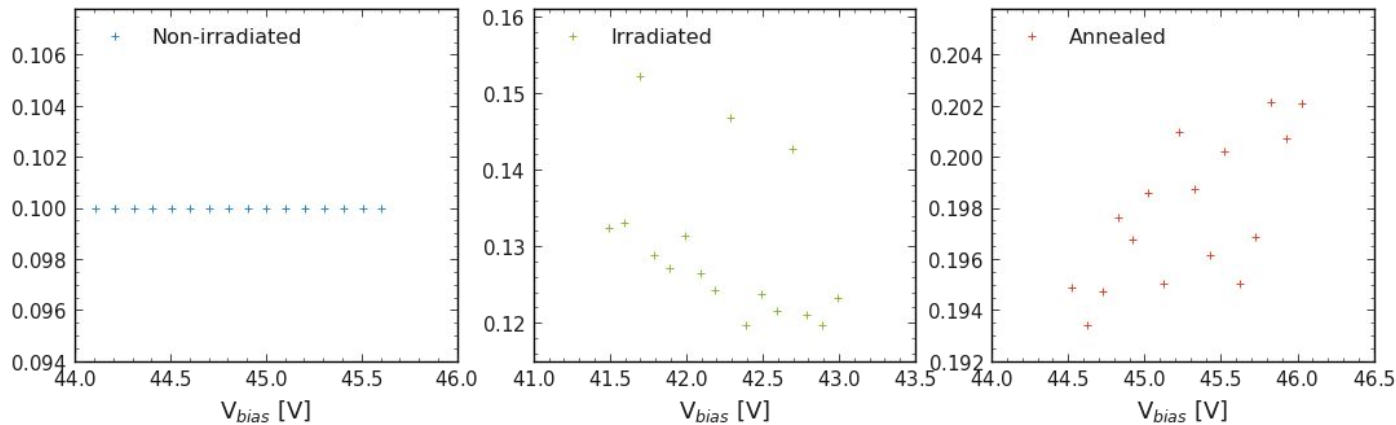
# Time resolution for first photon peak



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



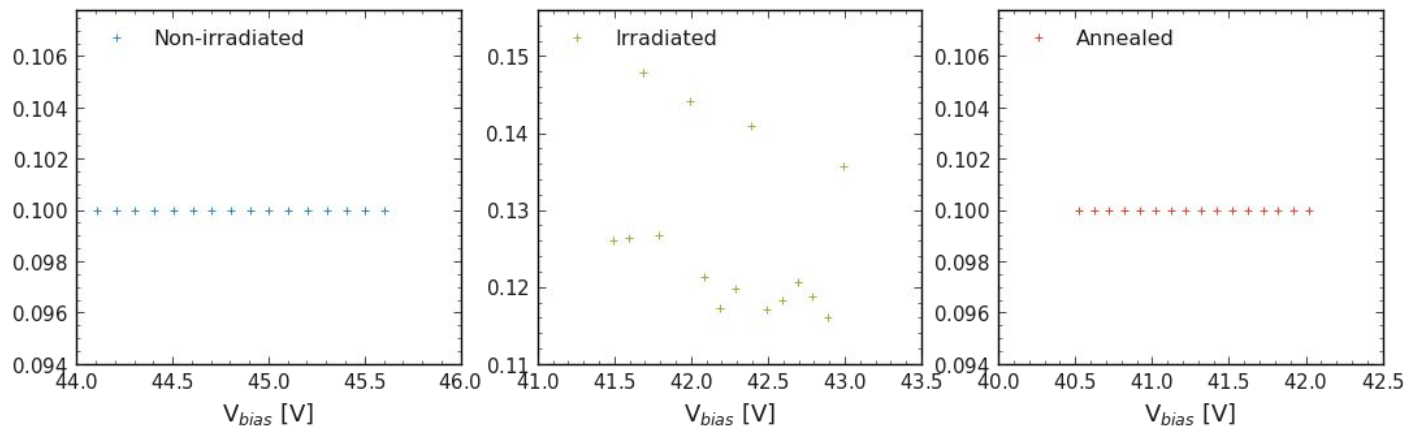
Time resolution of all peaks for SiPM #9 at -10°



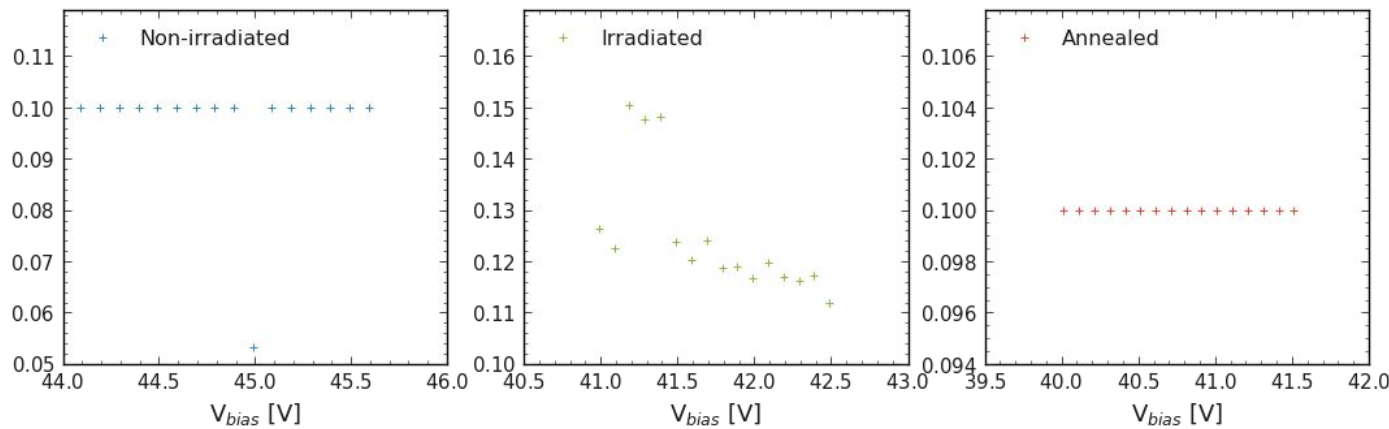
# Time resolution for first photon peak



Time resolution of all peaks for SiPM #9 at  $-20^\circ$



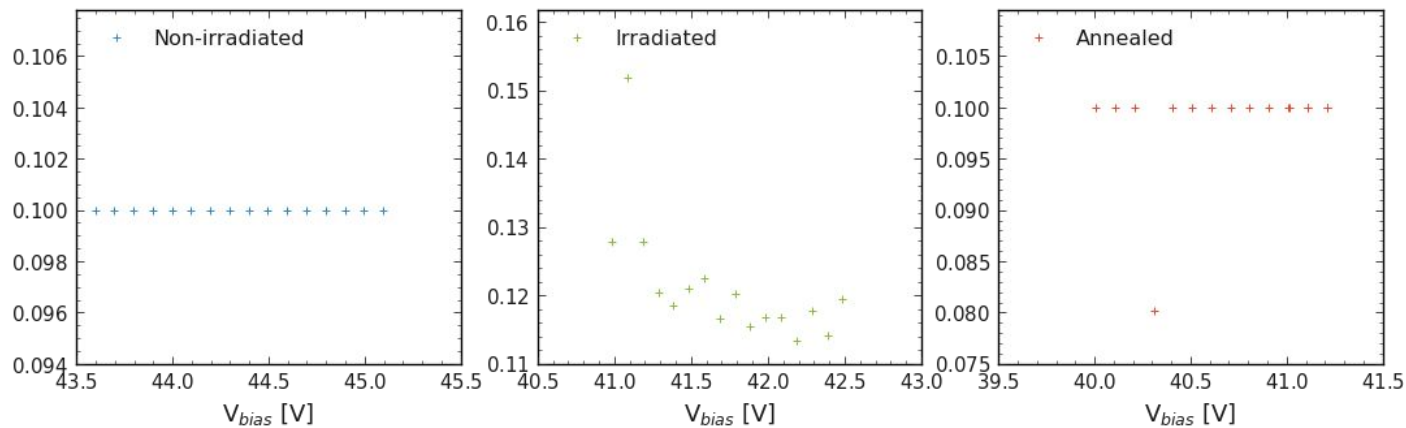
Time resolution of all peaks for SiPM #9 at  $-30^\circ$



# Time resolution for first photon peak

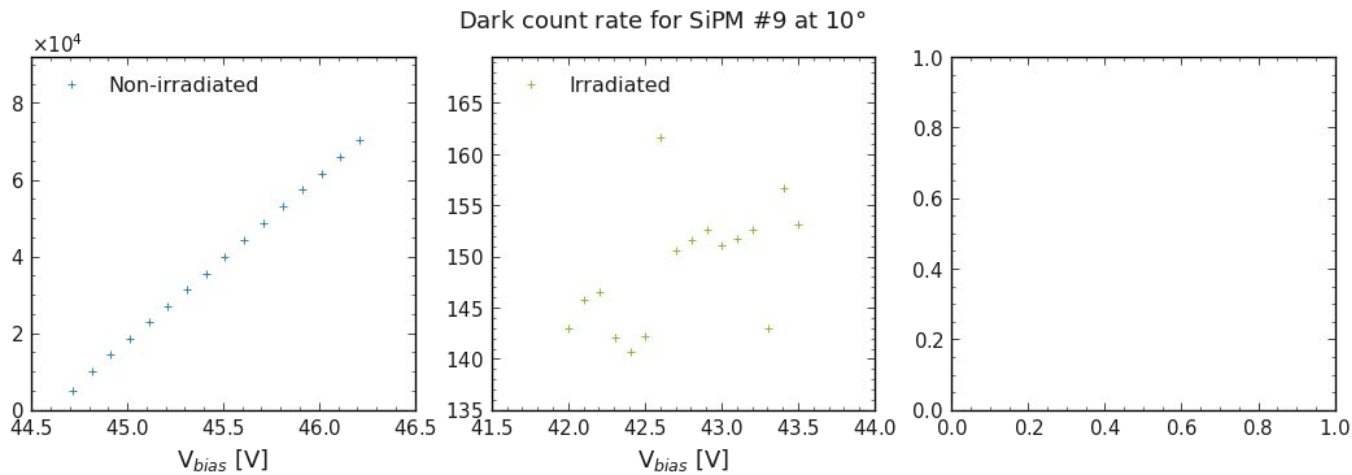
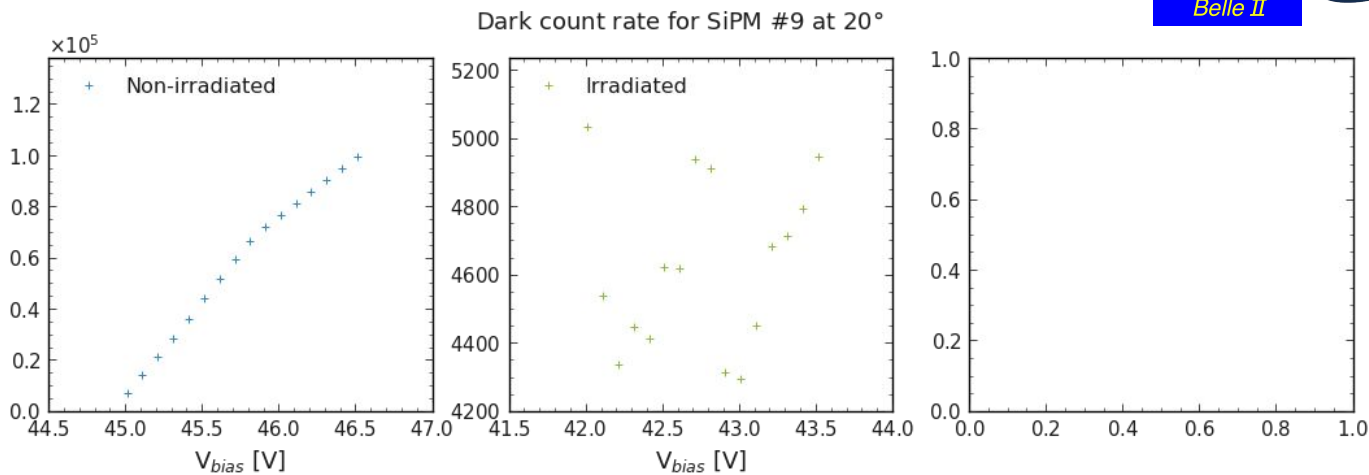


Time resolution of all peaks for SiPM #9 at  $-35^\circ$



# Dark count rate for SiPM #9

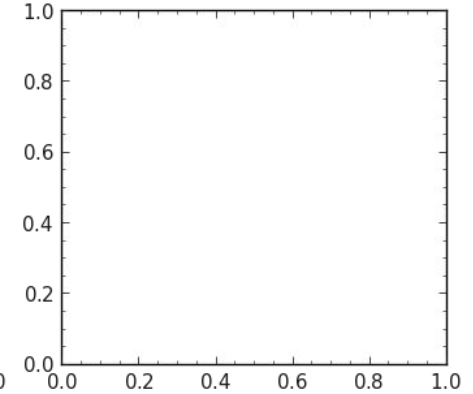
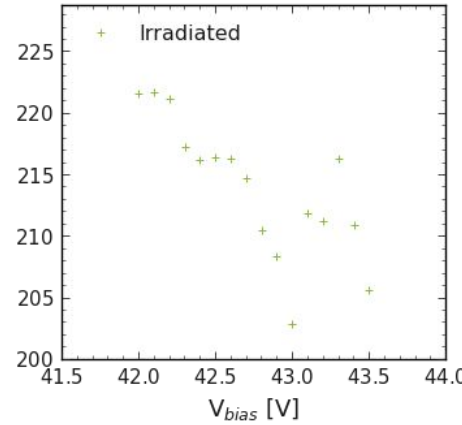
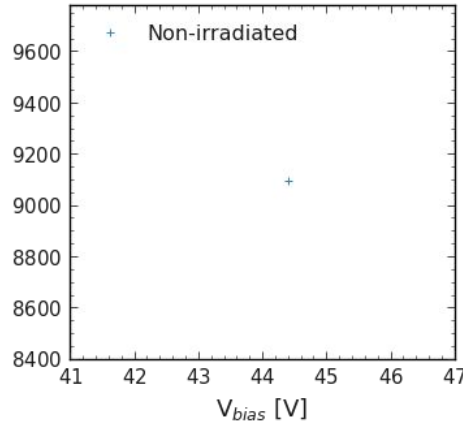
# Dark count rate



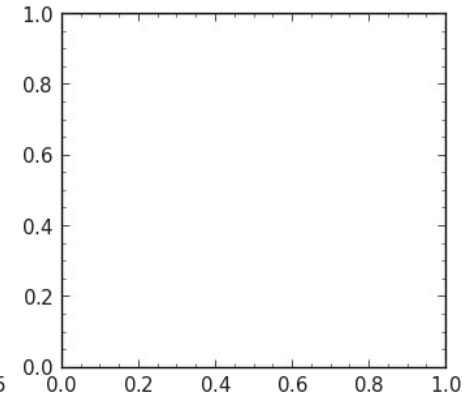
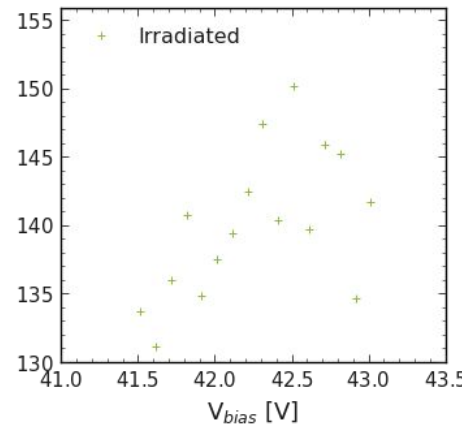
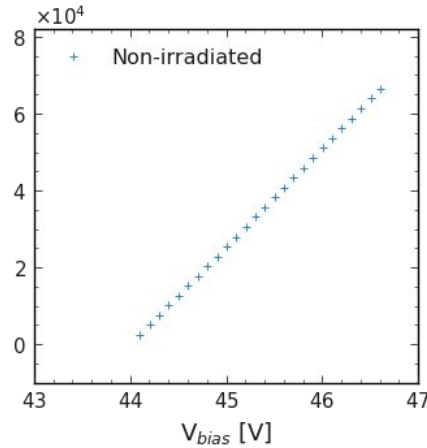


# Dark count rate

Dark count rate for SiPM #9 at 0°



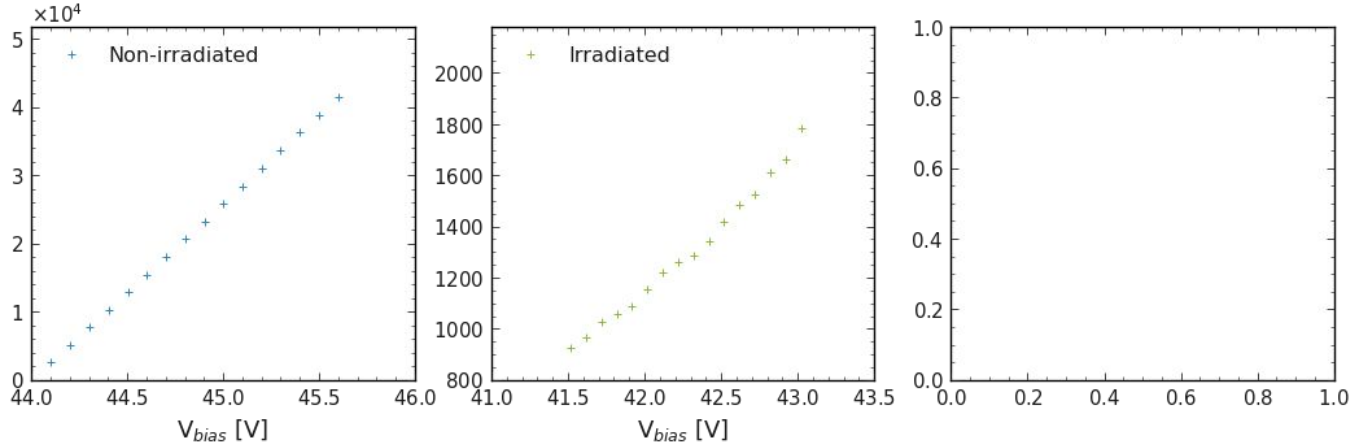
Dark count rate for SiPM #9 at -10°



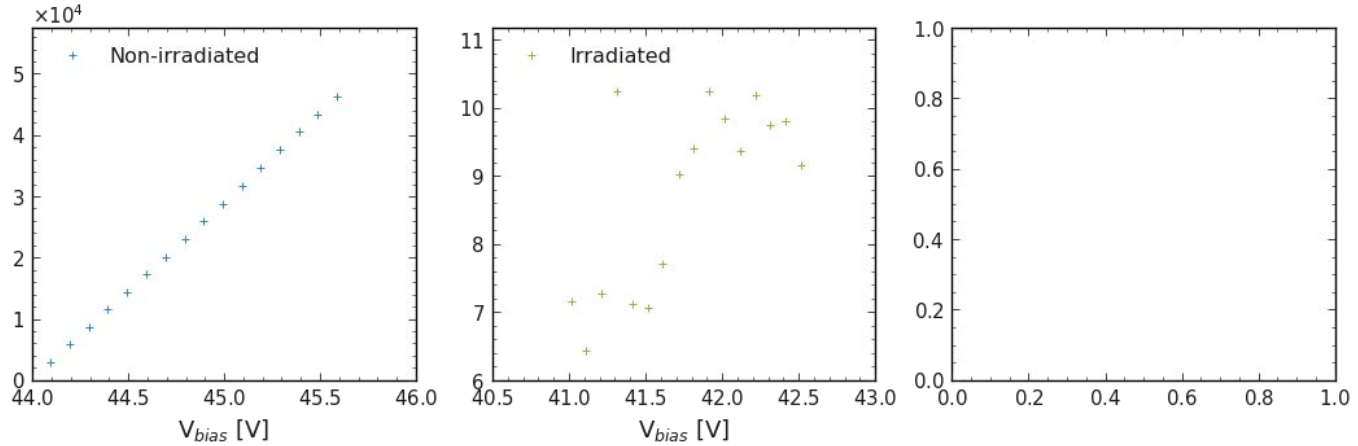
# Dark count rate



Dark count rate for SiPM #9 at  $-20^\circ$



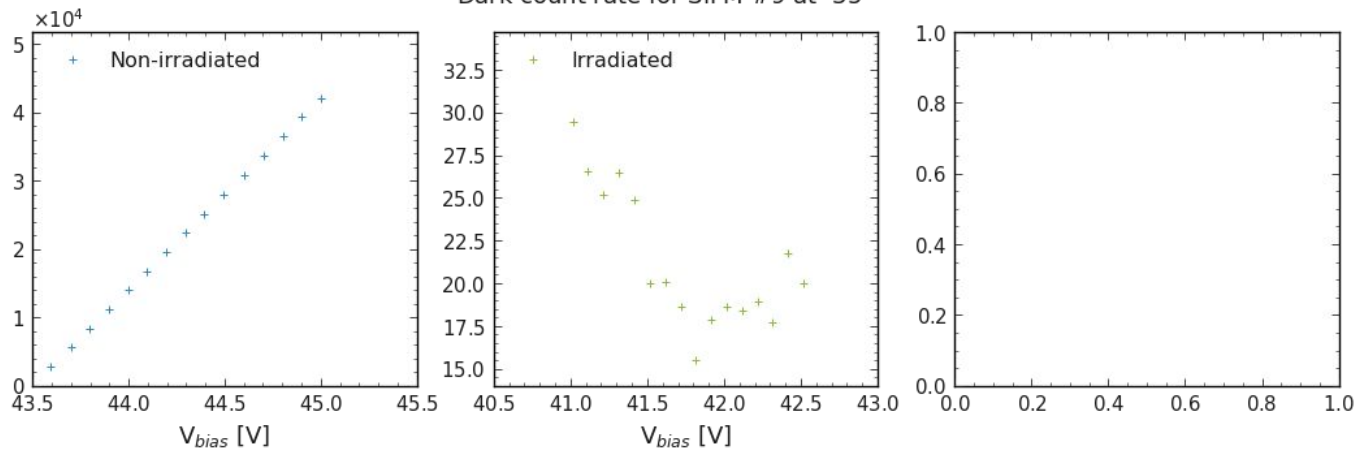
Dark count rate for SiPM #9 at  $-30^\circ$



# Dark count rate



Dark count rate for SiPM #9 at  $-35^\circ$



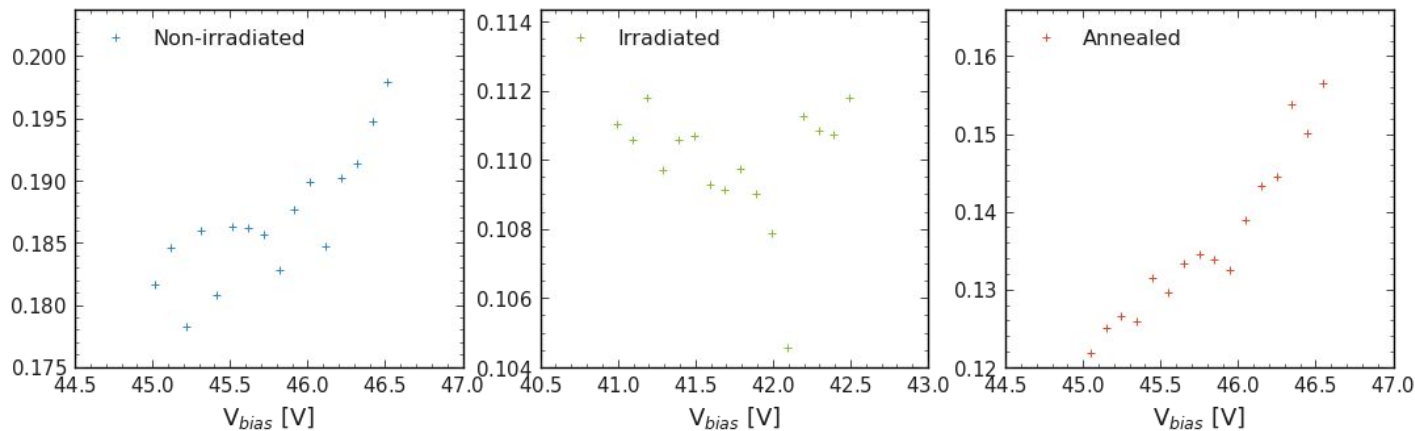
# SiMP #10

# Time resolution for all photon peaks for SiPM #10

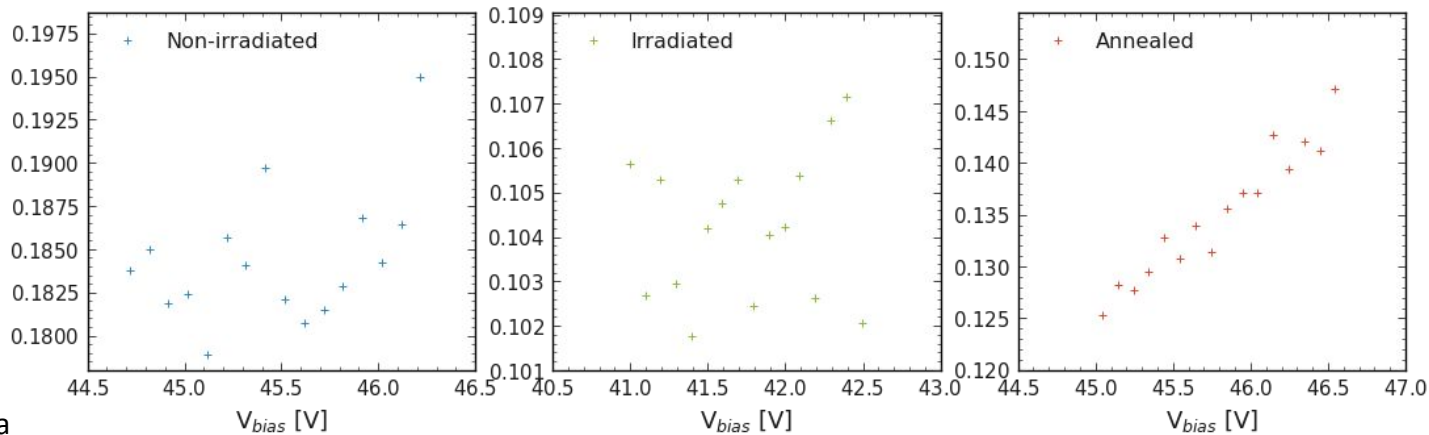
# Time resolution for first photon peak



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



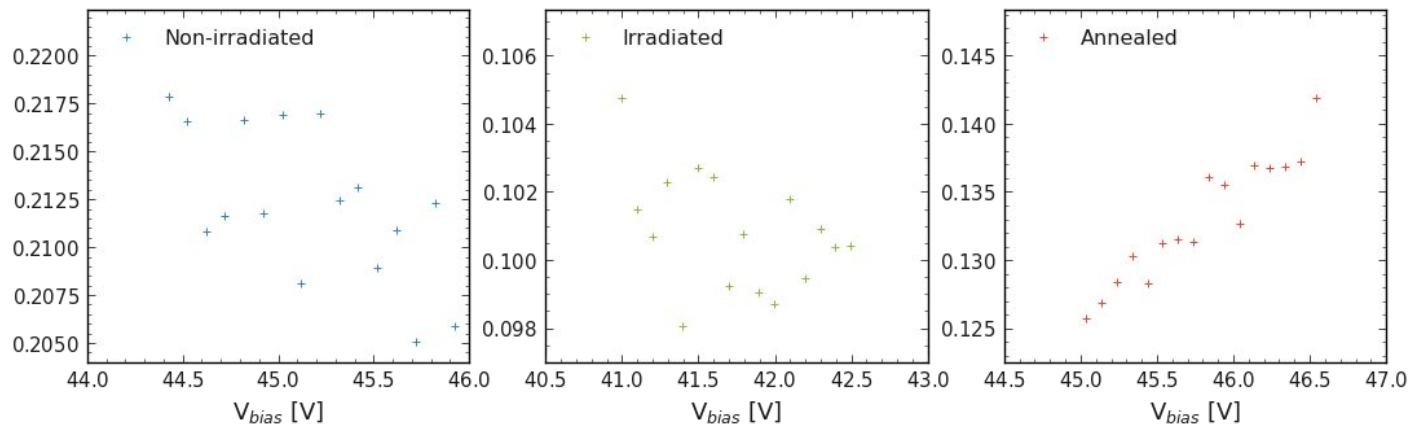
Time resolution of all peaks for SiPM #10 at 10°



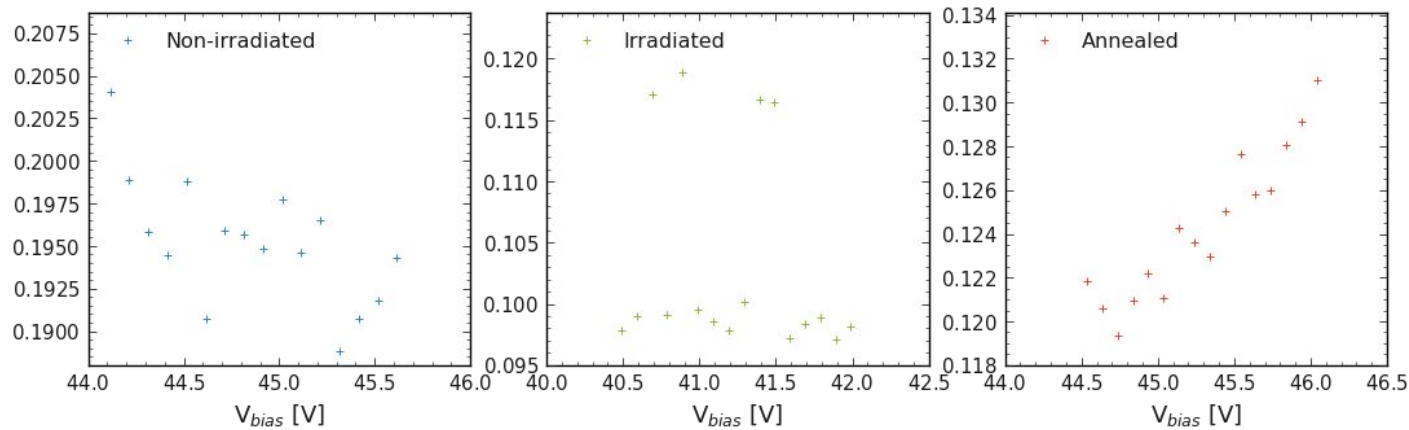
# Time resolution for first photon peak



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



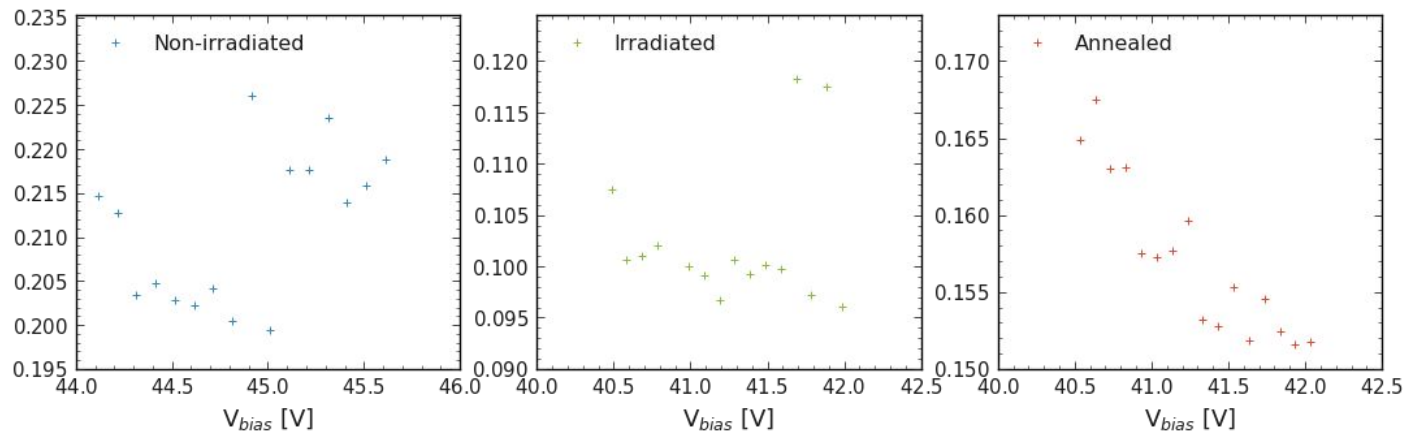
Time resolution of all peaks for SiPM #10 at -10°



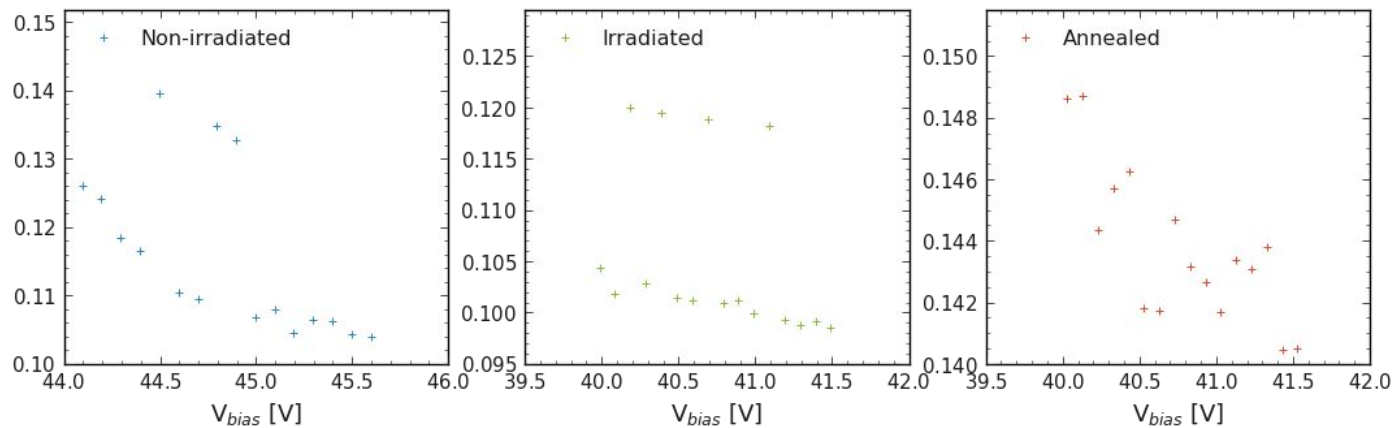
# Time resolution for first photon peak



Time resolution of all peaks for SiPM #10 at  $-20^\circ$



Time resolution of all peaks for SiPM #10 at  $-30^\circ$

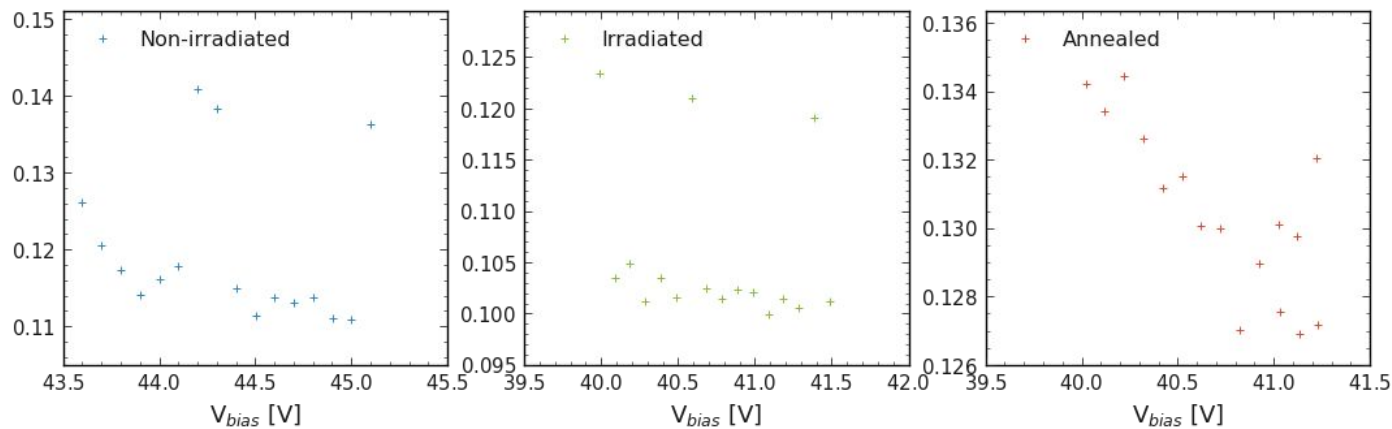




# Time resolution for first photon peak

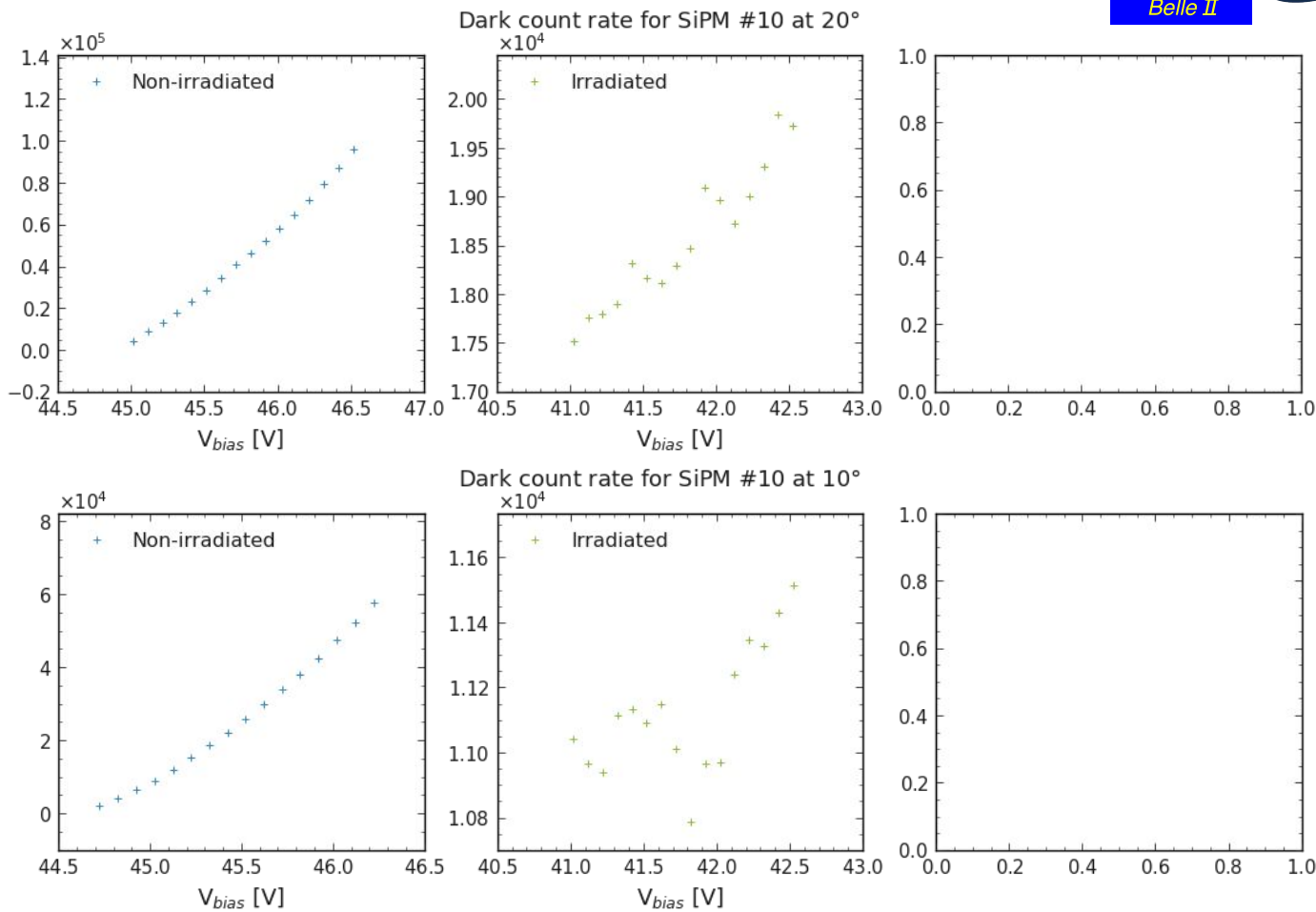


Time resolution of all peaks for SiPM #10 at  $-35^\circ$



# Dark count rate for SiPM #10

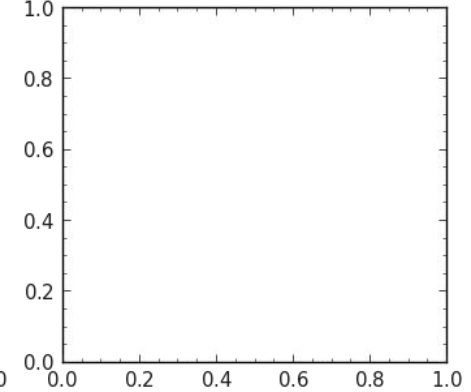
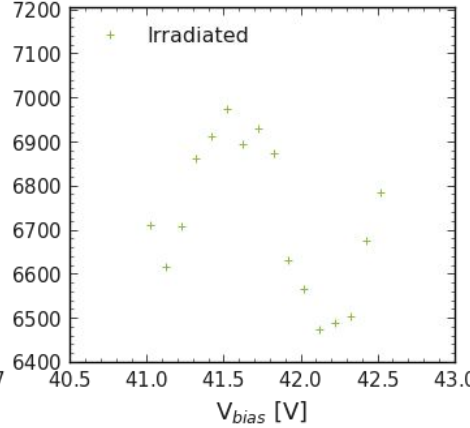
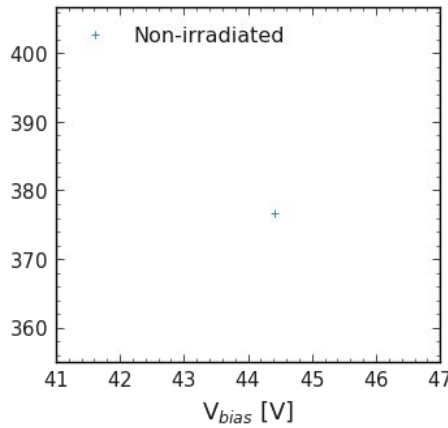
# Dark count rate



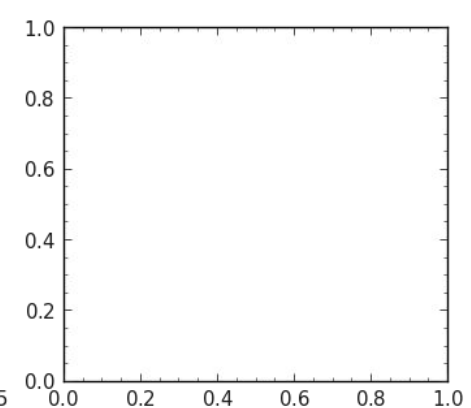
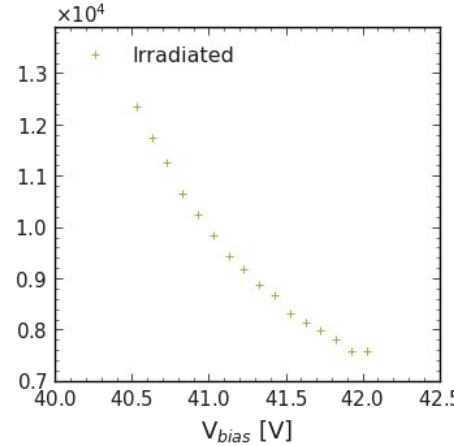
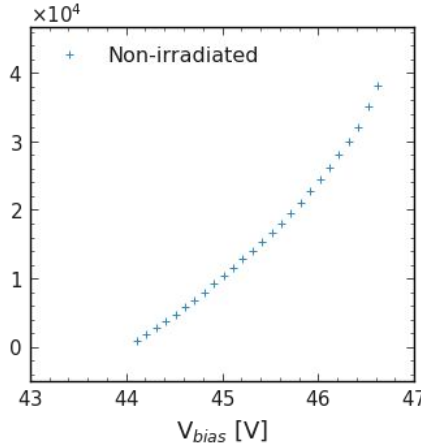
# Dark count rate



Dark count rate for SiPM #10 at 0°

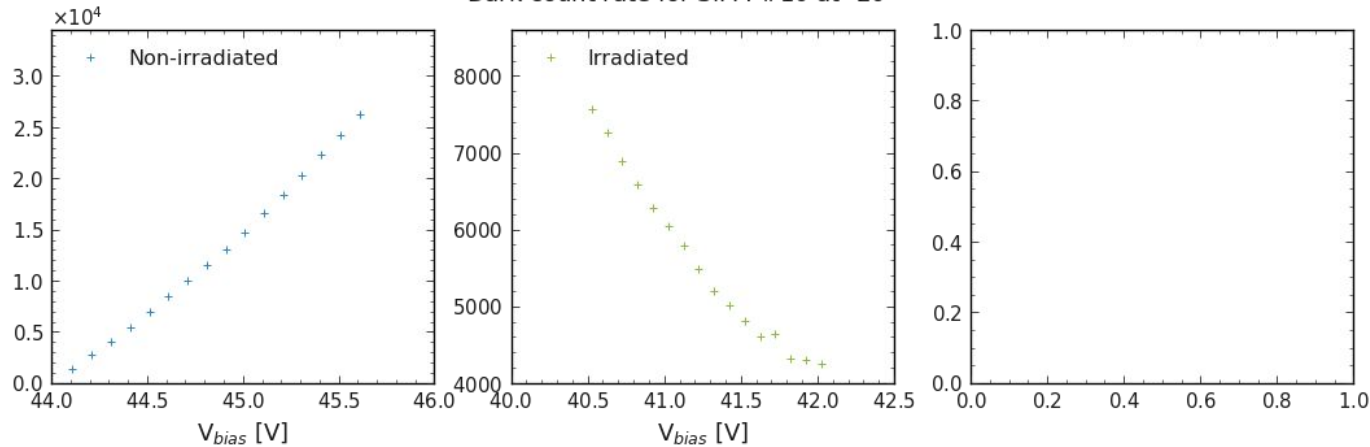


Dark count rate for SiPM #10 at -10°

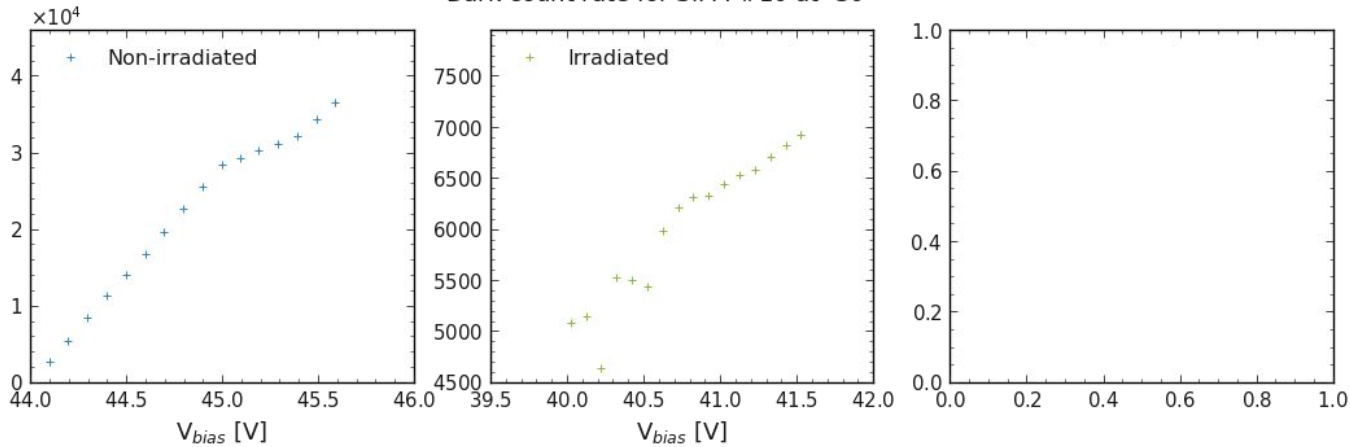


# Dark count rate

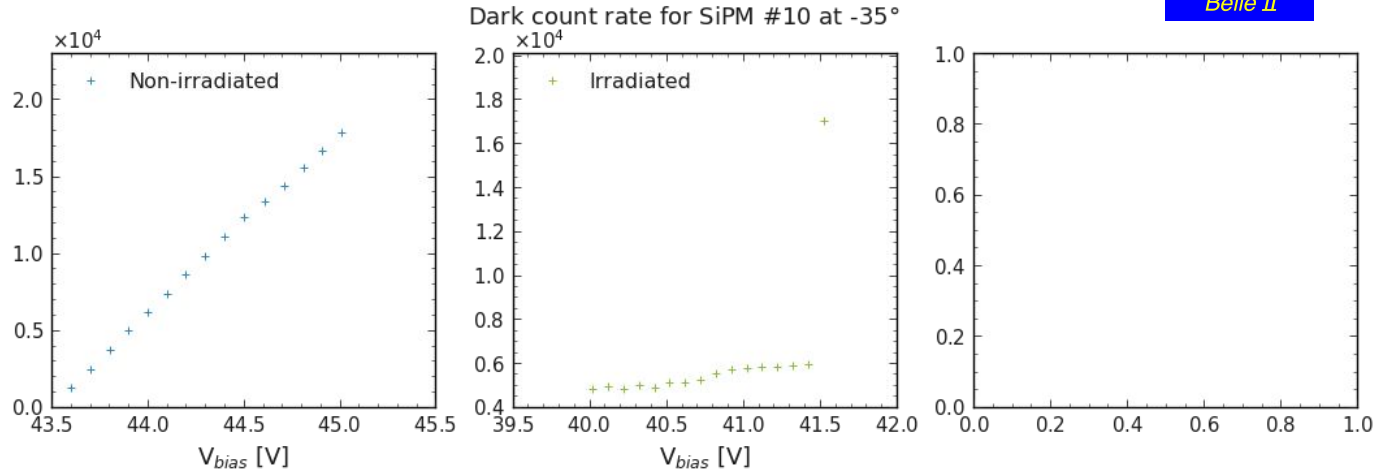
Dark count rate for SiPM #10 at  $-20^\circ$



Dark count rate for SiPM #10 at  $-30^\circ$



# Dark count rate



# Backup



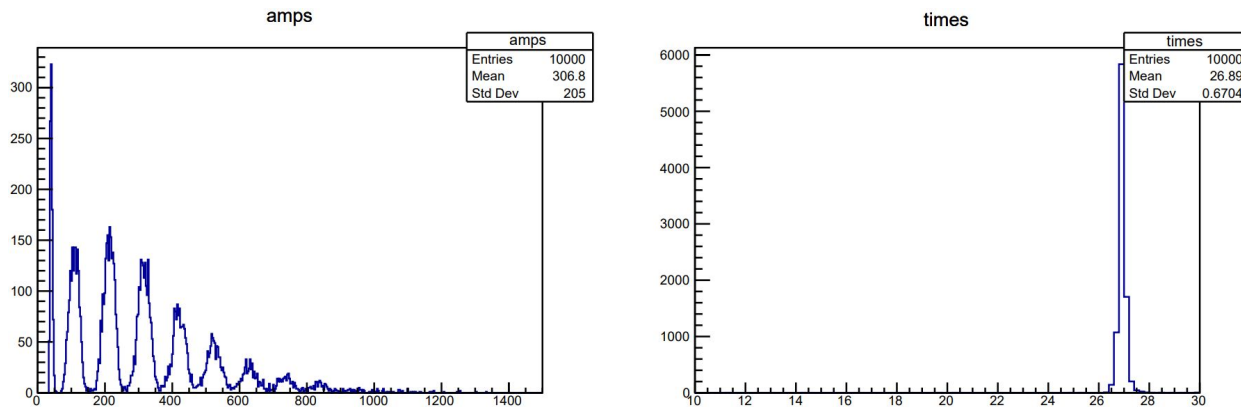
# Markov parameters tuning using SiPM #14



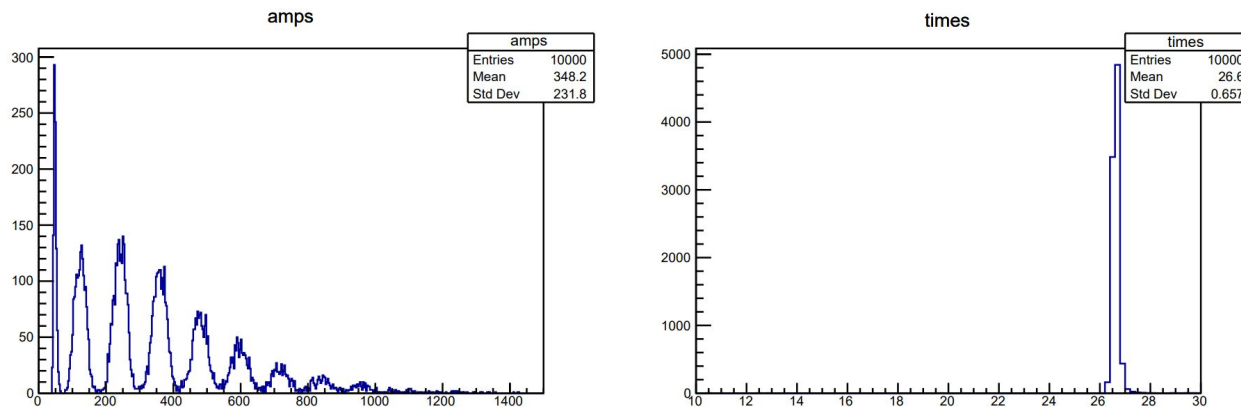
# Background iterated 10 times



## Difference between background and original waveform



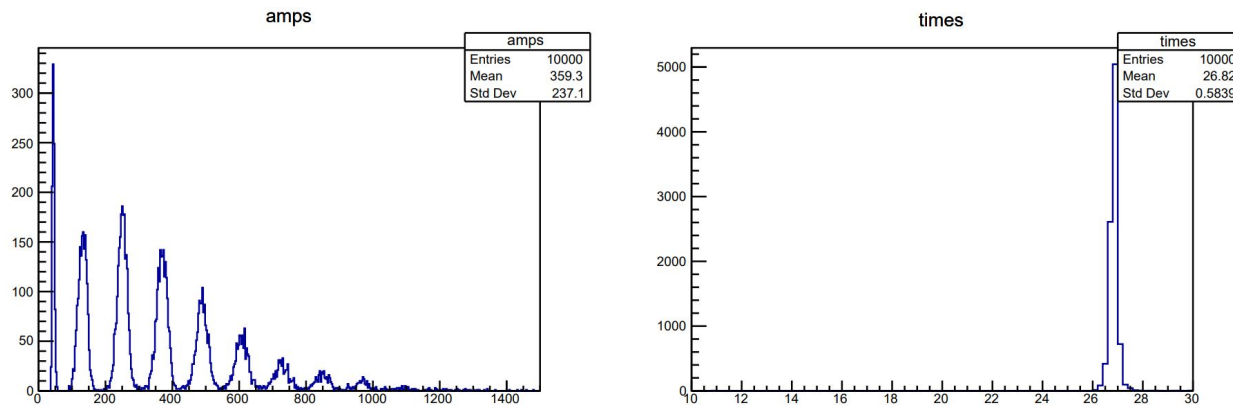
## Signal waveform extracted using Markov algorithm



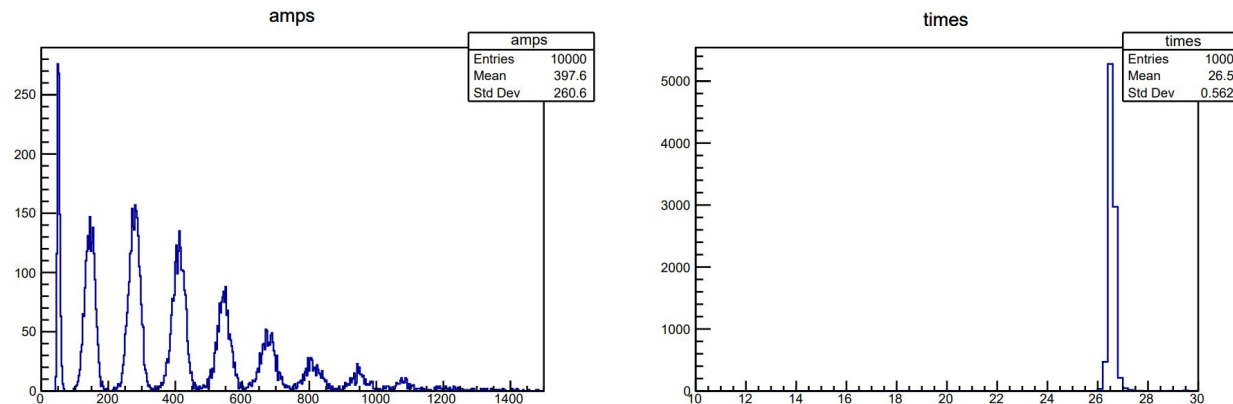
# Background iterated 20 times



## Difference between background and original waveform



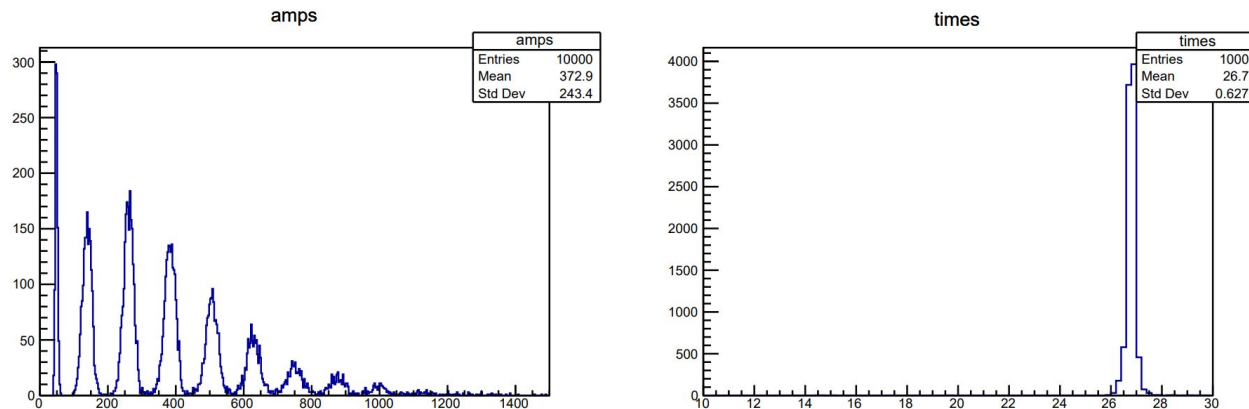
## Signal waveform extracted using Markov algorithm



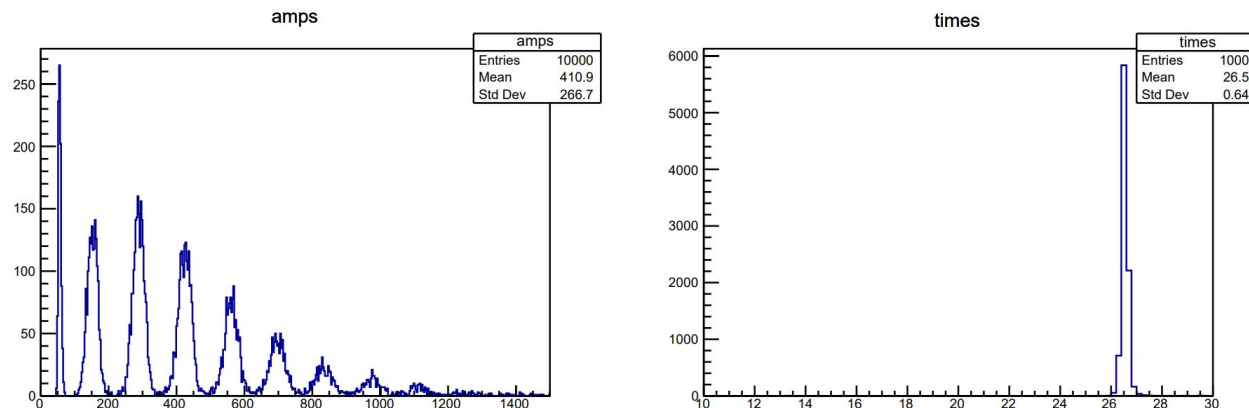
# Background iterated 30 times



## Difference between background and original waveform



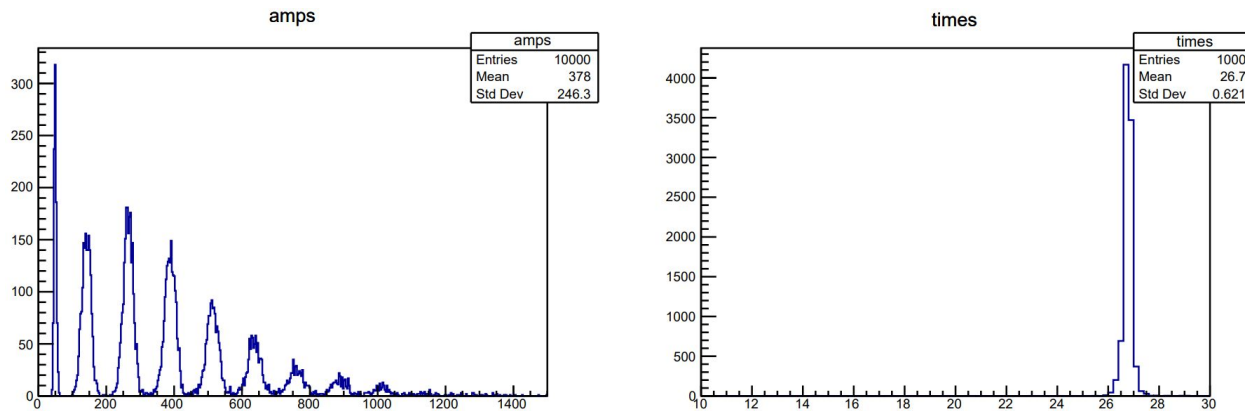
## Signal waveform extracted using Markov algorithm



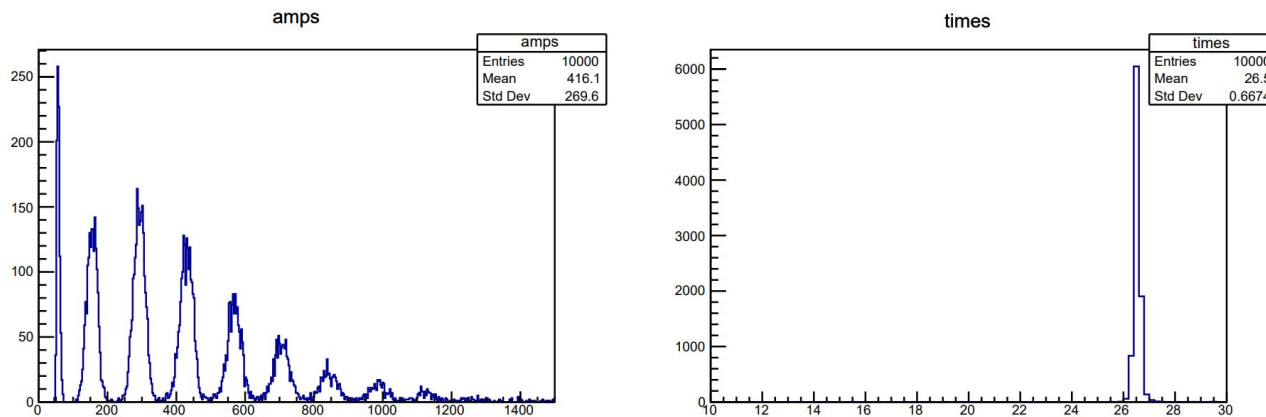
# Background iterated 40 times



## Difference between background and original waveform



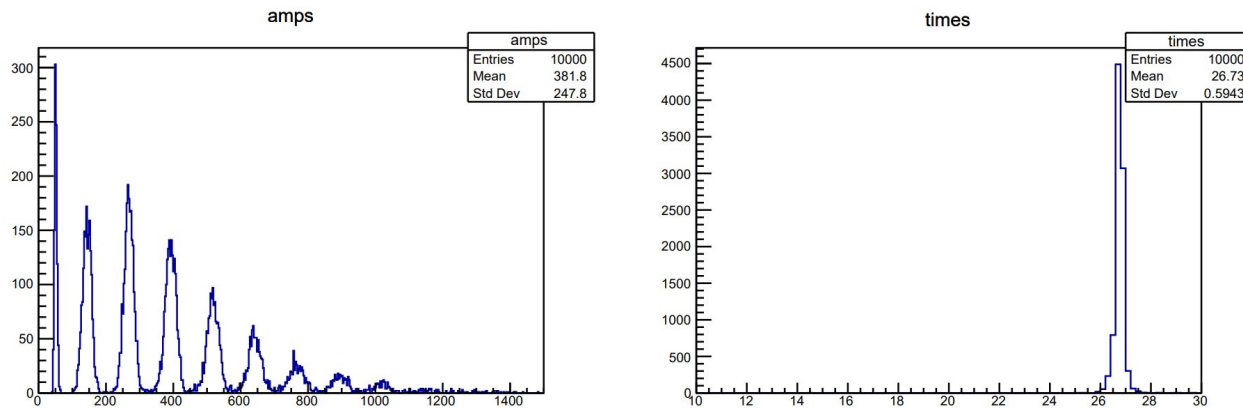
## Signal waveform extracted using Markov algorithm



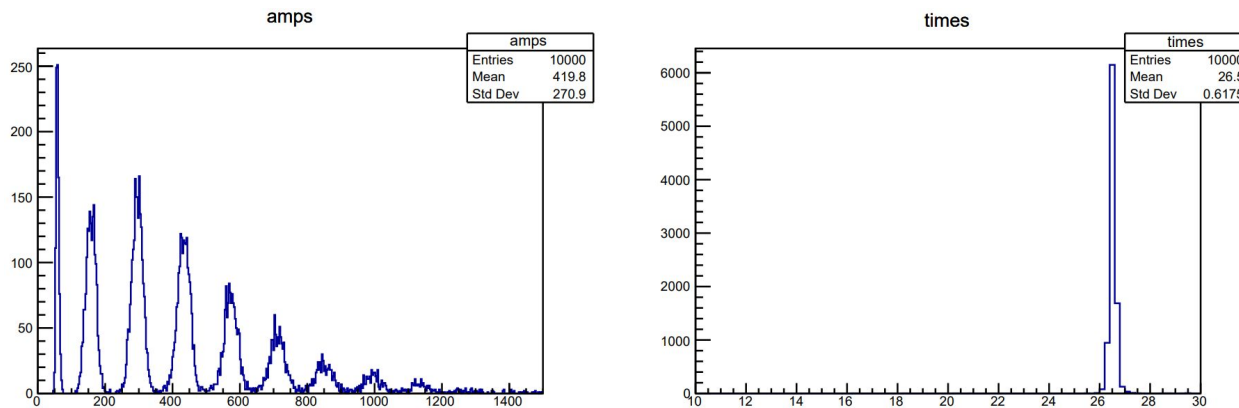
# Background iterated 50 times



## Difference between background and original waveform



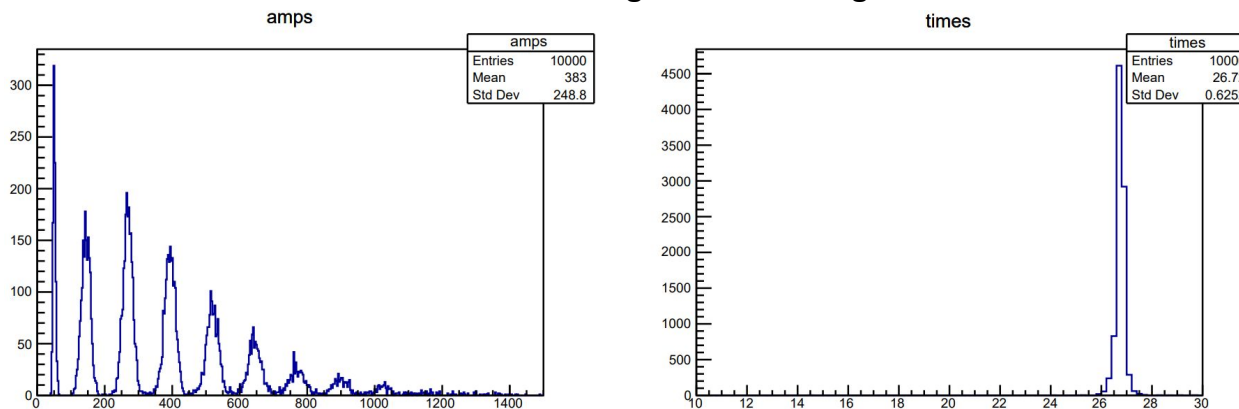
## Signal waveform extracted using Markov algorithm



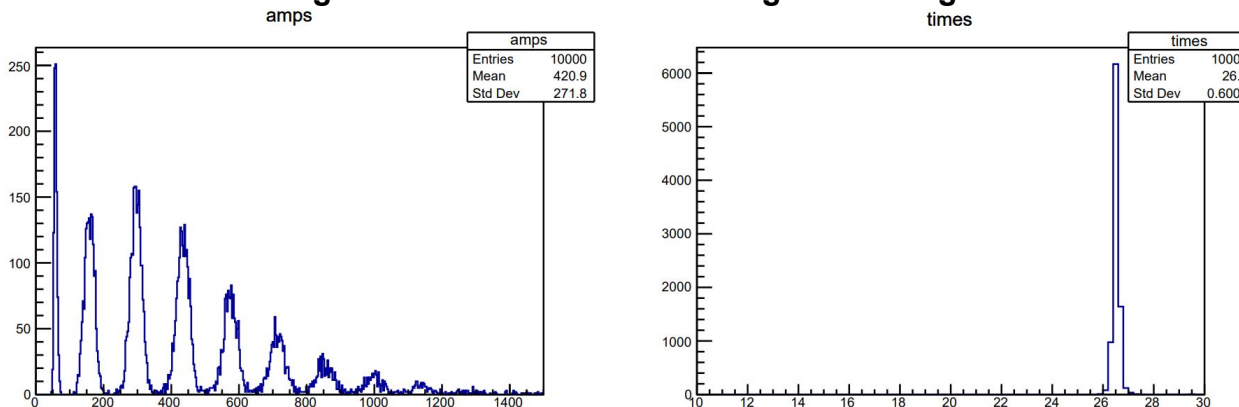
# Background iterated 60 times



## Difference between background and original waveform



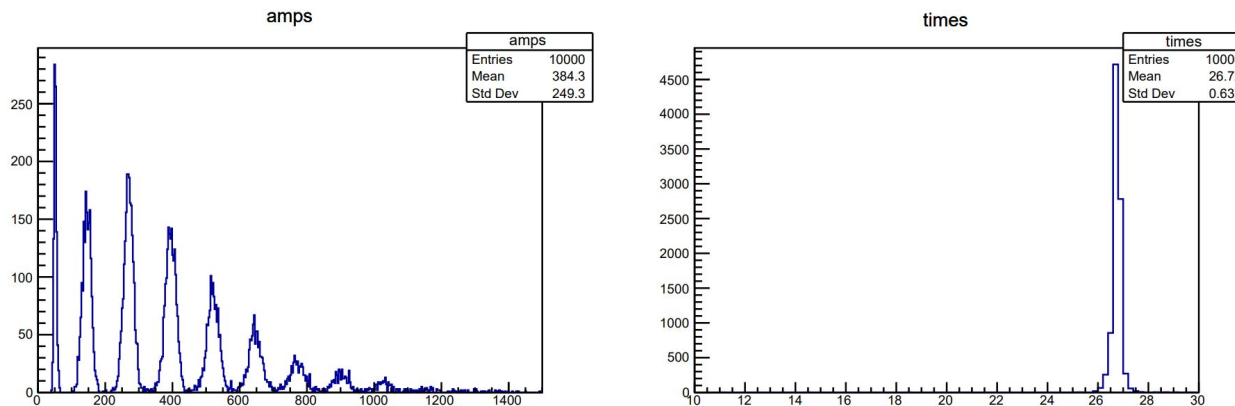
## Signal waveform extracted using Markov algorithm



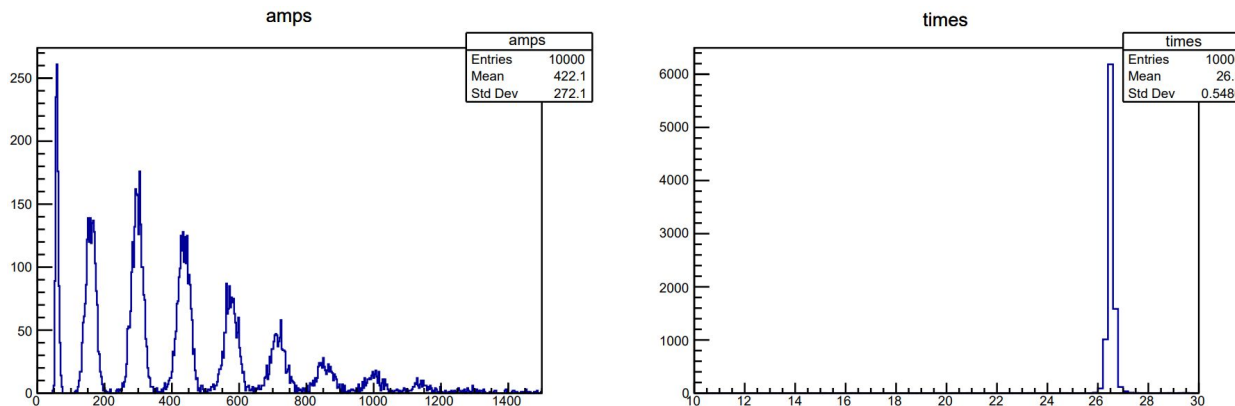
# Background iterated 70 times



## Difference between background and original waveform



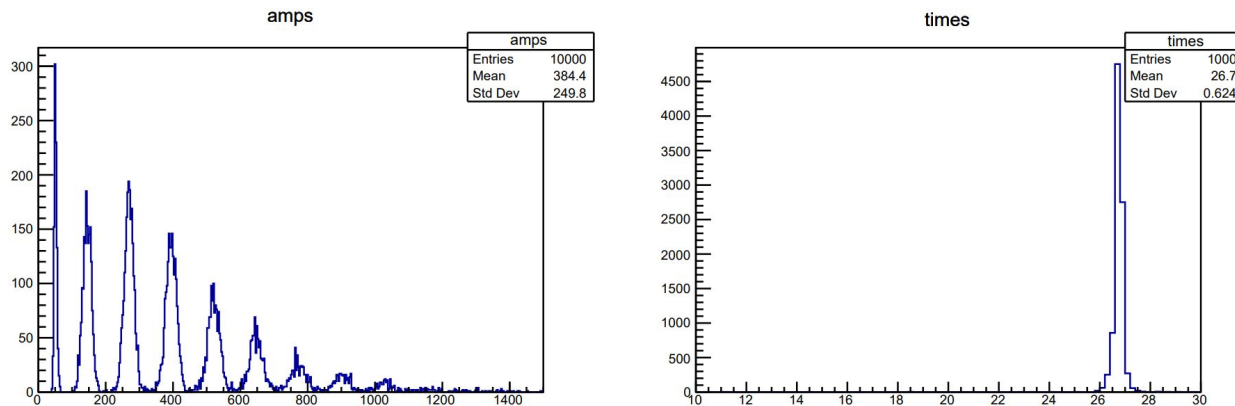
## Signal waveform extracted using Markov algorithm



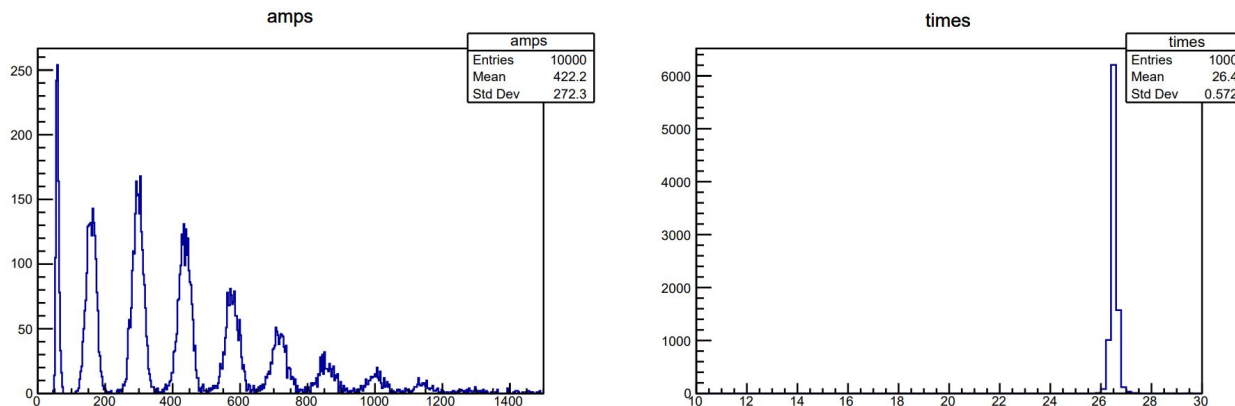
# Background iterated 80 times



## Difference between background and original waveform



## Signal waveform extracted using Markov algorithm





# Breakdown voltages at temperatures for SiPMs



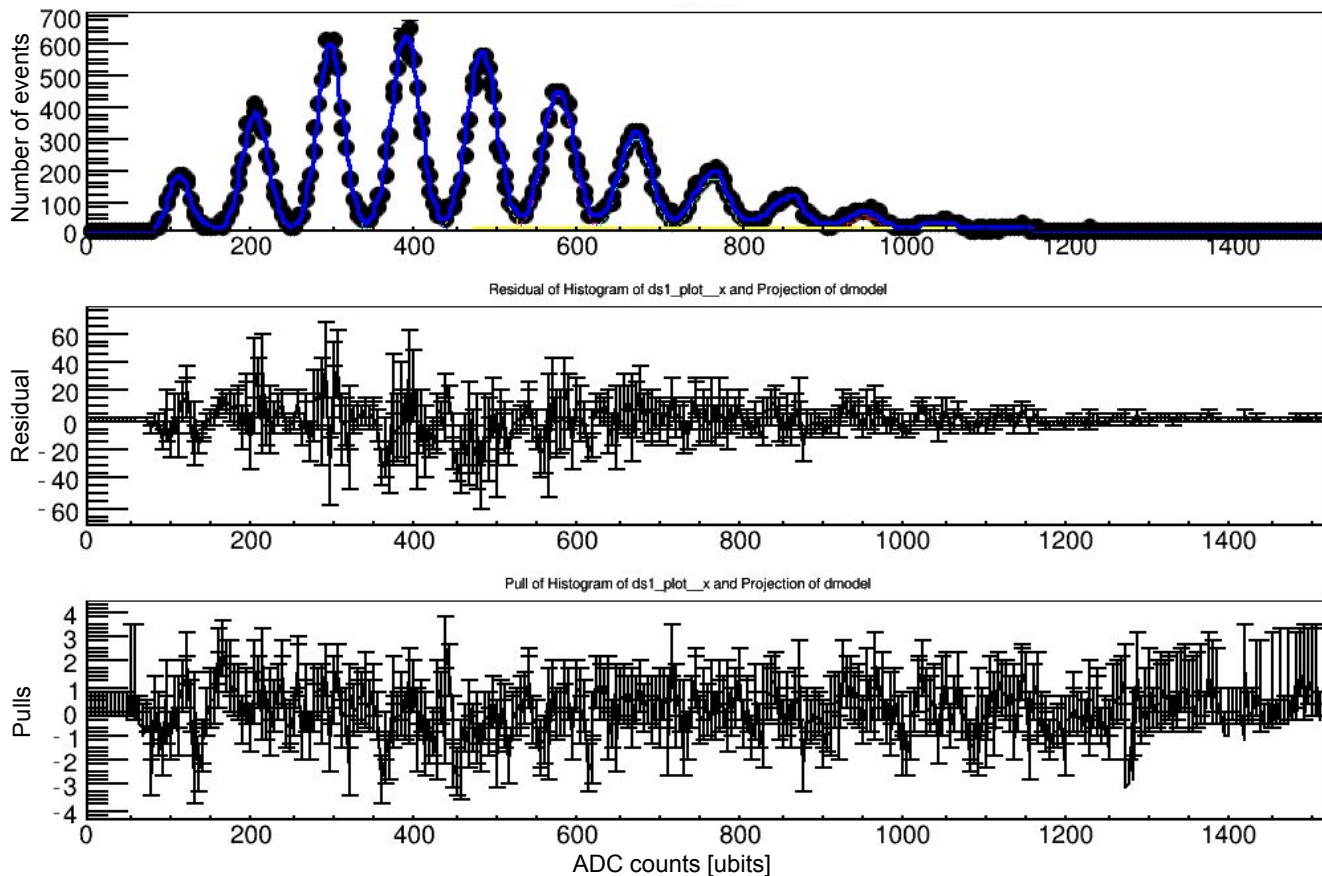
Index of SiPM Producer Dimension [mm×mm] Pitch [ $\mu\text{m}$ ]	11 FBK 1 × 1 15		12 FBK 1 × 1 15		13 FBK 1 × 1 15		14 FBK 1 × 1 15		15 Hamamatsu 3 × 3 50	
Temperature [°]	Breakdown voltage [ $V_0$ ]		Breakdown voltage [ $V_0$ ]		Breakdown voltage [ $V_0$ ]		Breakdown voltage [ $V_0$ ]		Breakdown voltage [ $V_0$ ]	
	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)

