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

Padova meeting
28/3/2024

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Content

Done:

- Irradiated SiPM modules in Padova
- Gain as function of bias voltage
- Gain as function of overvoltage
- Comparison time resolutions (for Markov and simple algorithms):
  - First, second, third and others (including second and third) using recognized spectra
  - All photon peaks using unrecognized spectra
- Darkcount rates for SiPMs - Preliminary (Missing and no-processed data)
- Change parameters in Markov algorithm and share them - Backup
- Update table with fitted breakdown voltages and slope with uncertainties

To Do:

- Add fitted spectra (one bias voltage ~ 1.0 per temperature per SiPM)
- Check results and provide better fits if needed
- Irradiation campaign in Legnaro from 22th to 24th 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 [μm]	Distance [cm]	Neutron 1 MeV eg/cm^2 fluence	Charge [mC]	Time [h]
8	FBK	3 × 3	15	18.36	$1.0{\cdot}10^{10}$	2.86	5.88
9	FBK	3 × 3	15	18.24	$5.0{\cdot}10^{9}$	1.41	2.90
10	FBK	3 × 3	15	33.24	$1.0{\cdot}10^{9}$	0.94	1.93
11	FBK	1 × 1	15	15.86	$2.0{\cdot}10^{10}$	4.26	8.77
12	FBK	1 × 1	15	30.86	$1.0{\cdot}10^{10}$	8.07	16.61
13	FBK	1 × 1	15	15.74	$5.0{\cdot}10^{9}$	1.05	2.16
14	FBK	1 × 1	15	30.74	$1.0{\cdot}10^{9}$	0.80	1.65
15	Hamamatsu	3 × 3	50	33.46	$1.0{\cdot}10^{9}$	0.95	1.95

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 [°C]	Status	Breakdown voltage [V_0]	Breakdown voltage [V_0]	Breakdown voltage [V_0]	Breakdown voltage [V_0]	Breakdown voltage [V_0]
20	No-irradiated	32.36 ± 0.80	32.70 ± 0.84	32.24 ± 1.16	32.43 ± 1.88	38.10 ± 2.24
	Irradiated	32.55 ± 1.75	32.03 ± 0.27	31.87 ± 0.49	32.13 ± 0.75	37.57 ± 0.98
	Annealed	32.29 ± 0.66	32.14 ± 0.57	31.91 ± 0.65	32.19 ± 0.75	38.00 ± 0.93
10	No-irradiated	33.72 ± 1.98	32.39 ± 0.51	31.71 ± 0.82	32.17 ± 1.52	38.31 ± 2.24
	Irradiated	32.13 ± 1.25	31.87 ± 0.35	31.36 ± 0.57	31.86 ± 0.32	37.22 ± 0.48
	Annealed	32.00 ± 1.03	31.91 ± 0.67	31.52 ± 0.61	32.16 ± 0.53	37.46 ± 1.03
0	No-irradiated	31.43 ± 1.41	32.07 ± 1.22	31.33 ± 1.68	31.87 ± 1.40	38.34 ± 8.88
	Irradiated	28.79 ± 2.70	31.21 ± 0.53	31.30 ± 0.41	31.52 ± 0.34	36.98 ± 0.52
	Annealed	31.63 ± 0.65	31.57 ± 0.37	31.49 ± 0.38	31.54 ± 0.53	37.19 ± 0.53
-10	No-irradiated	30.61 ± 2.58	31.65 ± 1.45	31.31 ± 0.82	31.64 ± 1.05	37.25 ± 9.79
	Irradiated	31.65 ± 0.63	31.24 ± 0.42	30.94 ± 0.36	31.29 ± 0.32	36.63 ± 0.31
	Annealed	31.38 ± 0.42	31.26 ± 0.46	30.95 ± 0.41	31.18 ± 0.67	36.67 ± 1.02
-20	No-irradiated	31.79 ± 1.59	31.18 ± 1.52	30.70 ± 0.98	31.13 ± 2.00	37.92 ± 6.71
	Irradiated	30.95 ± 0.53	30.92 ± 0.30	30.61 ± 0.33	30.94 ± 0.50	36.19 ± 0.82
	Annealed	30.85 ± 0.86	30.94 ± 0.25	30.66 ± 0.38	30.71 ± 0.42	36.25 ± 1.62
-30	No-irradiated	31.45 ± 0.62	31.33 ± 0.60	30.87 ± 0.81	30.91 ± 0.99	36.17 ± 1.42
	Irradiated	30.48 ± 0.37	30.61 ± 0.40	30.43 ± 0.32	30.50 ± 0.83	35.80 ± 0.46
	Annealed	30.19 ± 1.78	30.61 ± 0.27	30.43 ± 0.52	30.37 ± 1.05	36.20 ± 0.98
-35	No-irradiated	30.66 ± 3.92	30.96 ± 0.35	30.61 ± 0.28	30.84 ± 0.71	34.55 ± 5.39
	Irradiated	30.58 ± 0.48	30.47 ± 0.43	30.21 ± 0.37	30.08 ± 1.45	35.57 ± 0.58
	Annealed	30.45 ± 1.61	30.43 ± 0.40	30.32 ± 0.40	30.27 ± 1.33	35.68 ± 1.75
-40	No-irradiated	30.71 ± 0.70	30.68 ± 0.46	30.16 ± 0.97	30.65 ± 0.58	35.71 ± 0.84
	Irradiated	30.19 ± 0.79	30.54 ± 0.61	30.14 ± 0.45	30.35 ± 0.28	36.59 ± 2.63

- 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

Slopes 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 [°C]	Status	Slope	Slope	Slope	Slope	Slope
20	No-irradiated	2.815 ± 0.045	4.215 ± 0.070	3.894 ± 0.091	3.822 ± 0.144	5.050 ± 0.201
	Irradiated	2.098 ± 0.072	3.739 ± 0.020	3.526 ± 0.034	3.490 ± 0.051	4.633 ± 0.081
	Annealed	4.342 ± 0.057	4.376 ± 0.049	4.267 ± 0.055	4.348 ± 0.064	6.301 ± 0.103
10	No-irradiated	4.546 ± 0.179	4.101 ± 0.042	3.670 ± 0.061	3.787 ± 0.116	6.023 ± 0.240
	Irradiated	3.043 ± 0.075	3.771 ± 0.026	3.388 ± 0.038	3.458 ± 0.022	4.709 ± 0.040
	Annealed	4.317 ± 0.088	4.366 ± 0.058	4.158 ± 0.050	4.460 ± 0.047	6.131 ± 0.113
0	No-irradiated	2.754 ± 0.080	4.003 ± 0.100	3.522 ± 0.122	3.707 ± 0.106	6.928 ± 1.103
	Irradiated	1.454 ± 0.081	3.563 ± 0.038	3.443 ± 0.028	3.405 ± 0.023	4.917 ± 0.046
	Annealed	4.217 ± 0.054	4.282 ± 0.031	4.249 ± 0.032	4.201 ± 0.044	6.239 ± 0.060
-10	No-irradiated	2.188 ± 0.118	3.856 ± 0.116	3.606 ± 0.061	3.764 ± 0.081	4.764 ± 0.850
	Irradiated	2.757 ± 0.035	3.661 ± 0.031	3.353 ± 0.025	3.383 ± 0.022	4.950 ± 0.028
	Annealed	4.194 ± 0.036	4.236 ± 0.039	4.058 ± 0.034	4.101 ± 0.055	6.076 ± 0.113
-20	No-irradiated	2.798 ± 0.092	3.657 ± 0.116	3.365 ± 0.069	3.486 ± 0.145	6.756 ± 0.820
	Irradiated	2.668 ± 0.029	3.580 ± 0.021	3.287 ± 0.022	3.291 ± 0.033	4.876 ± 0.073
	Annealed	4.023 ± 0.069	4.148 ± 0.021	4.002 ± 0.031	3.950 ± 0.033	5.975 ± 0.176
-30	No-irradiated	3.000 ± 0.038	3.992 ± 0.050	3.700 ± 0.063	3.654 ± 0.075	5.191 ± 0.137
	Irradiated	2.384 ± 0.018	3.509 ± 0.028	3.267 ± 0.021	3.159 ± 0.054	4.853 ± 0.041
	Annealed	3.764 ± 0.137	4.066 ± 0.023	3.970 ± 0.042	3.874 ± 0.083	6.349 ± 0.114
-35	No-irradiated	2.315 ± 0.191	3.792 ± 0.028	3.578 ± 0.021	3.658 ± 0.054	4.031 ± 0.412
	Irradiated	2.435 ± 0.024	3.472 ± 0.031	3.207 ± 0.024	3.025 ± 0.090	4.808 ± 0.052
	Annealed	3.923 ± 0.129	4.013 ± 0.033	3.953 ± 0.032	3.873 ± 0.105	5.914 ± 0.191
-40	No-irradiated	3.077 ± 0.044	4.217 ± 0.040	3.808 ± 0.079	4.021 ± 0.049	5.952 ± 0.092
	Irradiated	1.900 ± 0.031	3.547 ± 0.045	3.201 ± 0.030	3.170 ± 0.018	6.098 ± 0.294

SiMP #11

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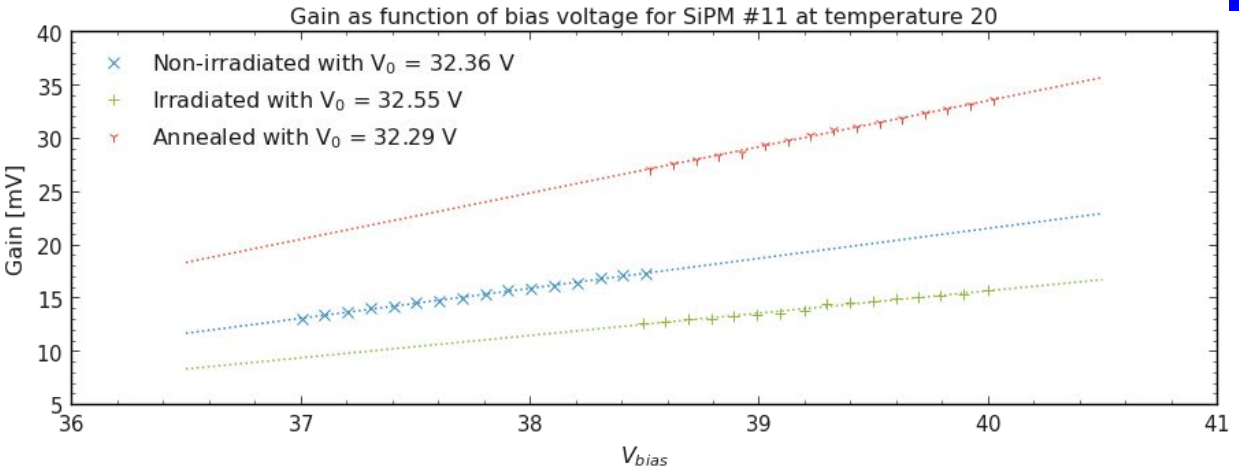
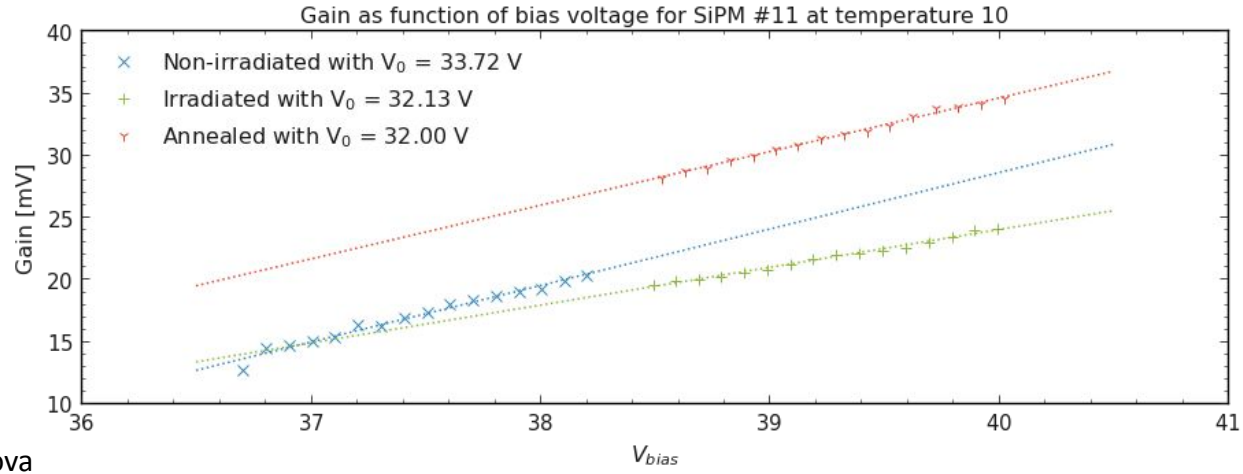
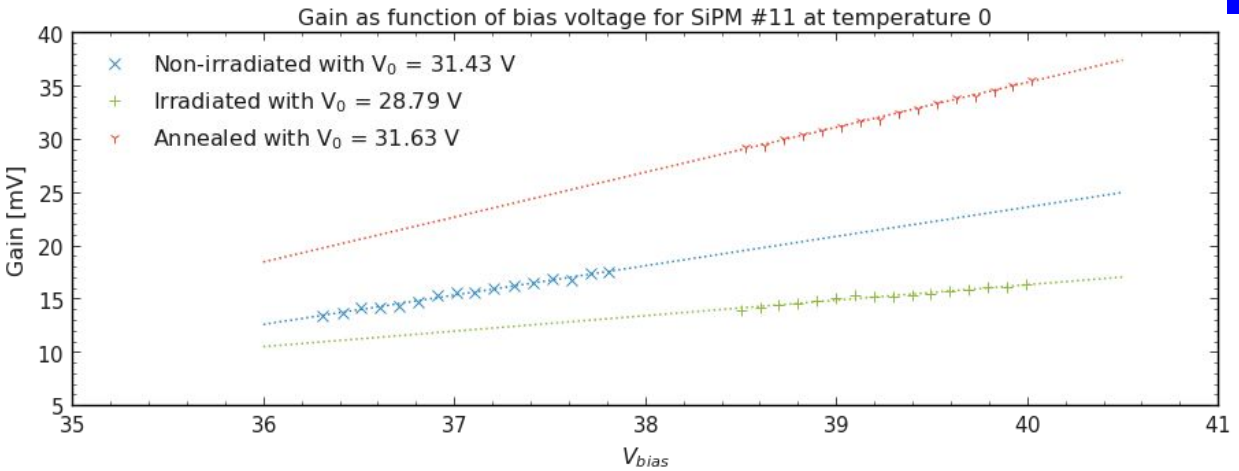
Gain as function of bias voltage for SiPM #11

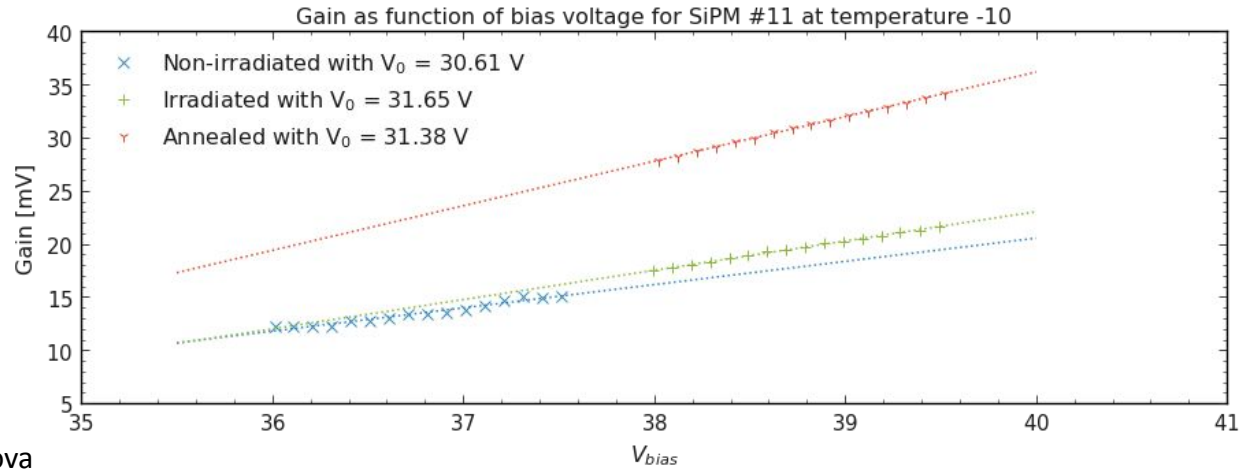
Gain as function of bias voltage



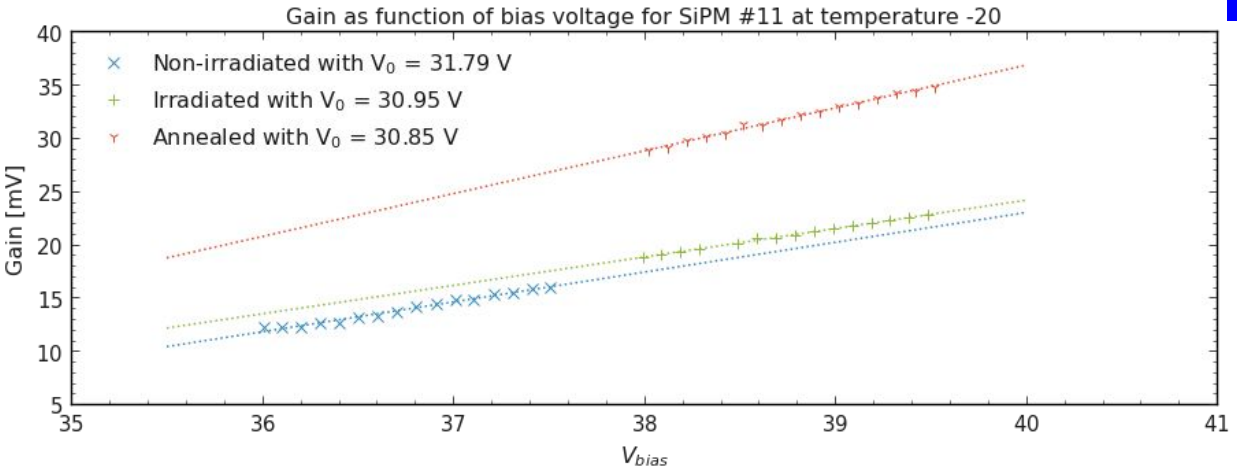


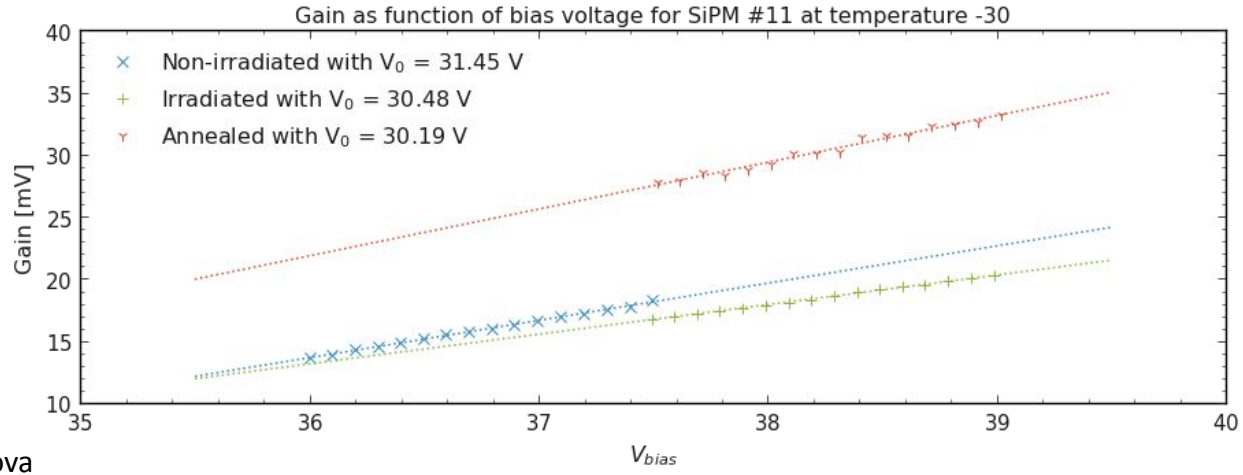
Gain as function of bias voltage



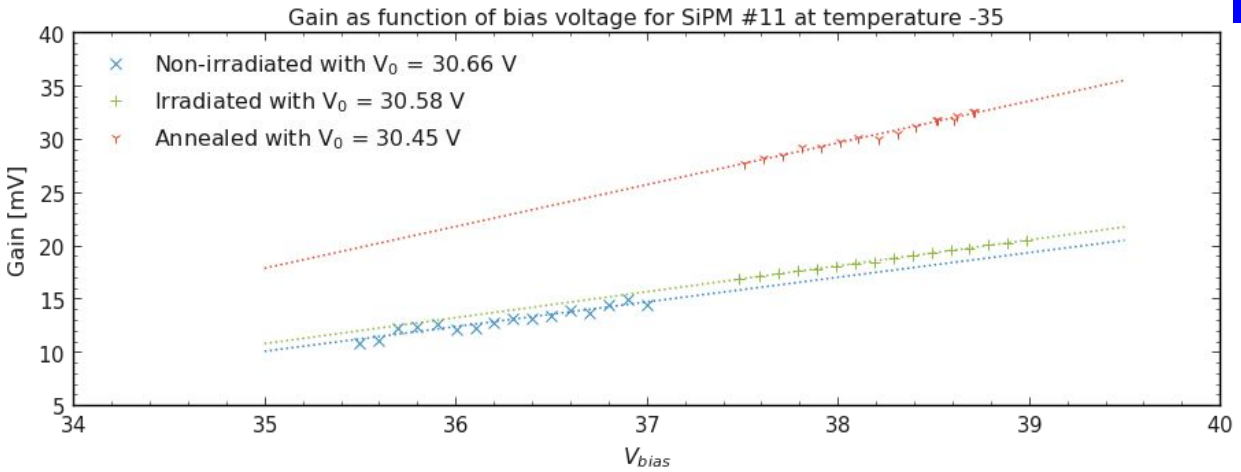


Gain as function of bias voltage





Gain as function of bias voltage



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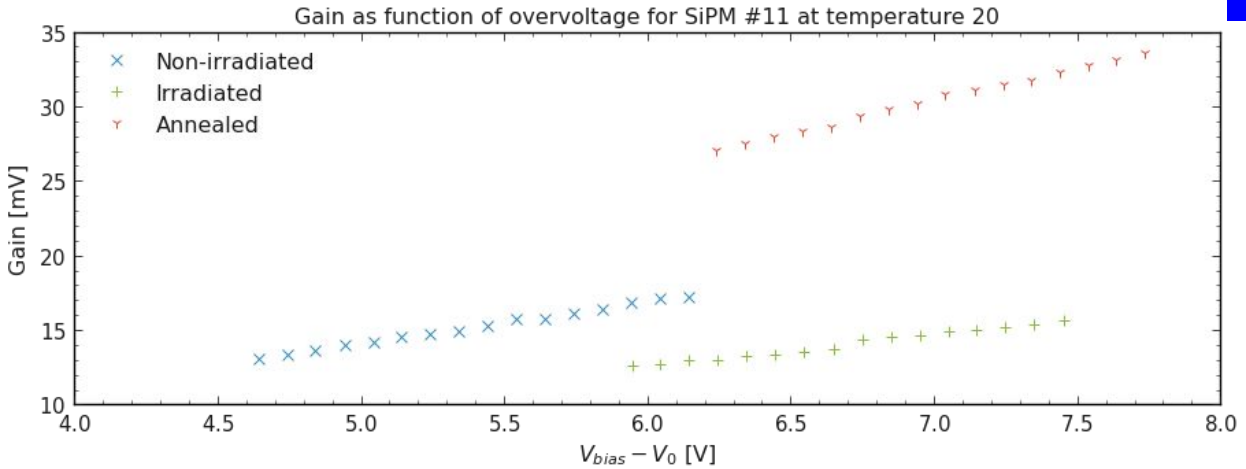
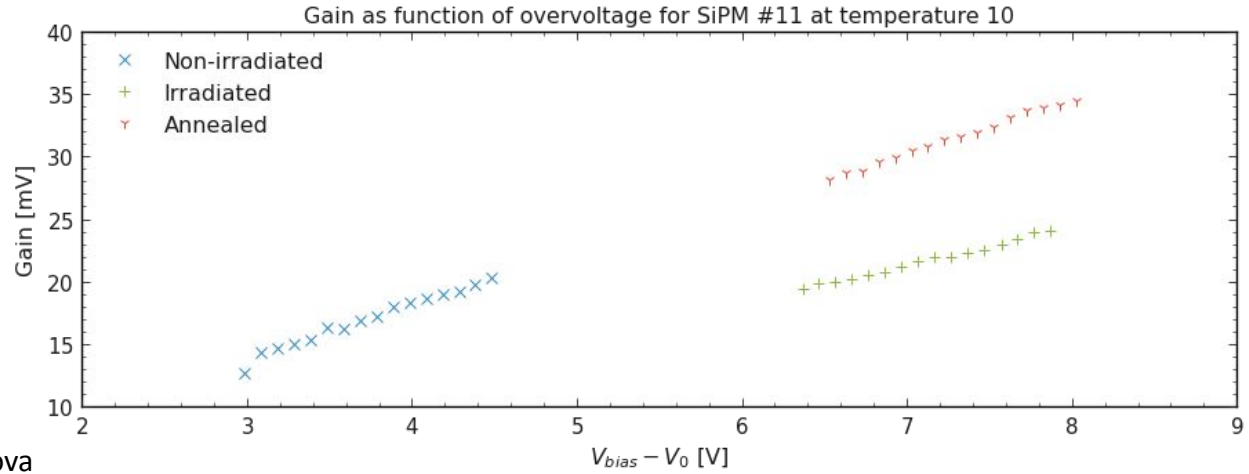
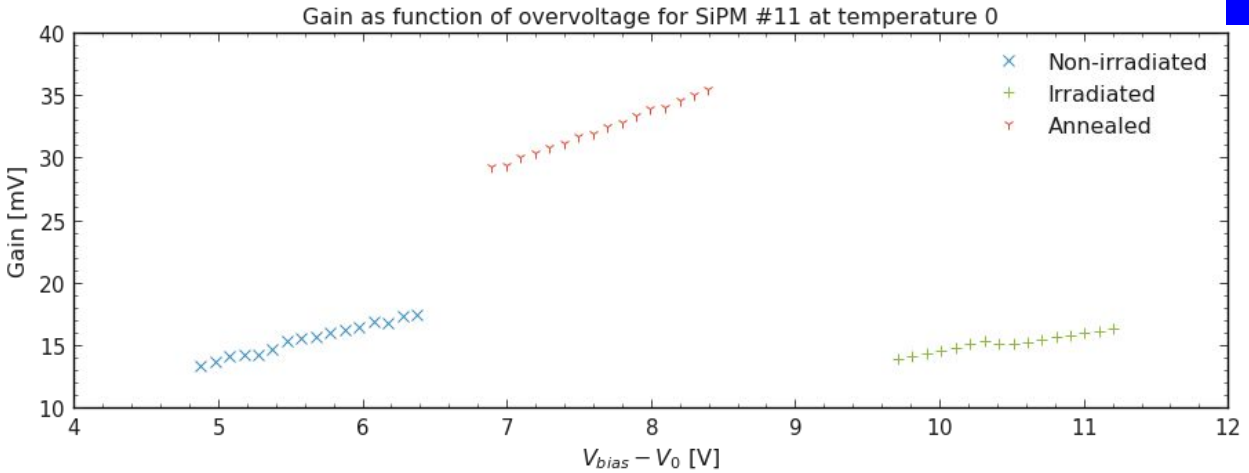
Gain as function of overvoltage for SiPM #11

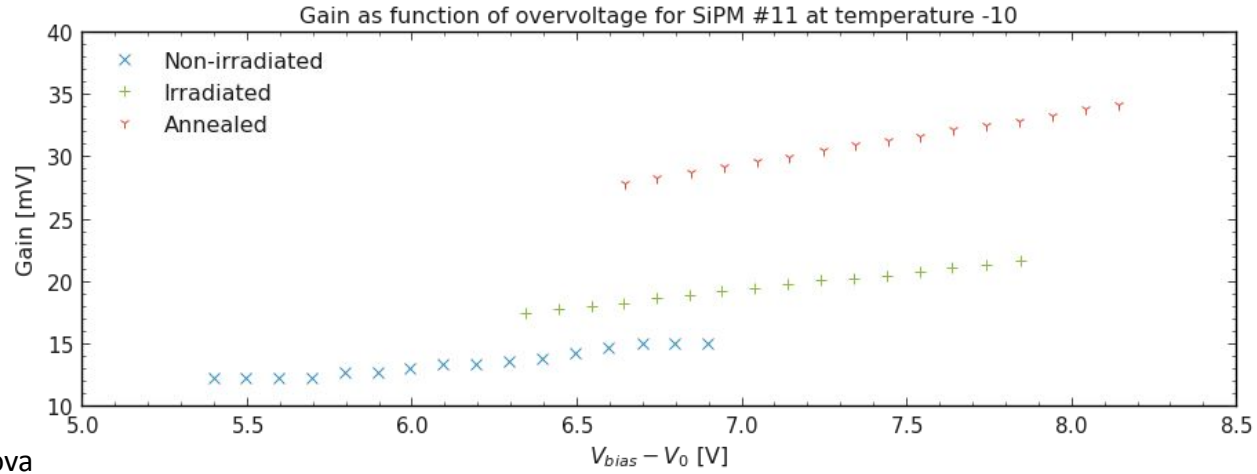
Gain as function of overvoltage



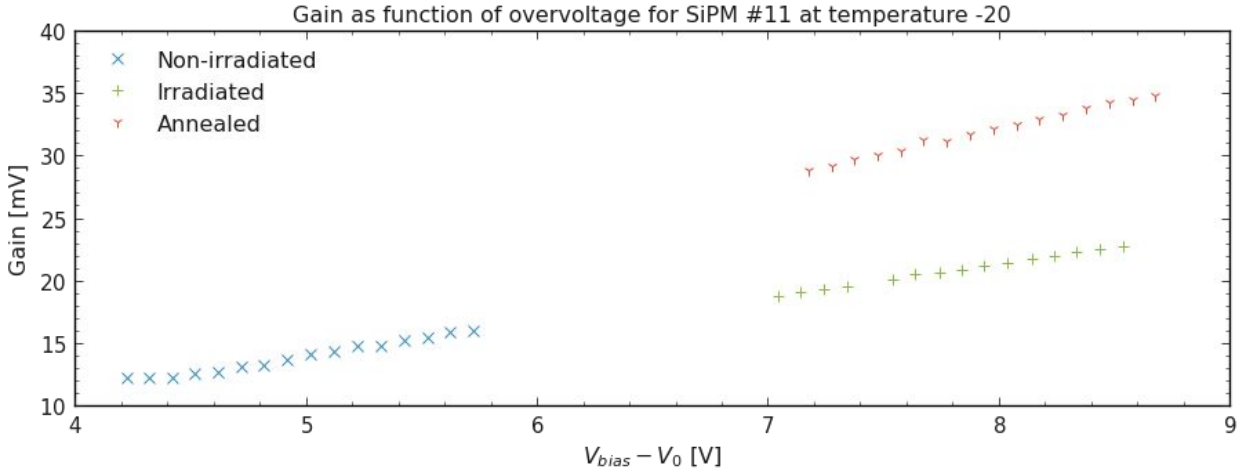


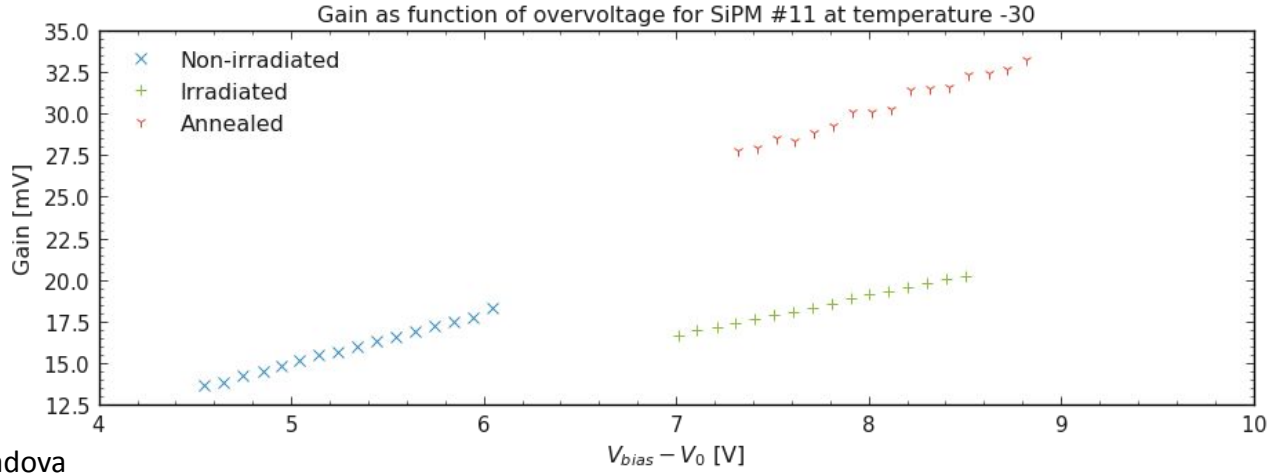
Gain as function of overvoltage



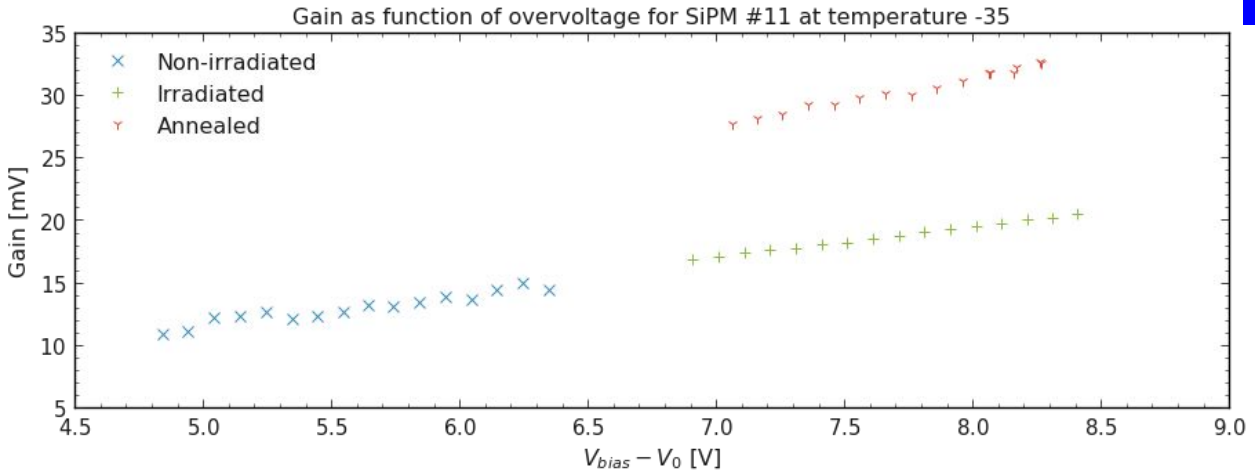


Gain as function of overvoltage



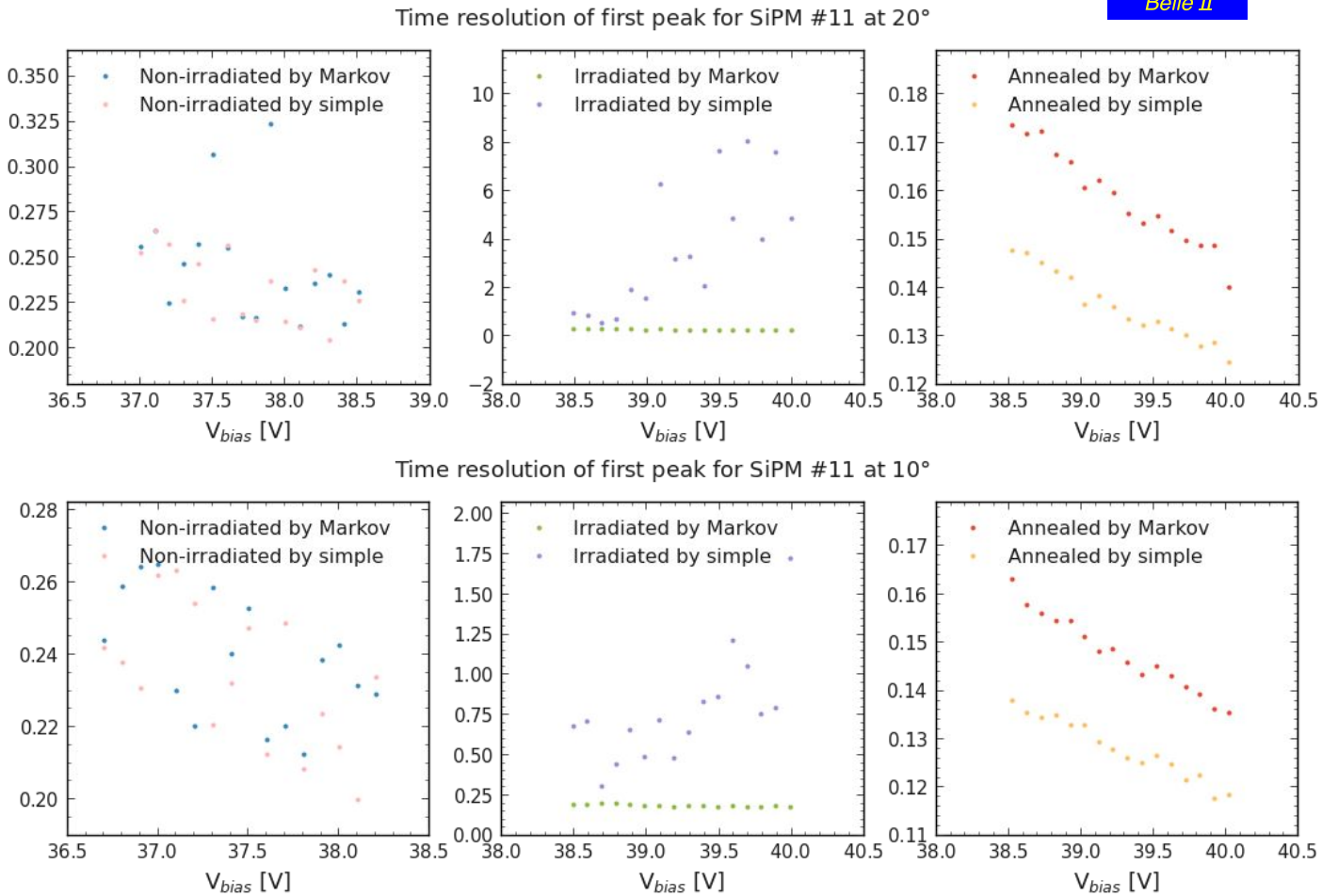


Gain as function of overvoltage



Time resolution for first photon peak for SiPM #11

Time resolution for first photon peak



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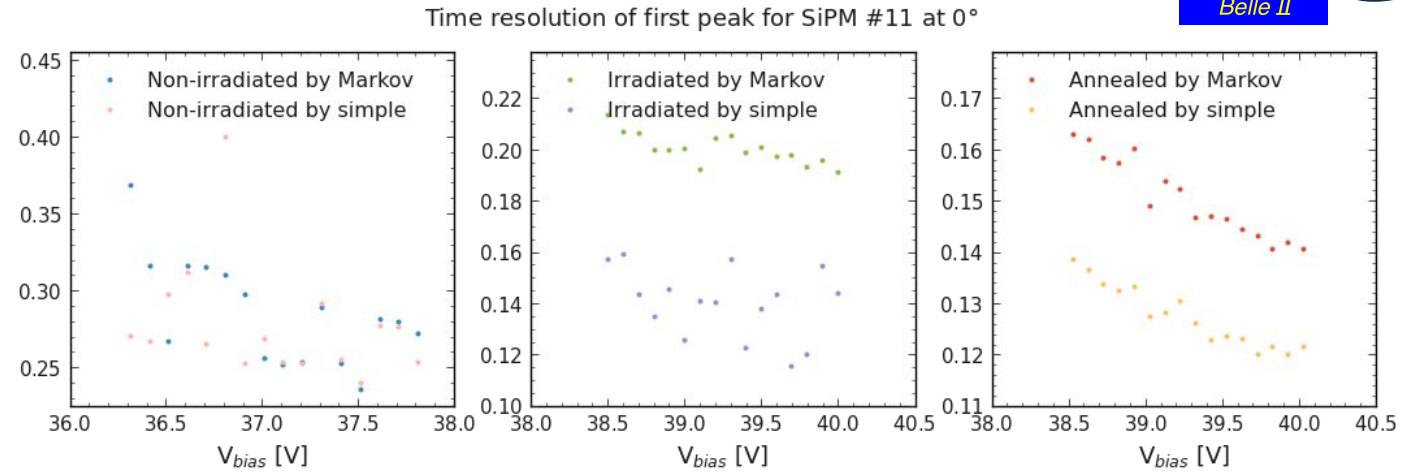

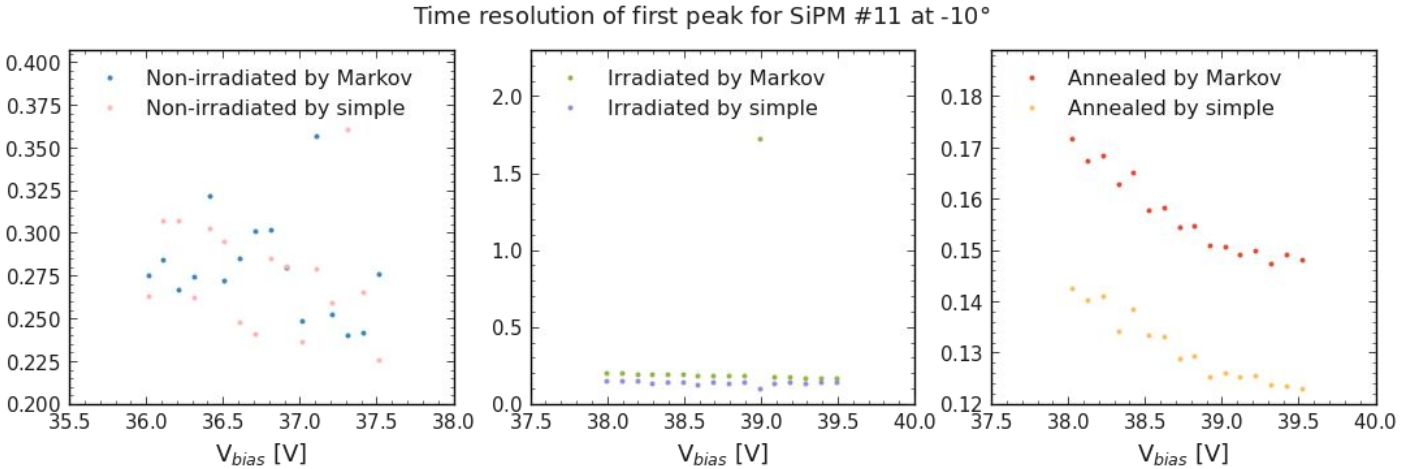

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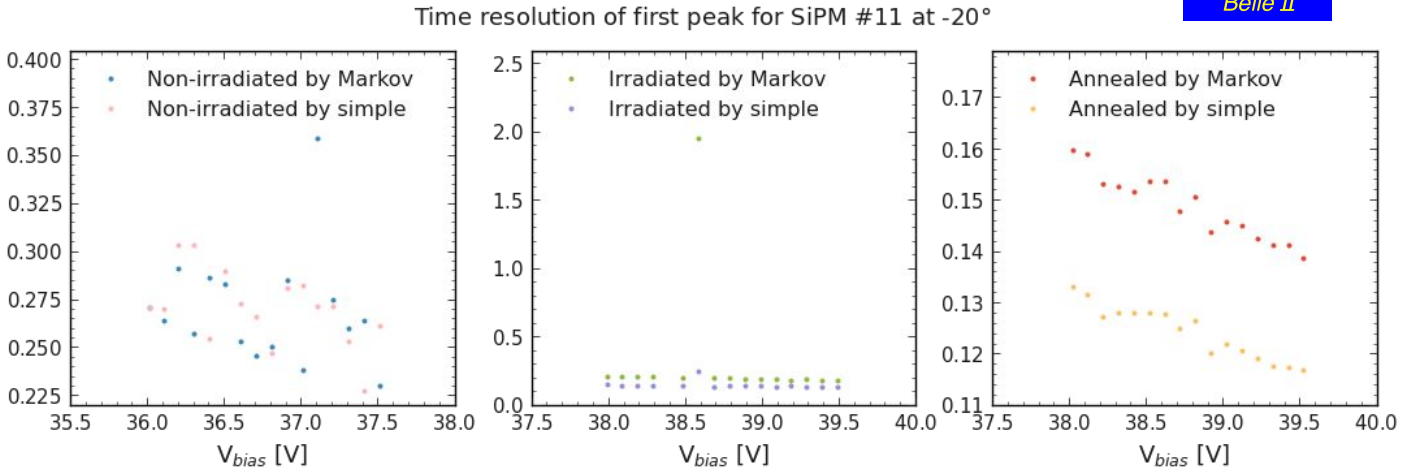
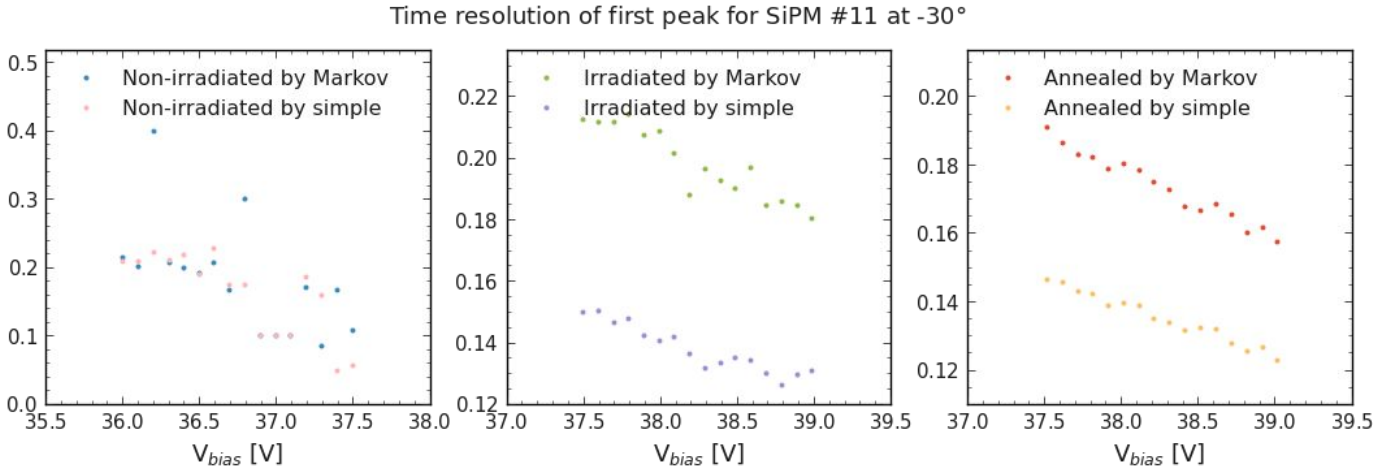
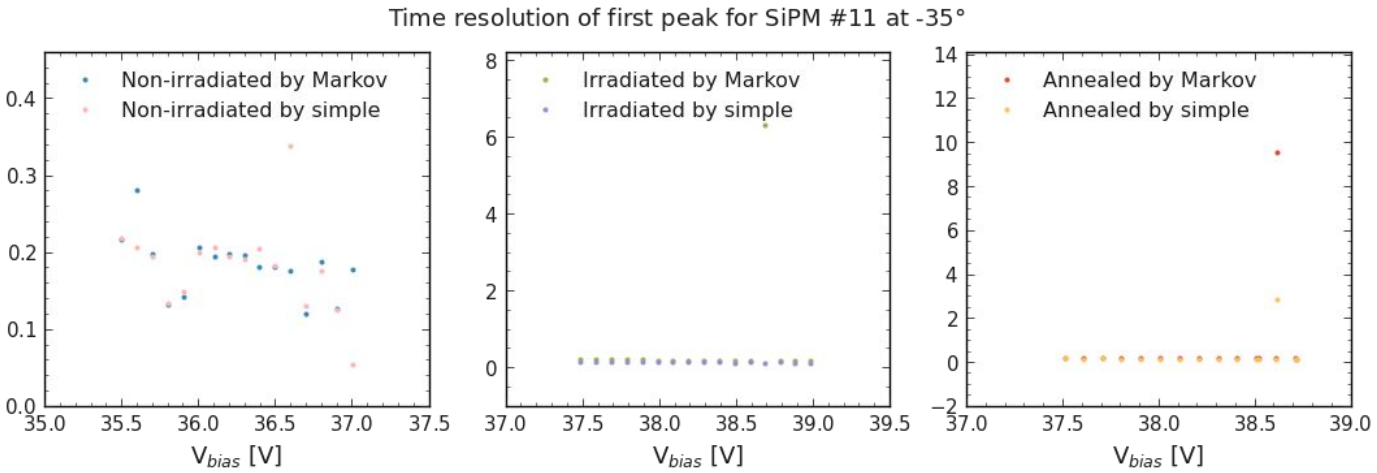
Time resolution for first photon peak



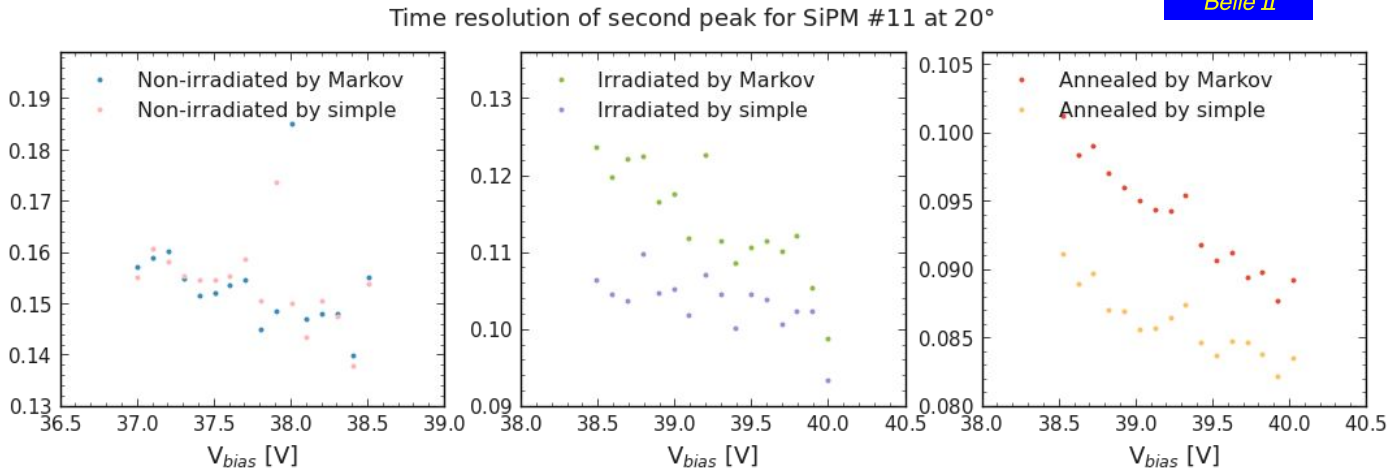


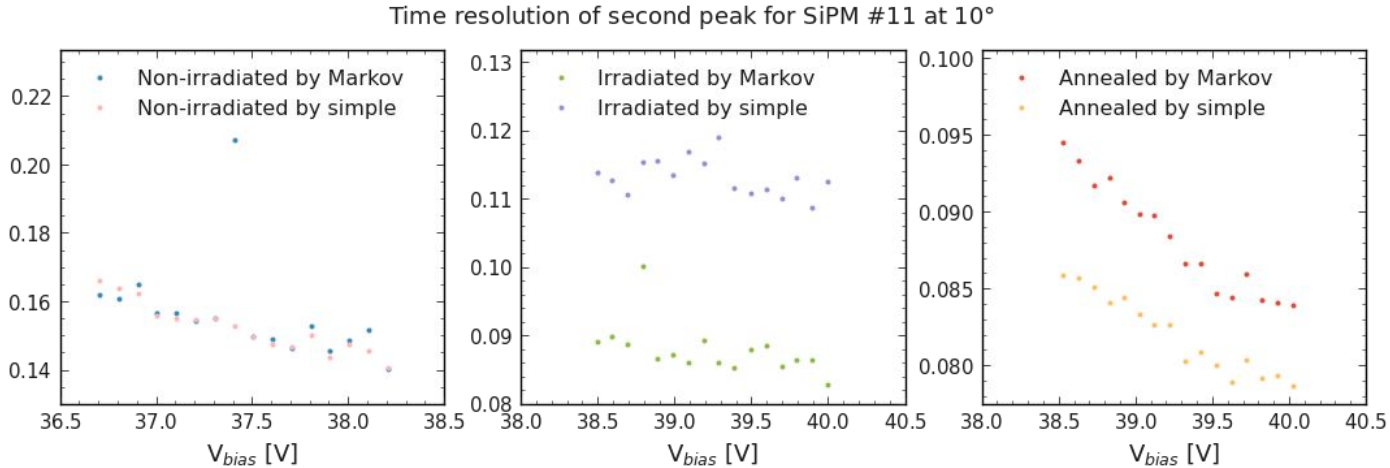
Time resolution for first photon peak



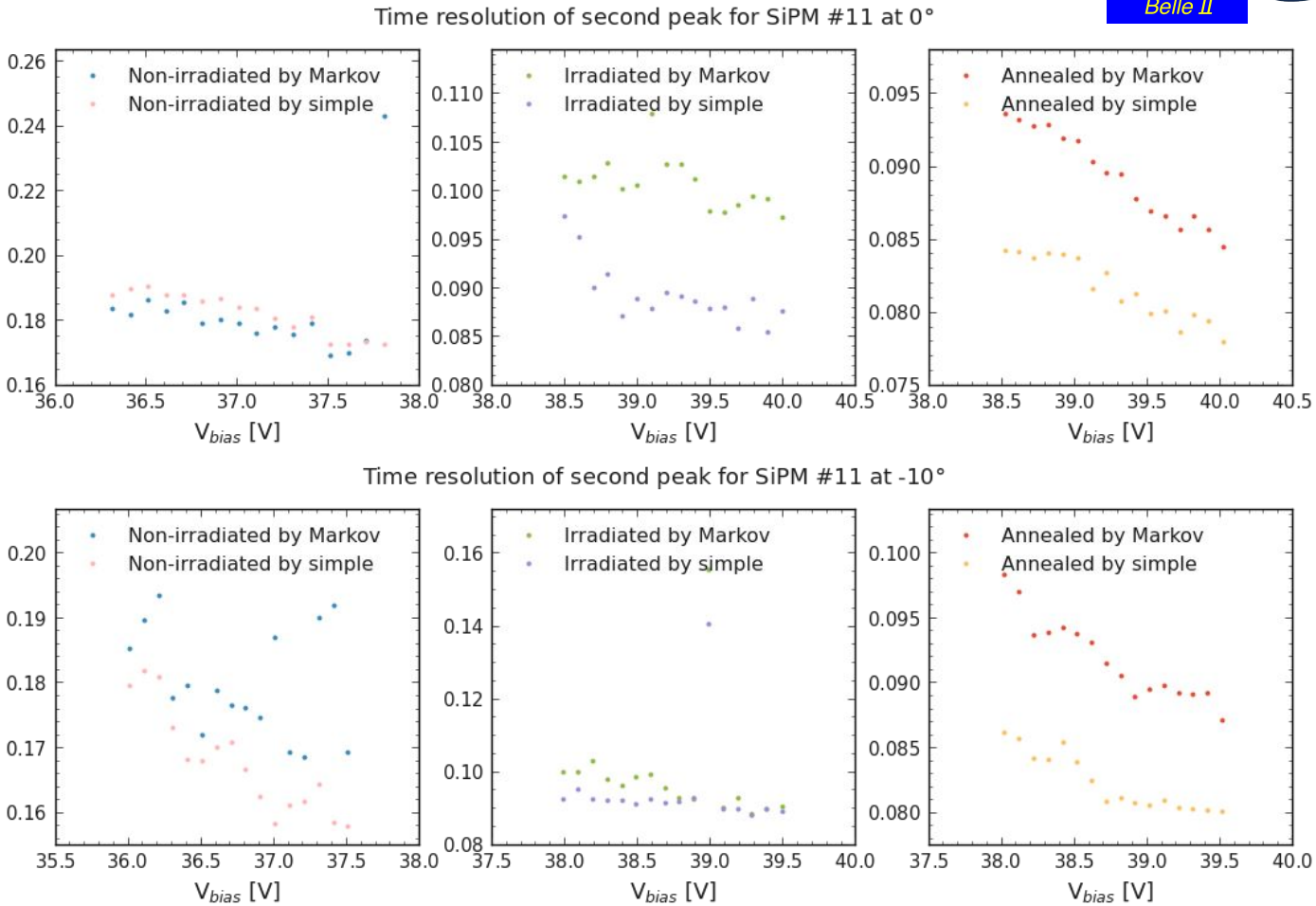
Time resolution for second photon peak for SiPM #11

Time resolution for second photon peak

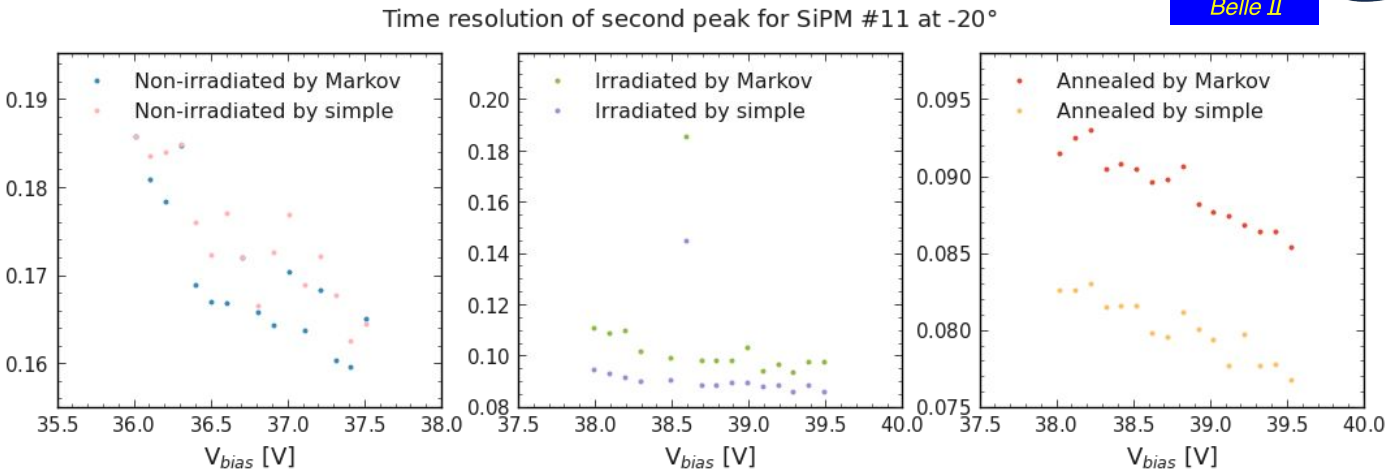


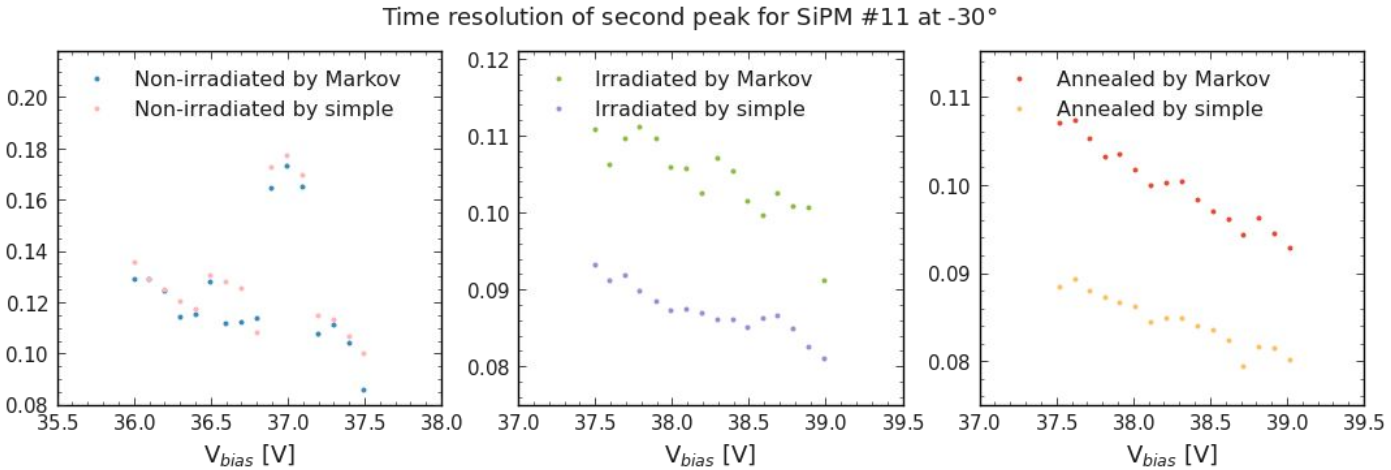


Time resolution for second photon peak

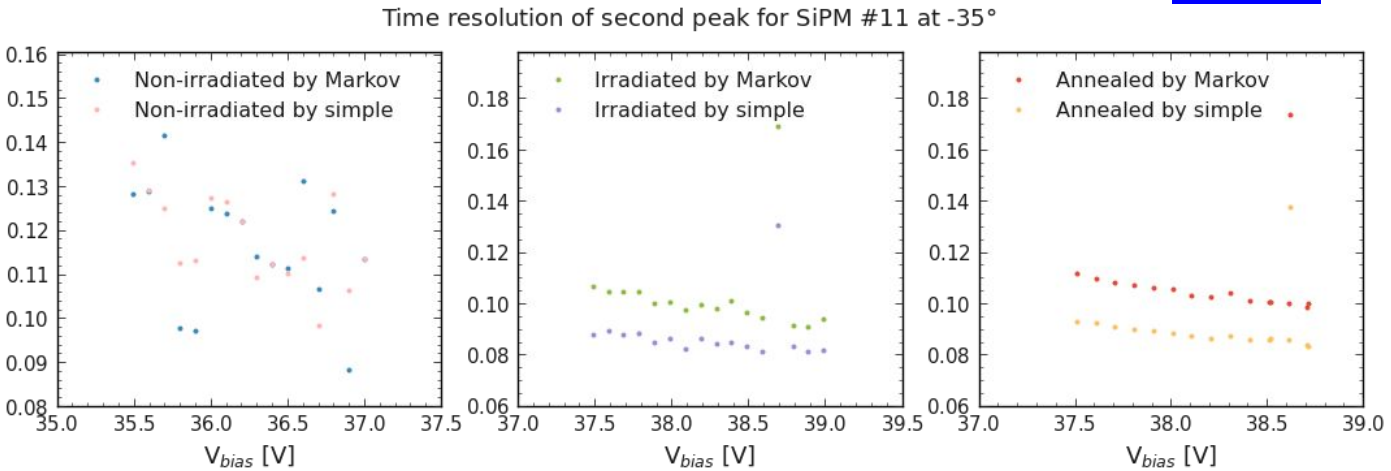


Time resolution for second photon peak



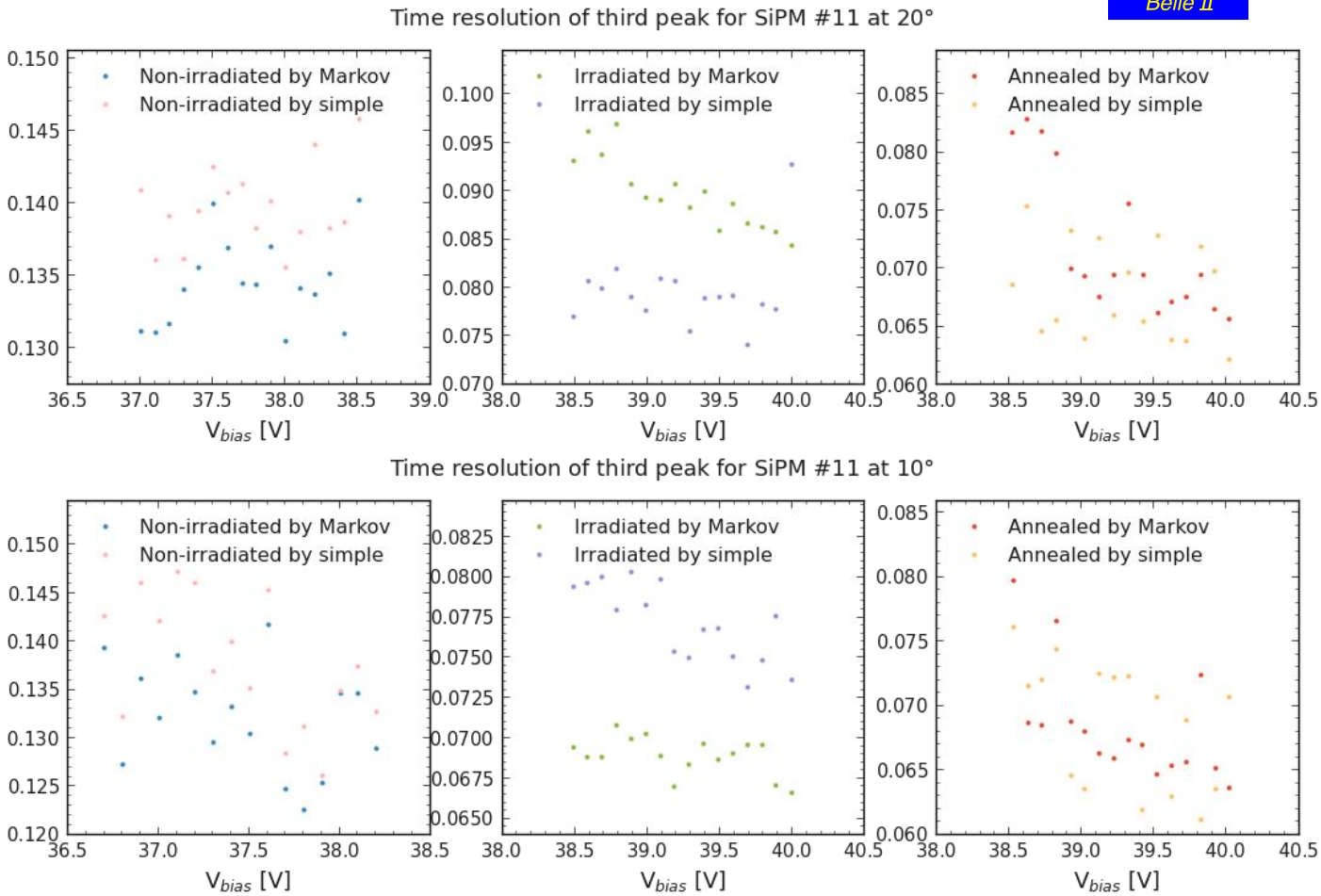


Time resolution for second photon peak

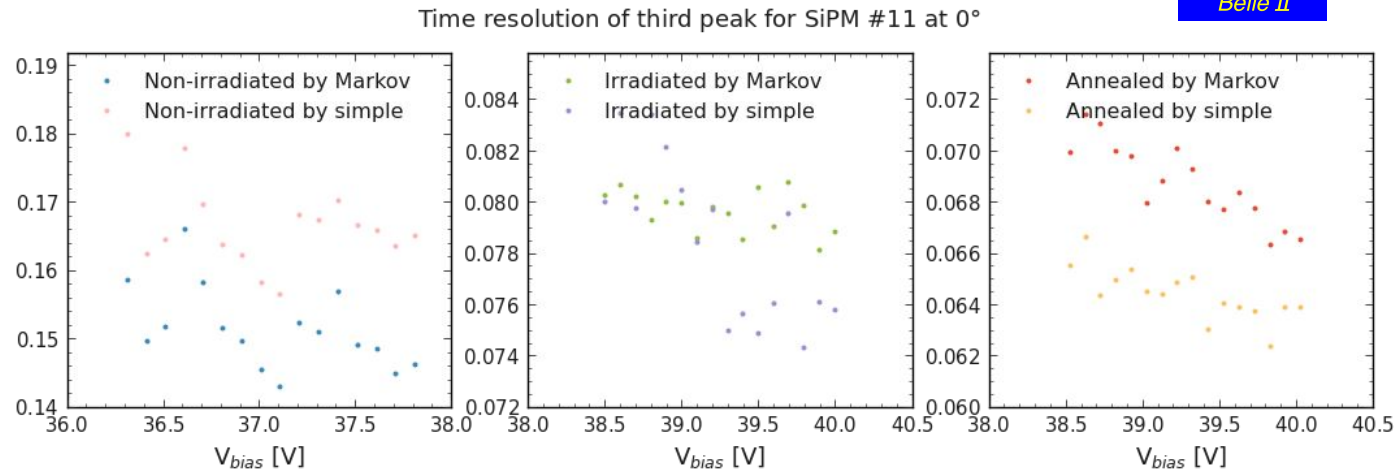


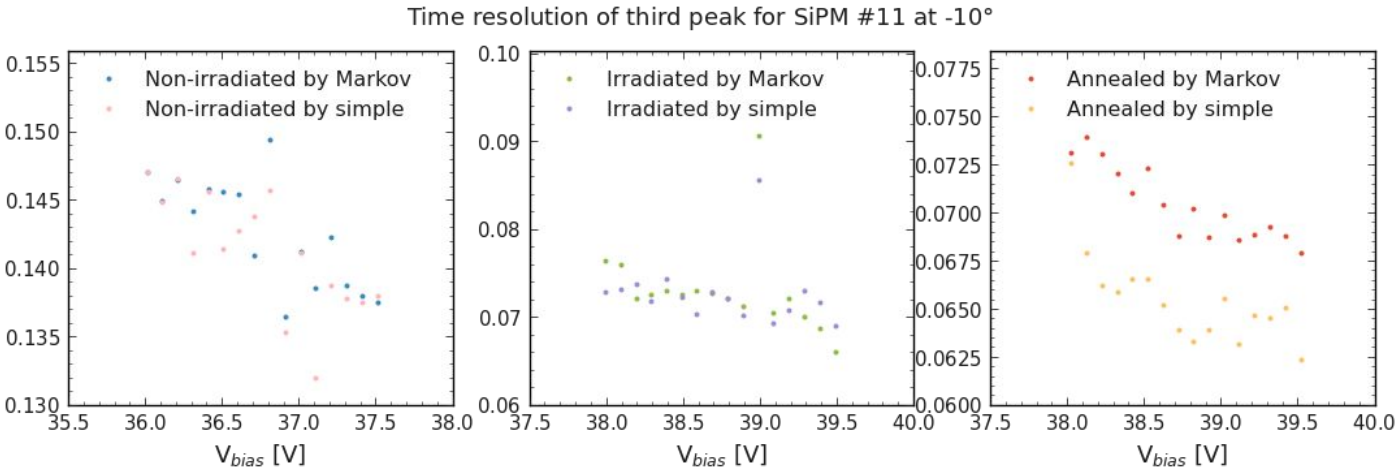
Time resolution for third photon peak for SiPM #11

Time resolution for third photon peak

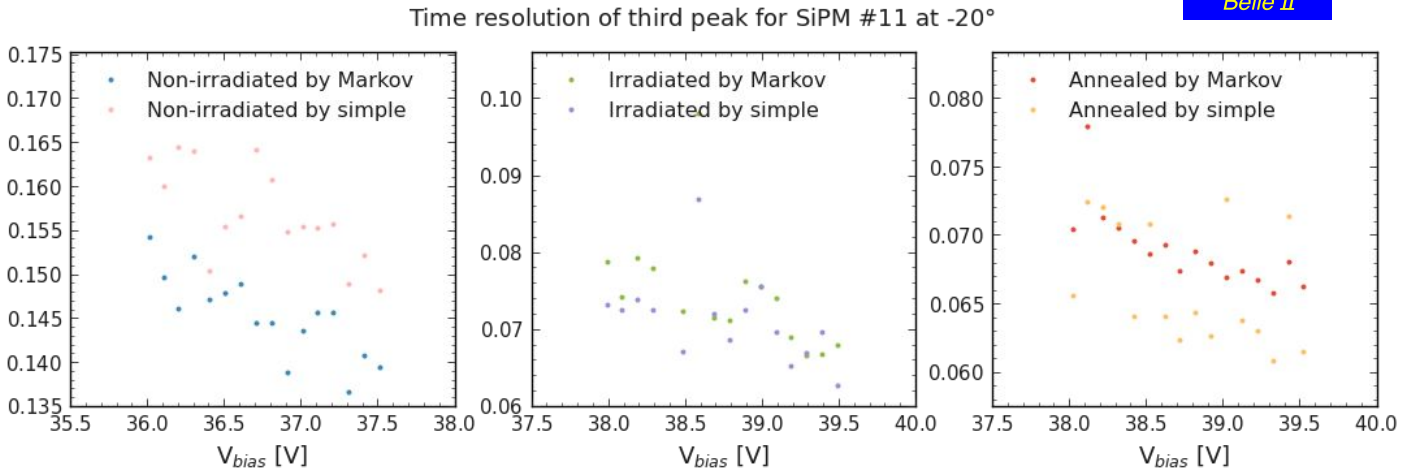


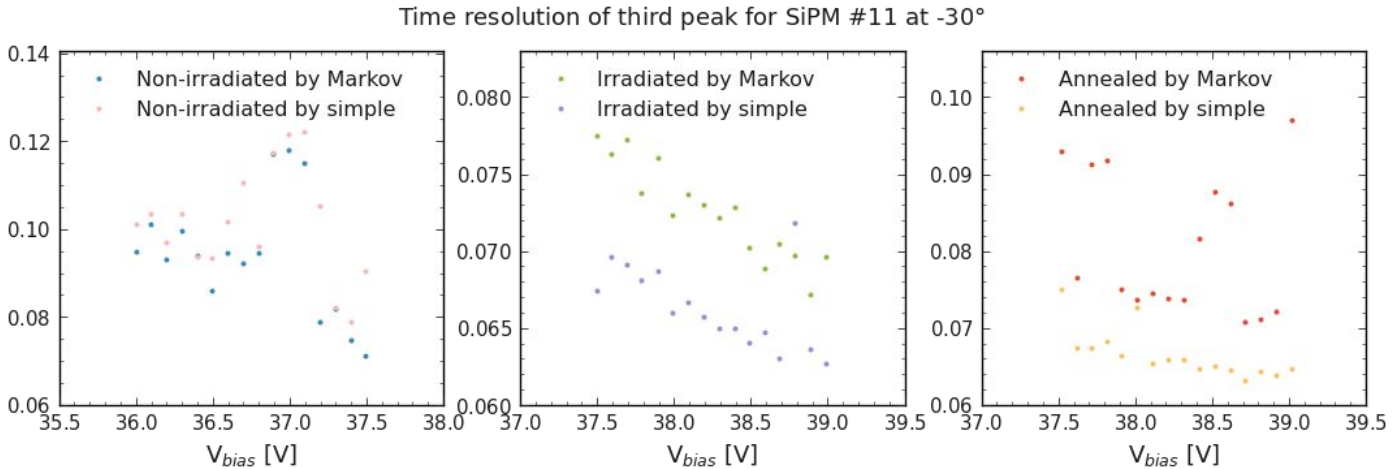
Time resolution for third photon peak



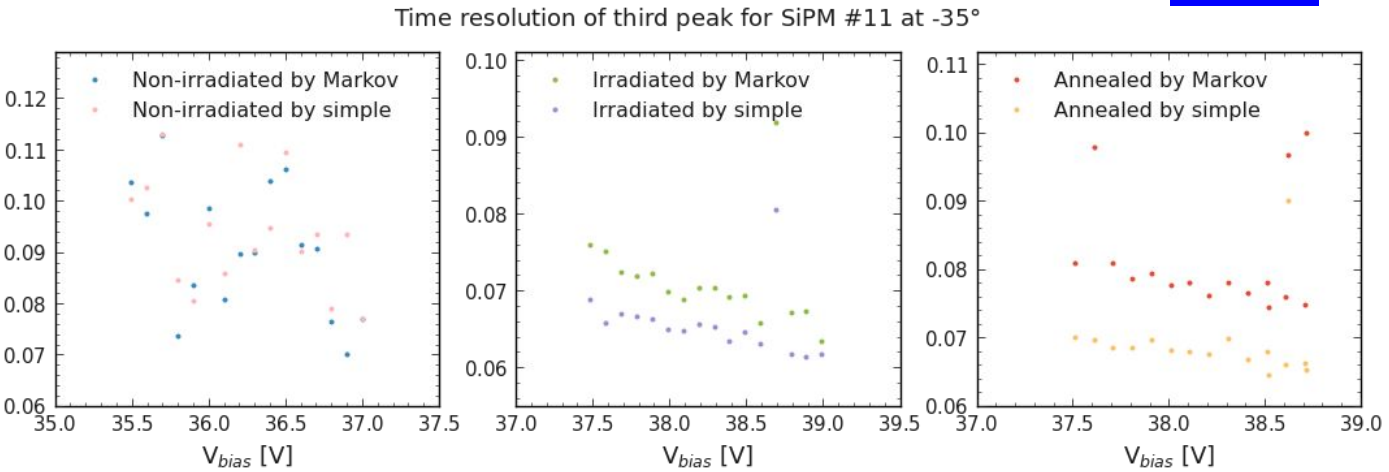


Time resolution for third photon peak



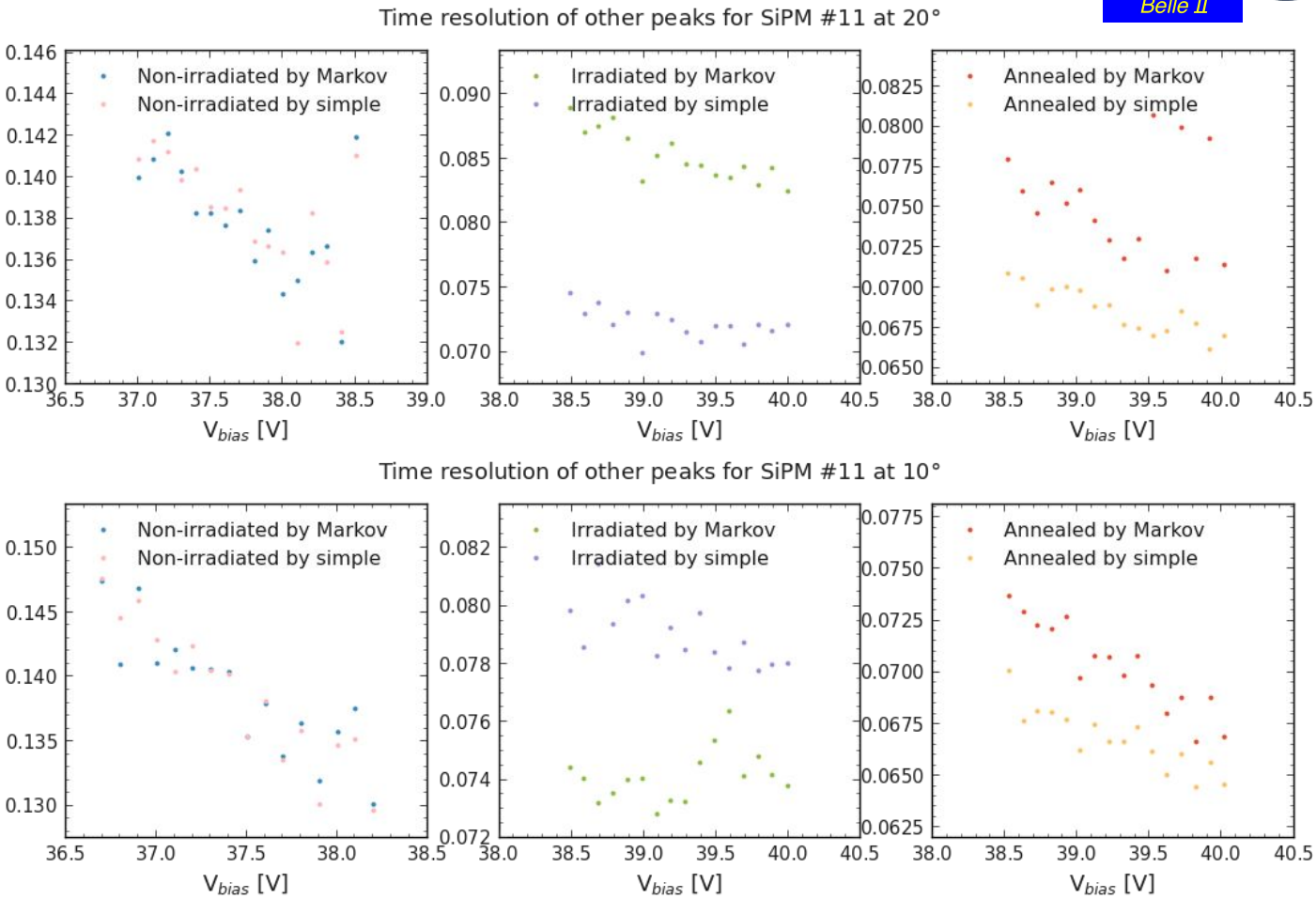


Time resolution for third photon peak

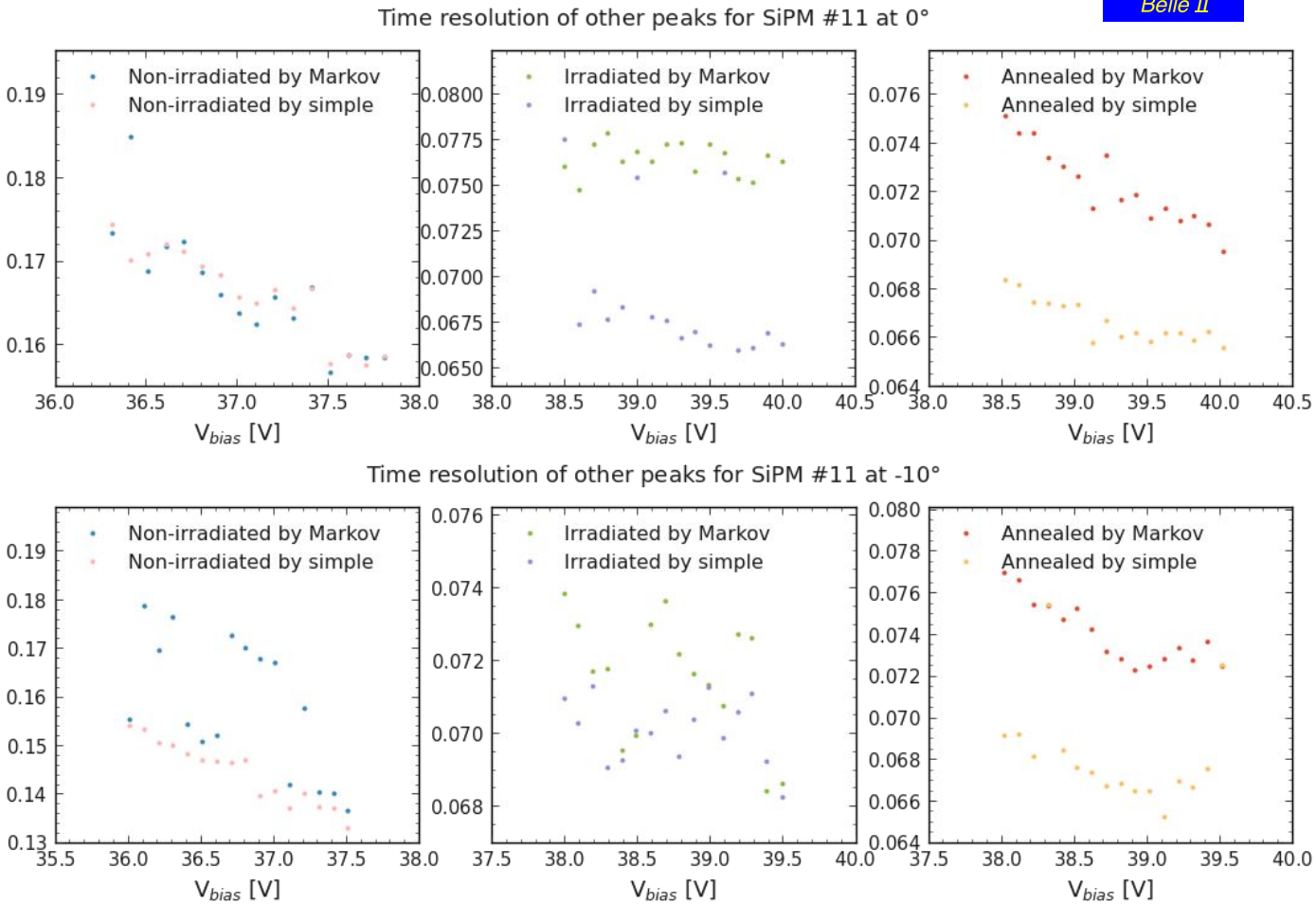


Time resolution for other photon peaks for SiPM #11

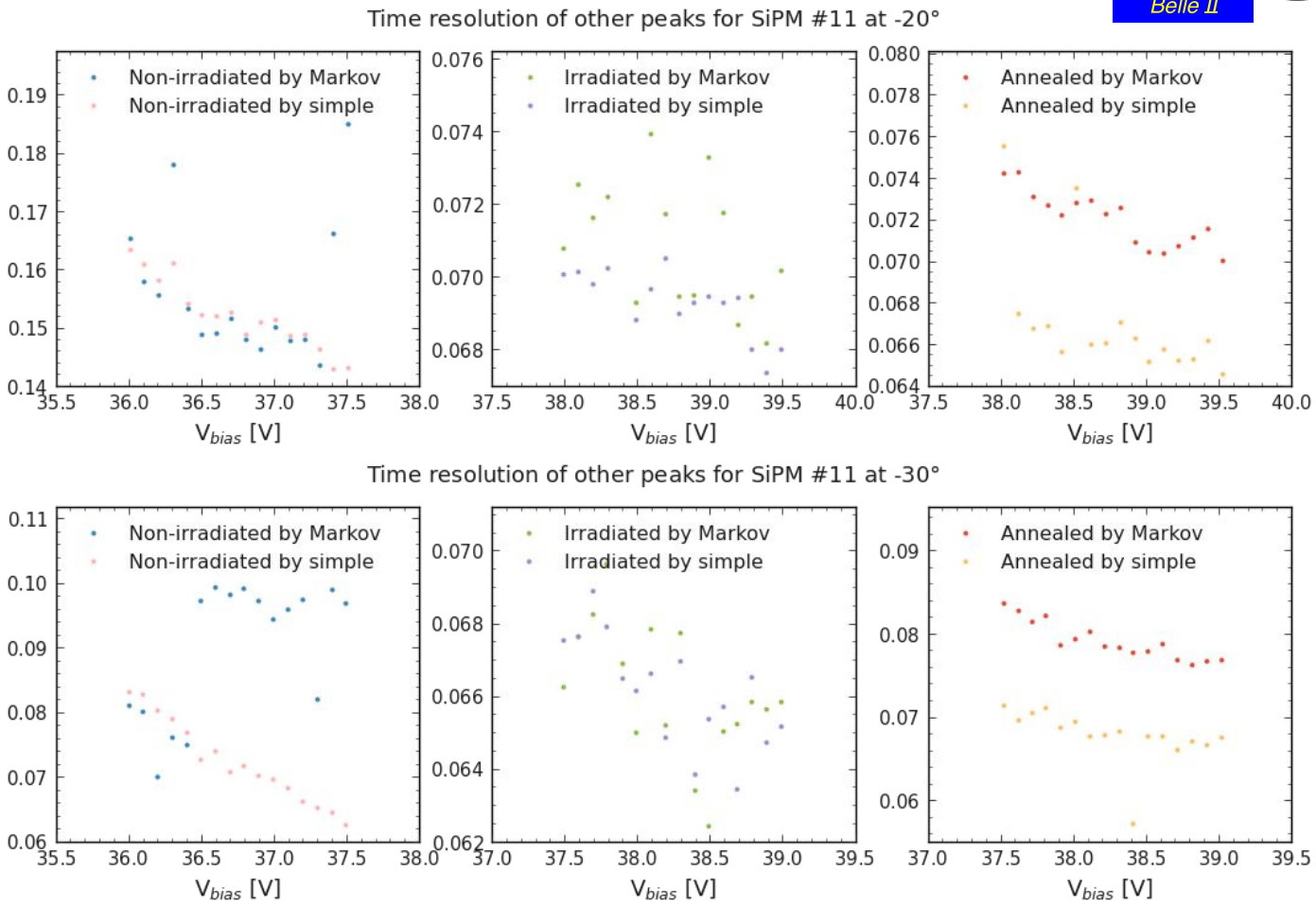
Time resolution for other photon peaks



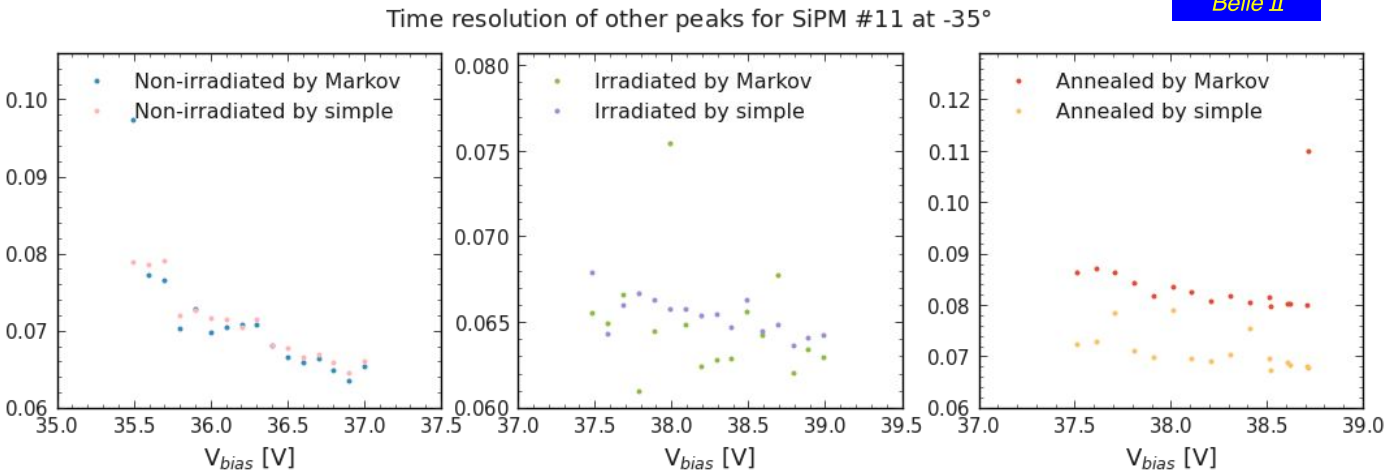
Time resolution for other photon peaks



Time resolution for other photon peaks

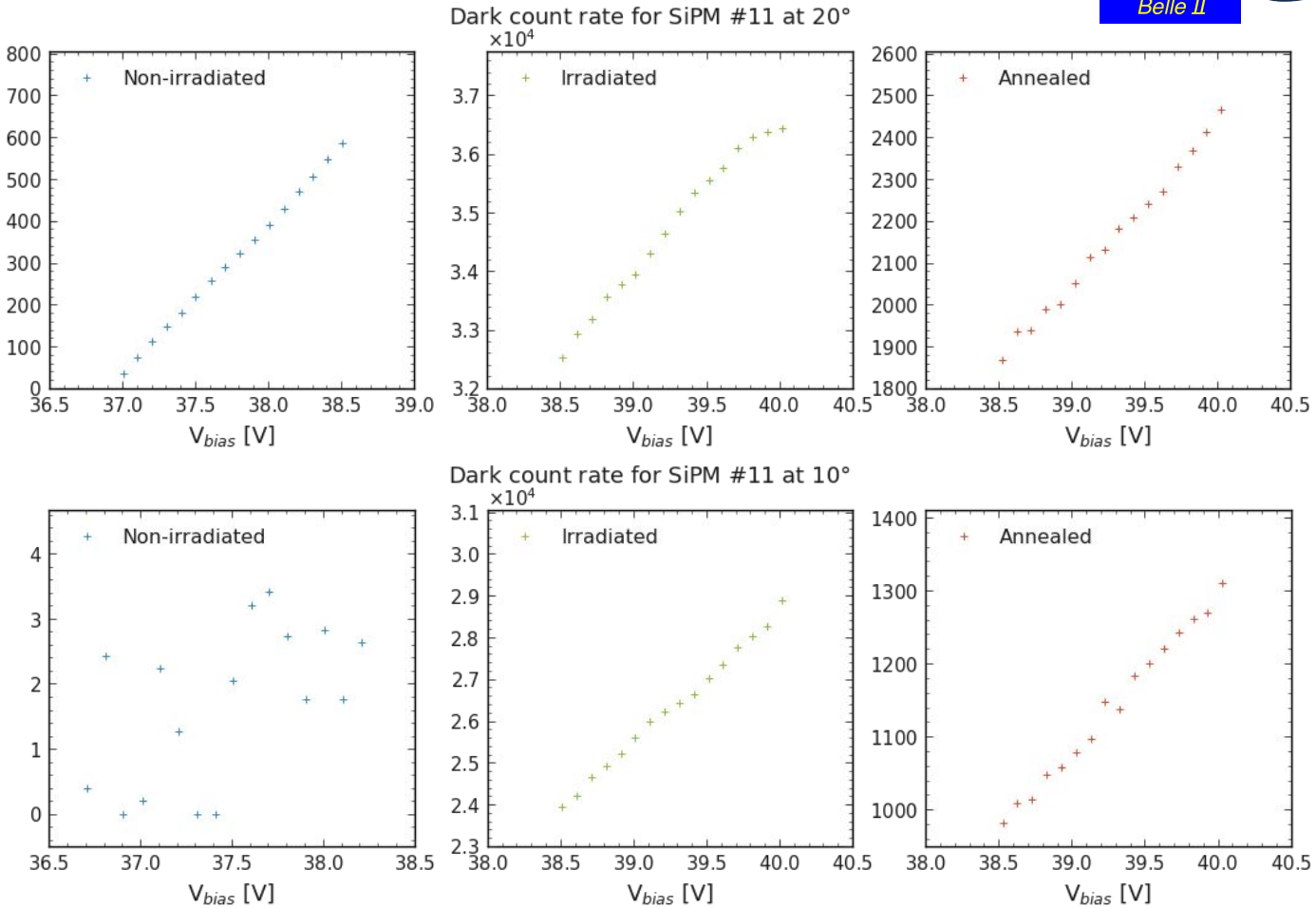


Time resolution for other photon peaks

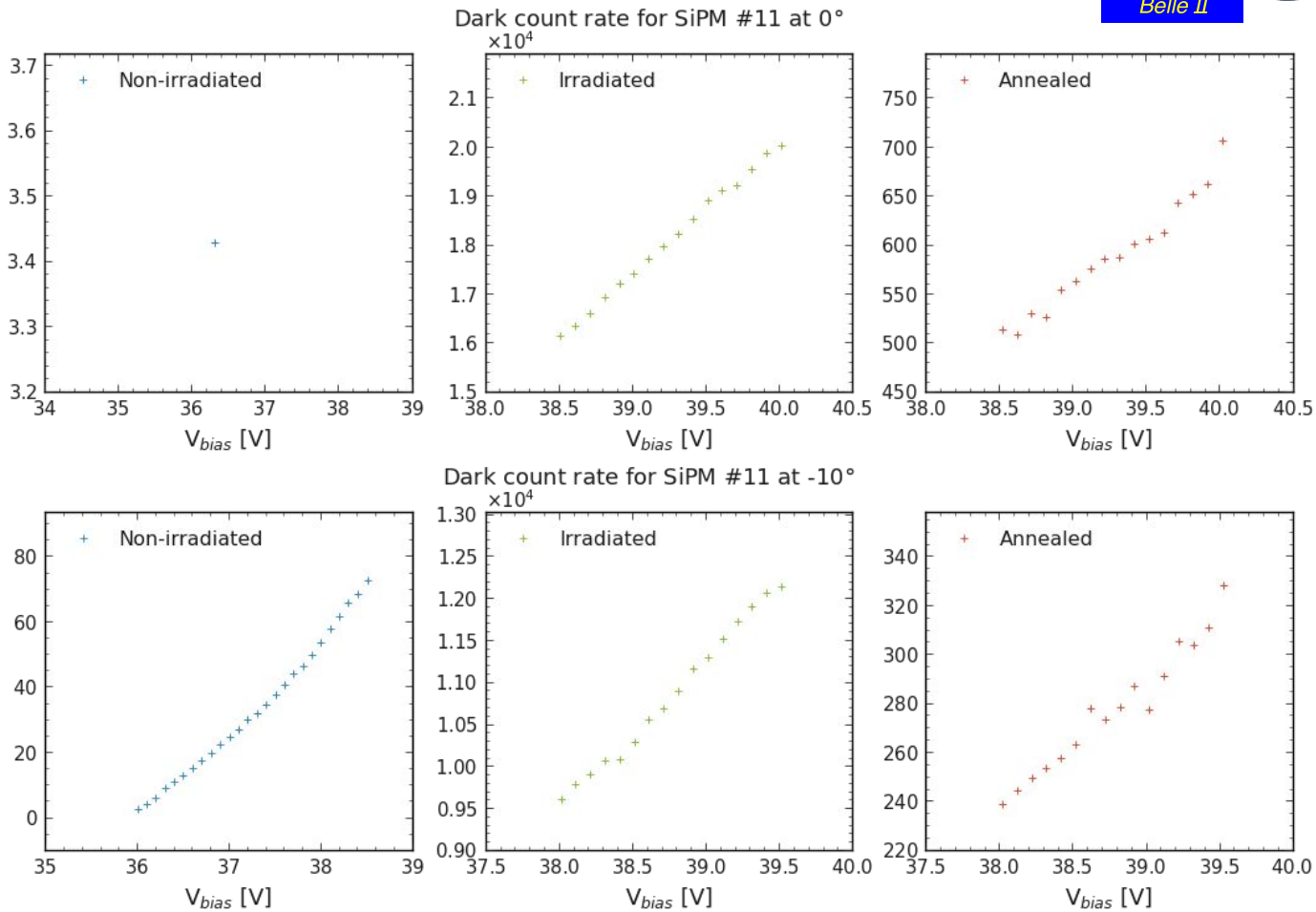


Dark count rate for SiPM #11

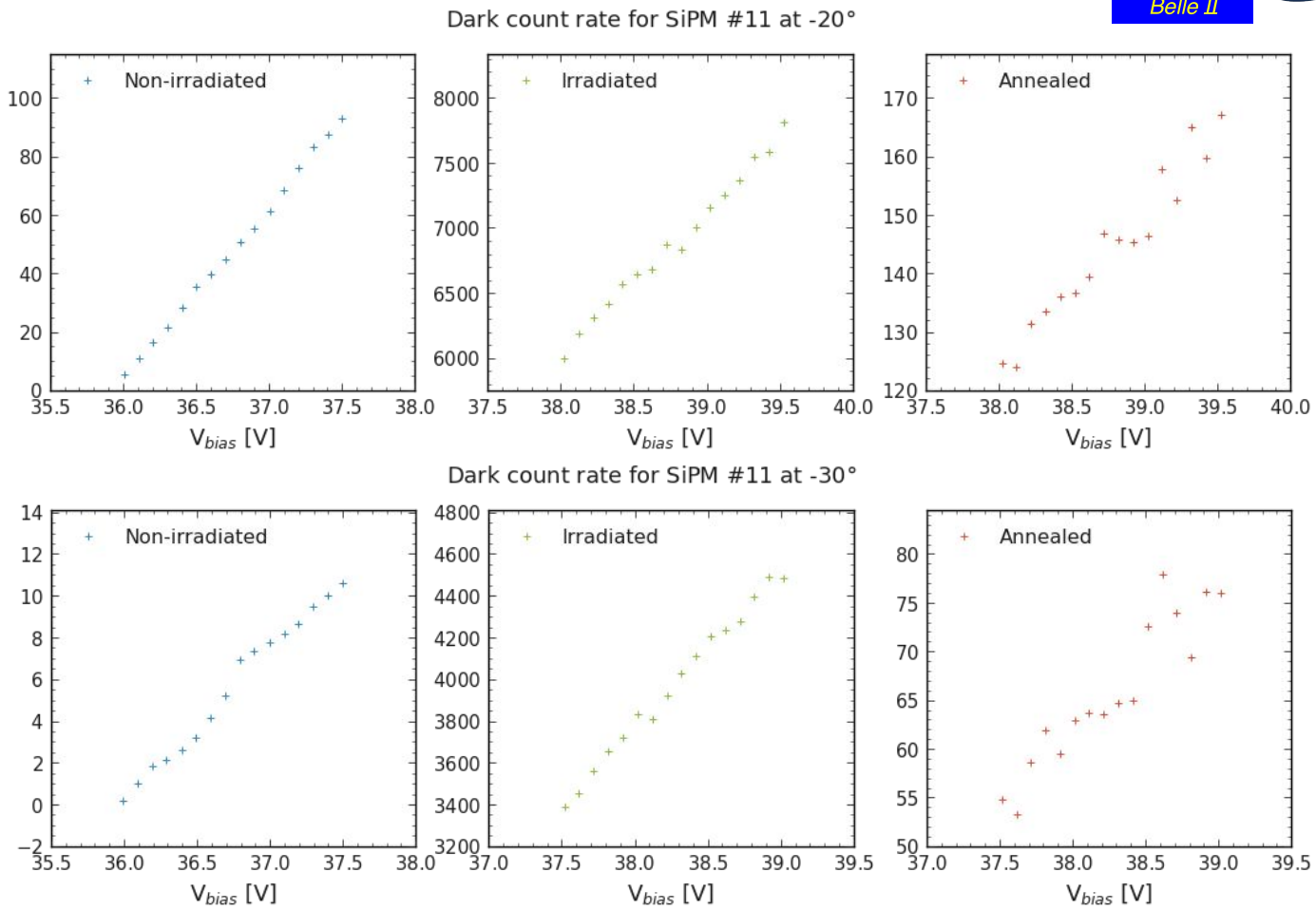
Dark count rate



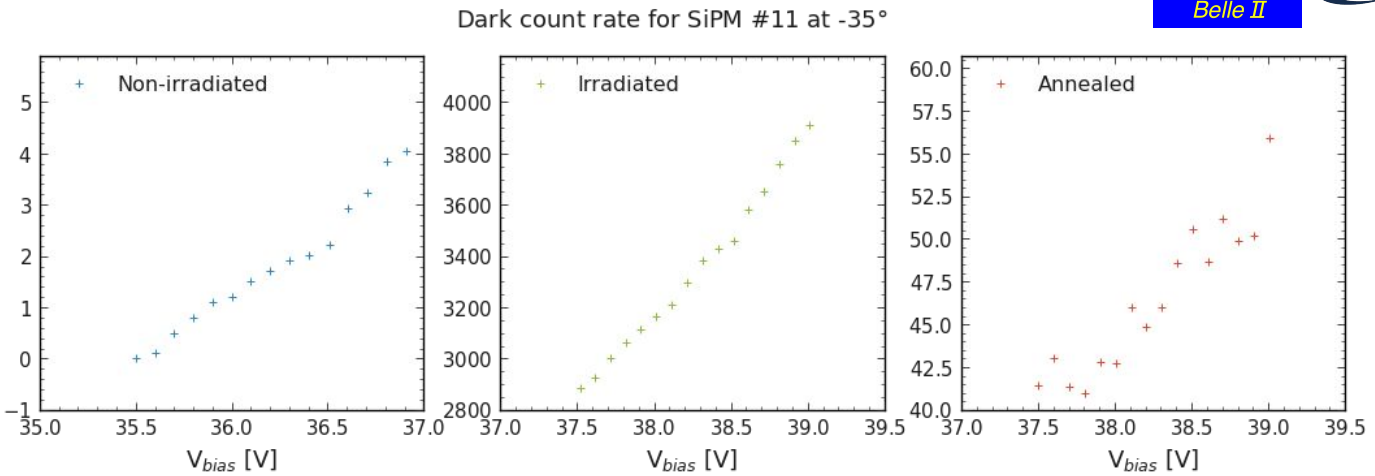
Dark count rate



Dark count rate



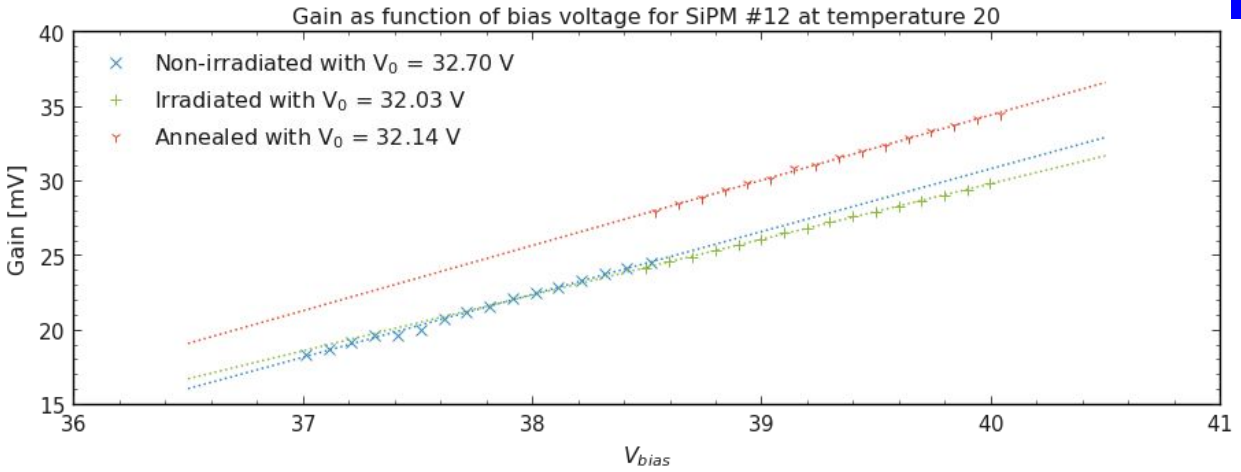
Dark count rate

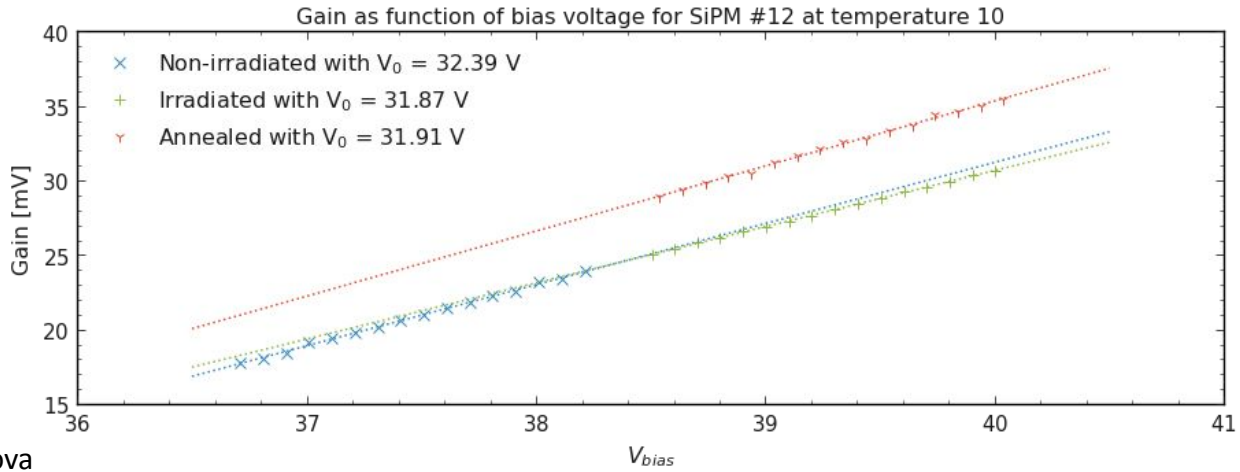


SiMP #12

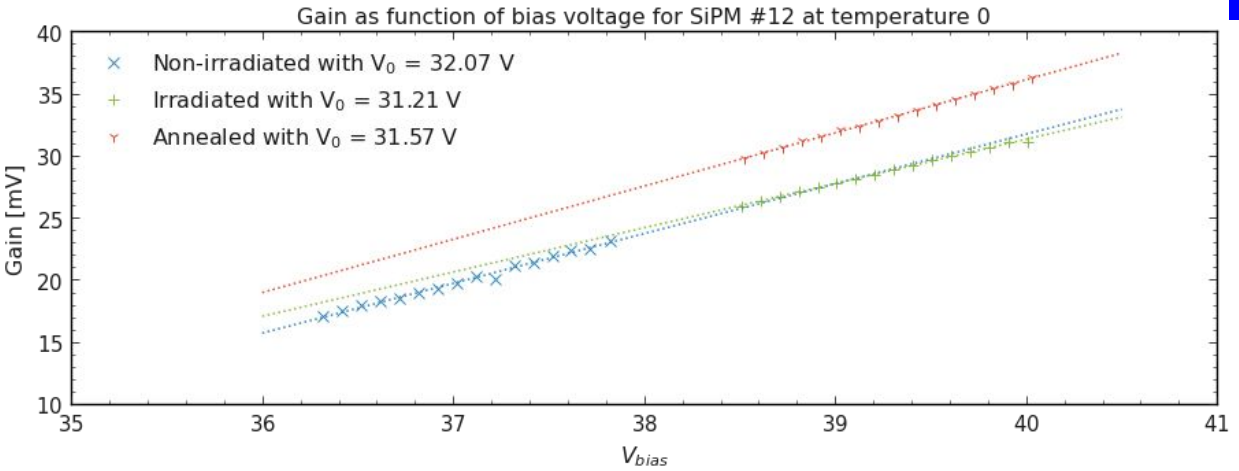
Gain as function of bias voltage for SiPM #12

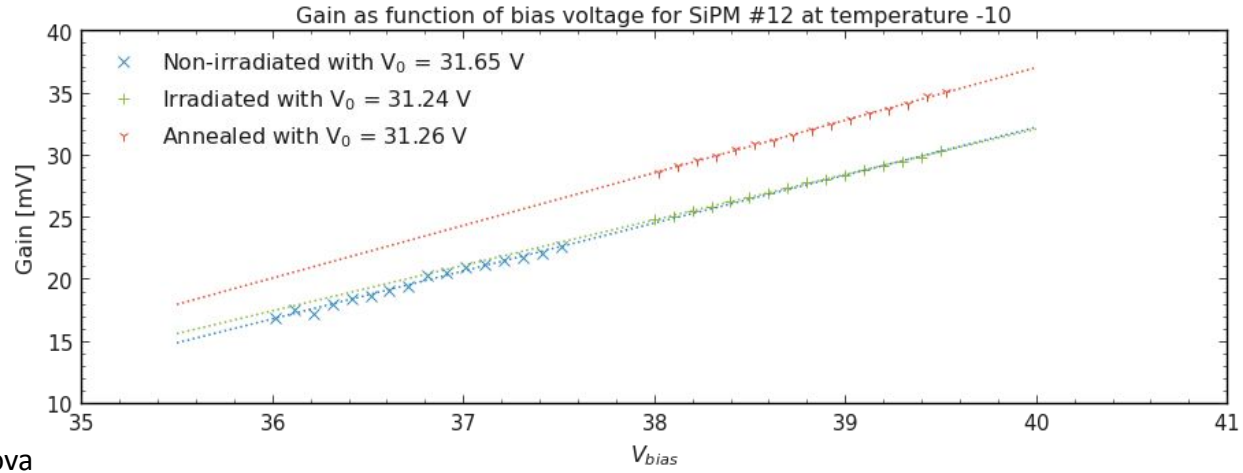
Gain as function of bias voltage



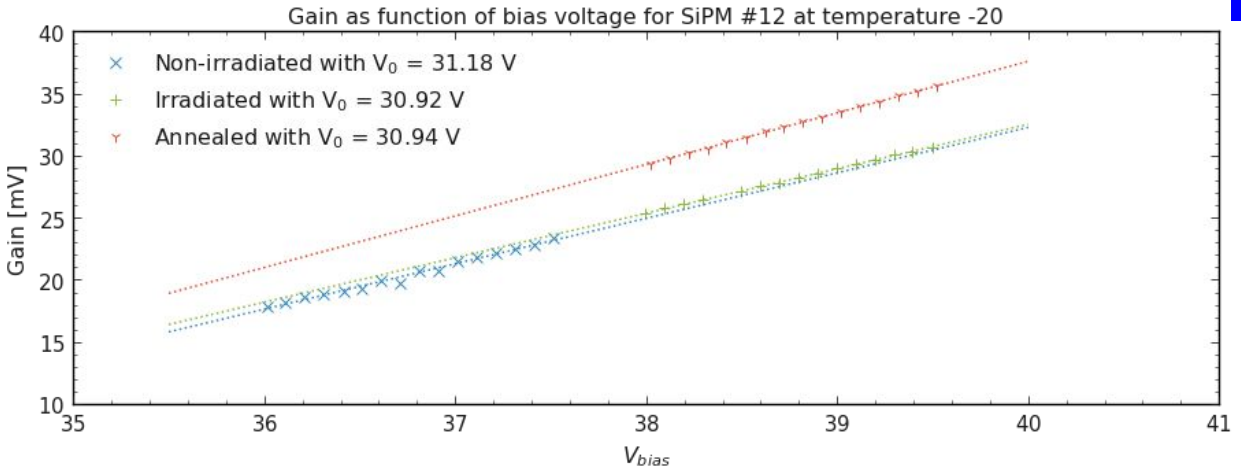


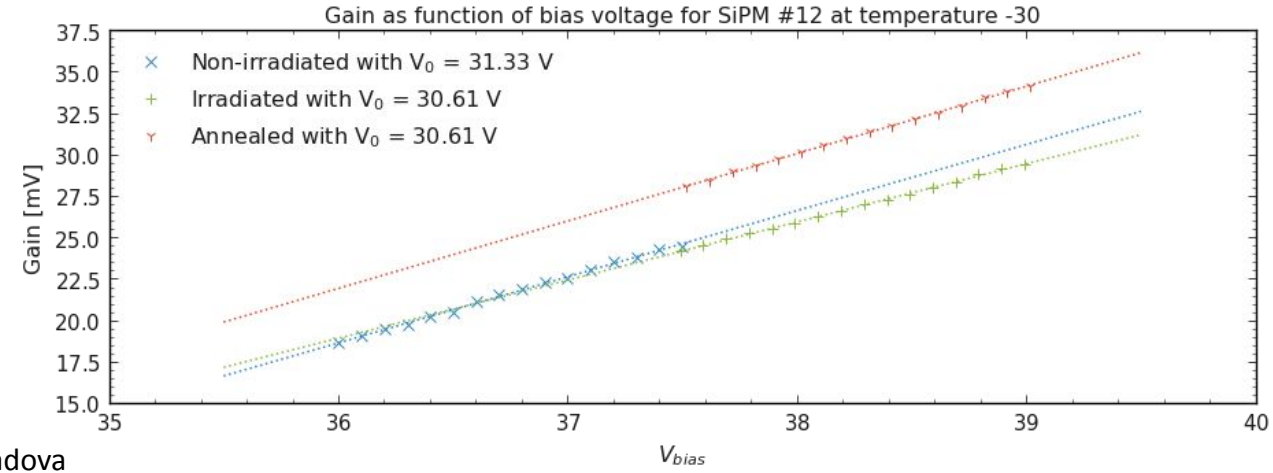
Gain as function of bias voltage



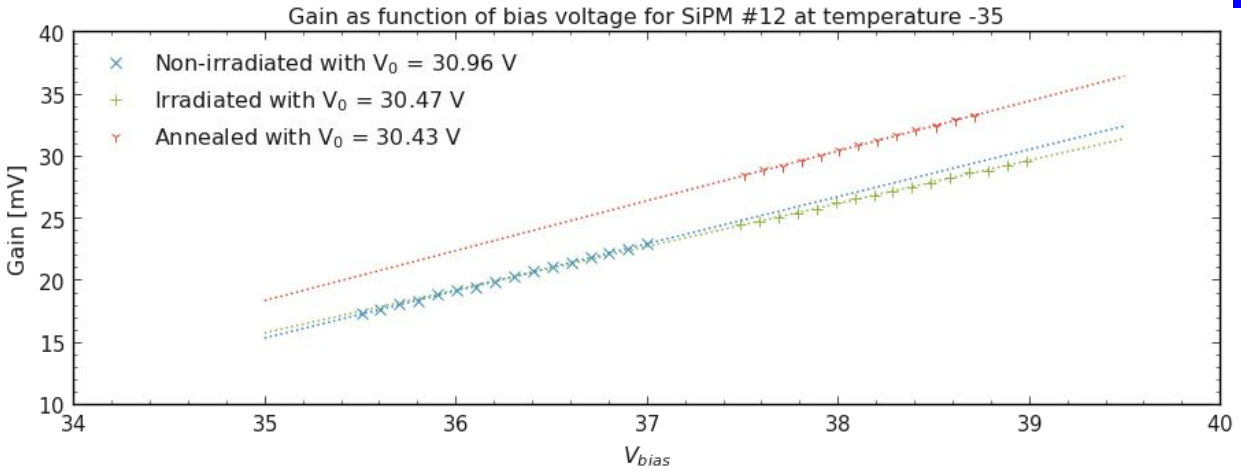


Gain as function of bias voltage



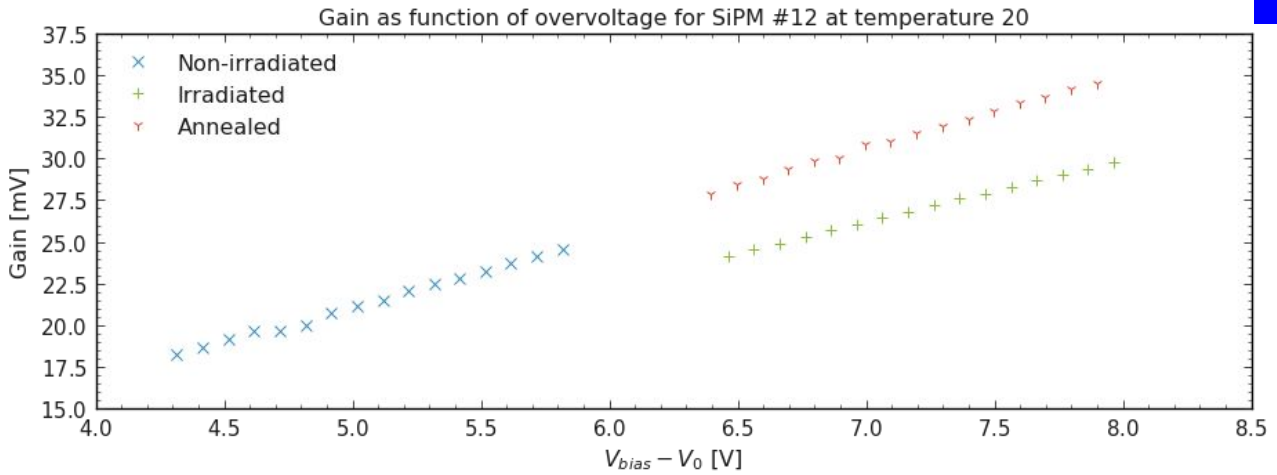


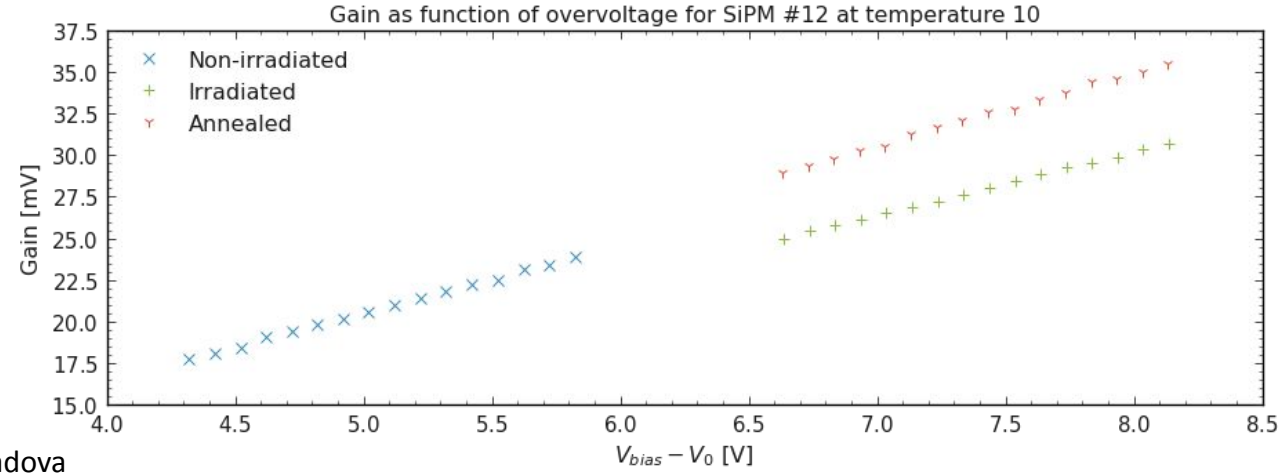
Gain as function of bias voltage



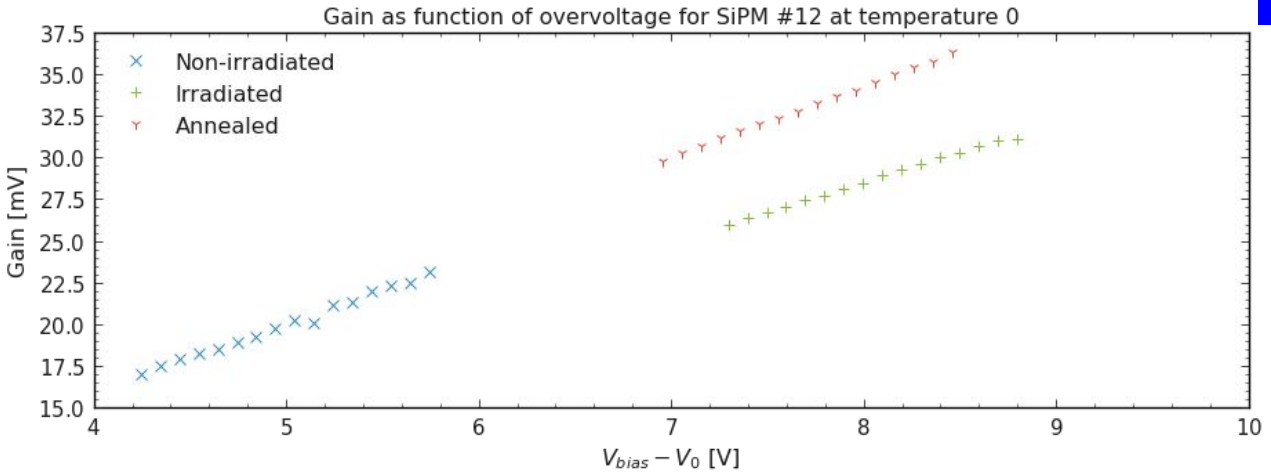
Gain as function of overvoltage for SiPM #12

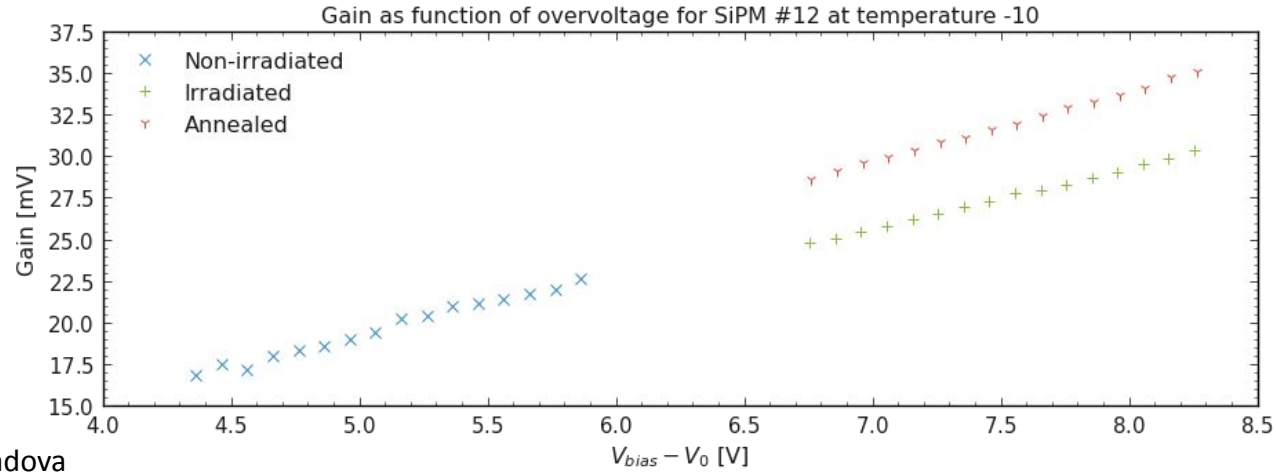
Gain as function of overvoltage



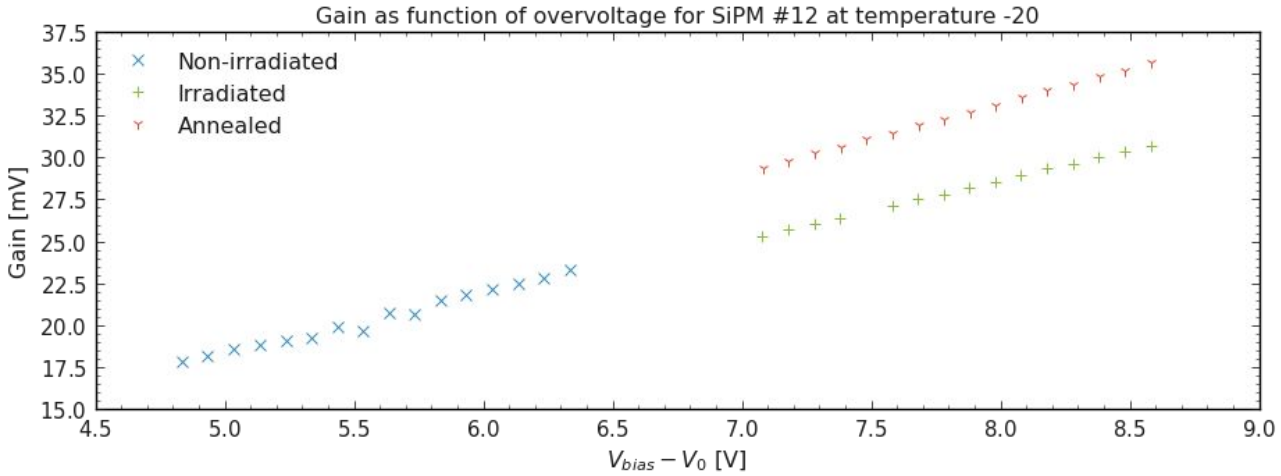


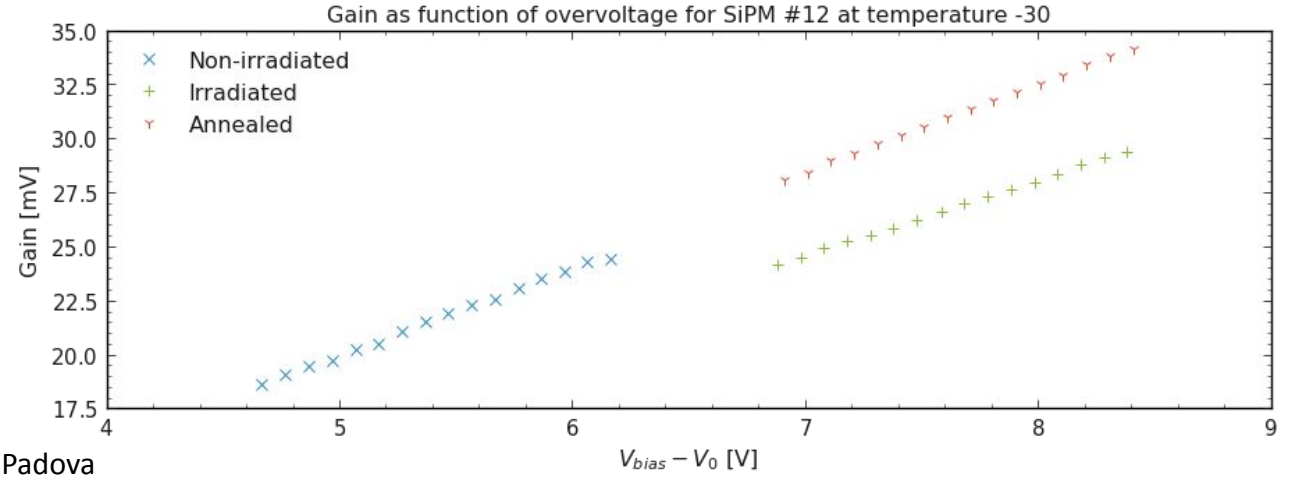
Gain as function of overvoltage



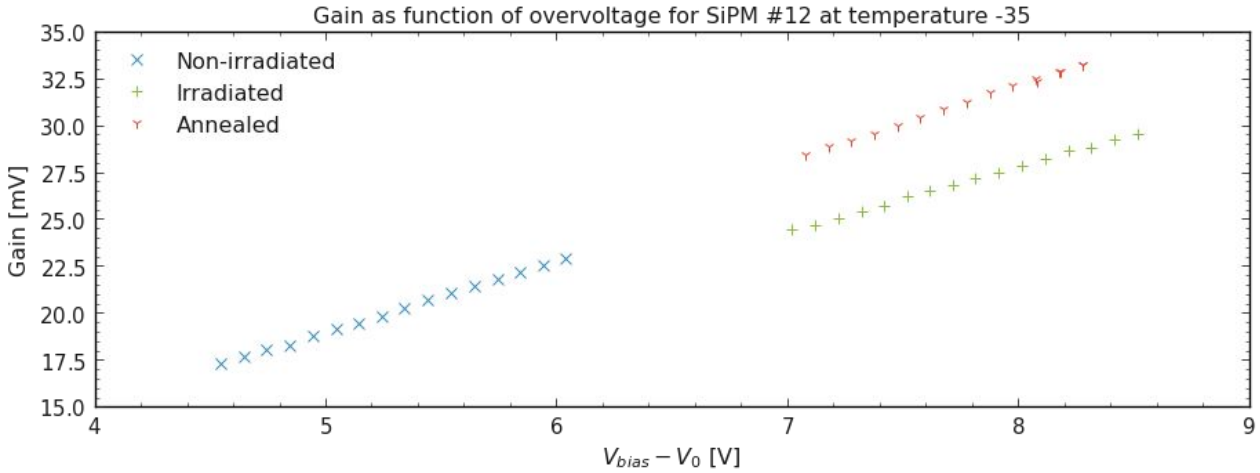


Gain as function of overvoltage



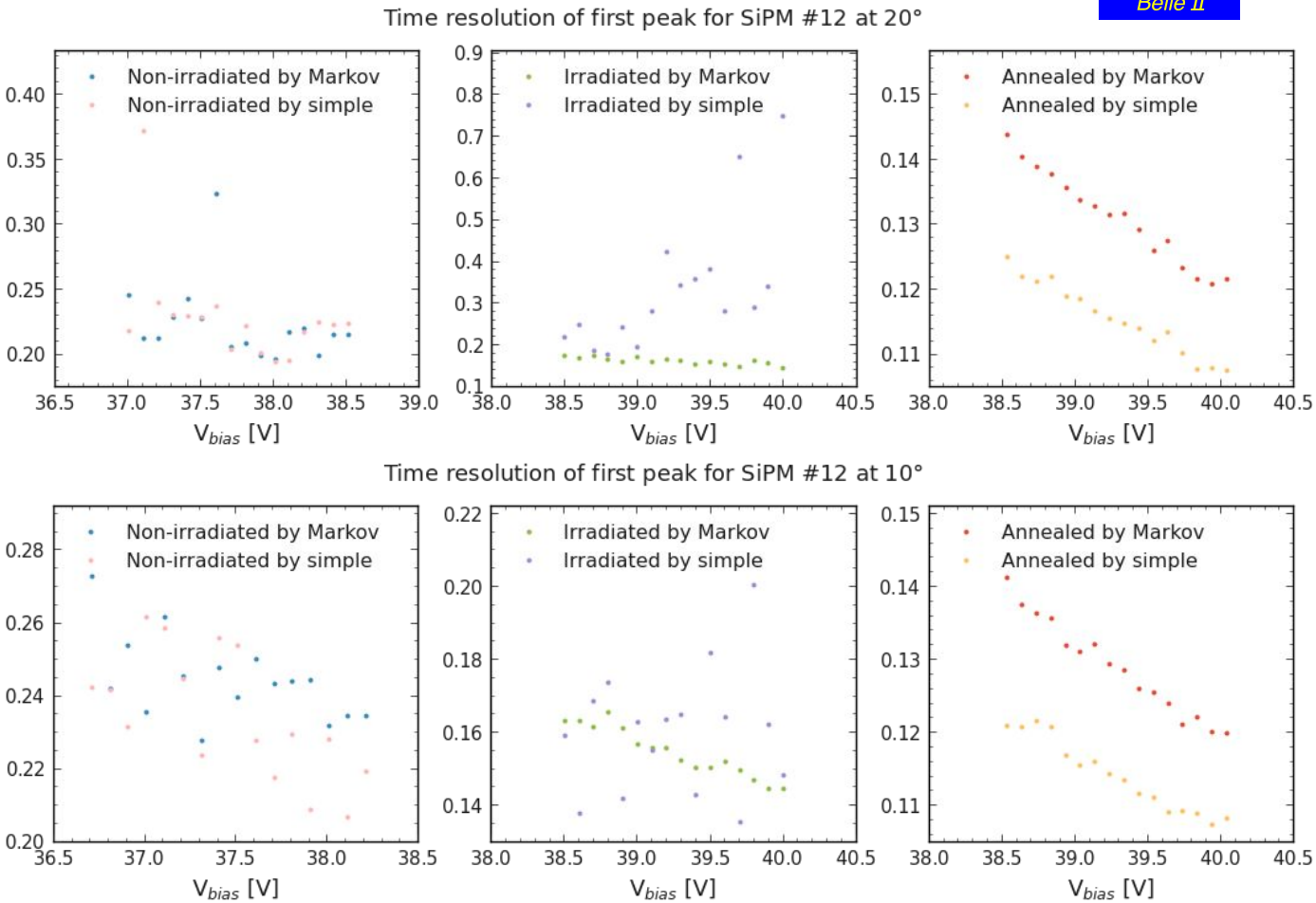


Gain as function of overvoltage

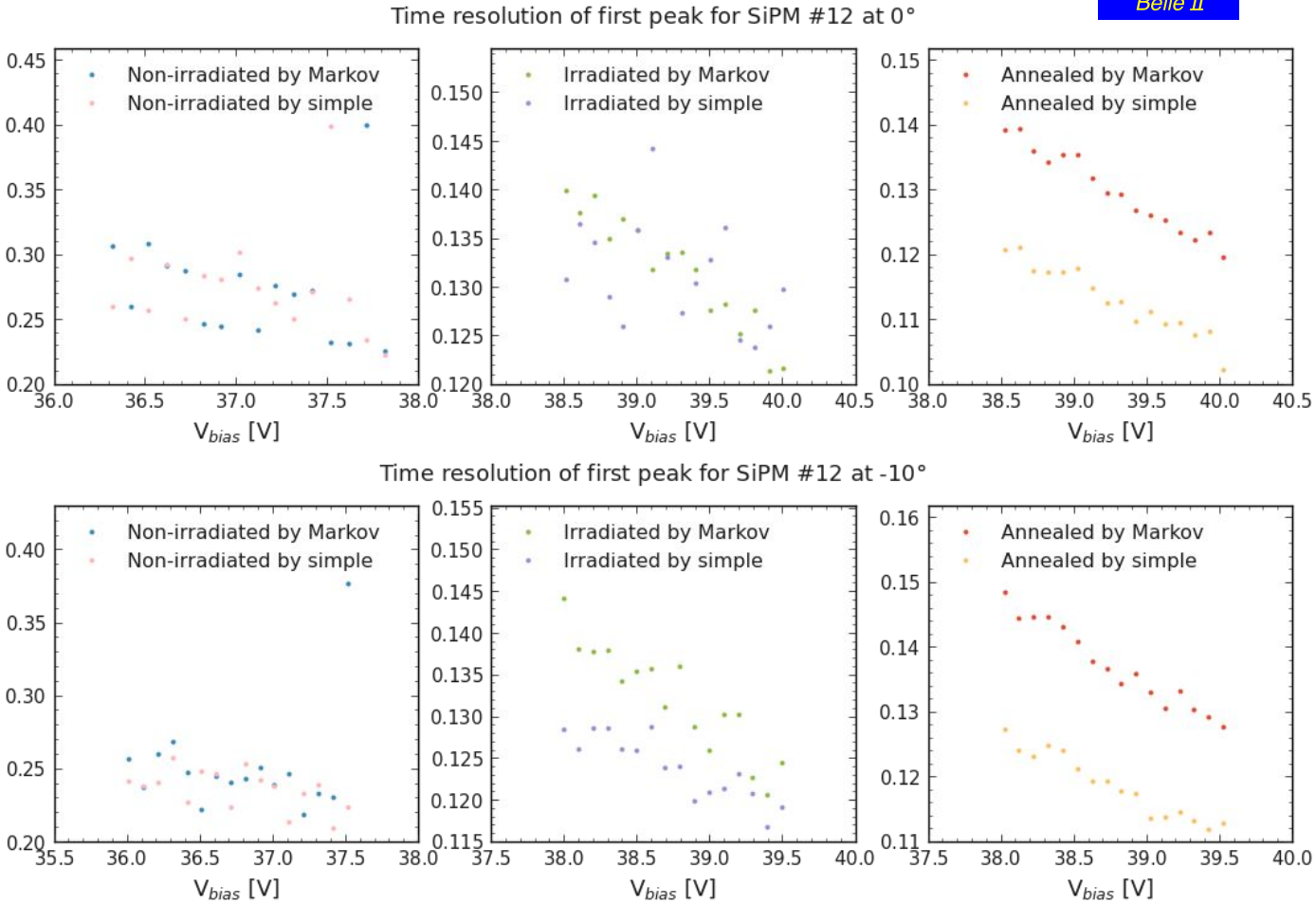


Time resolution for first photon peak for SiPM #12

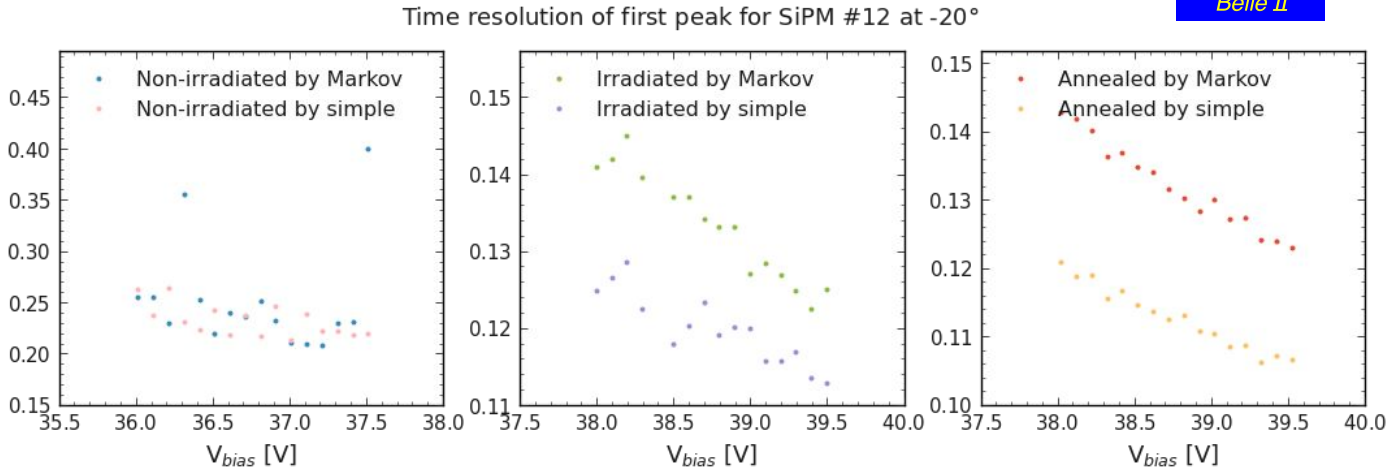
Time resolution for first photon peak

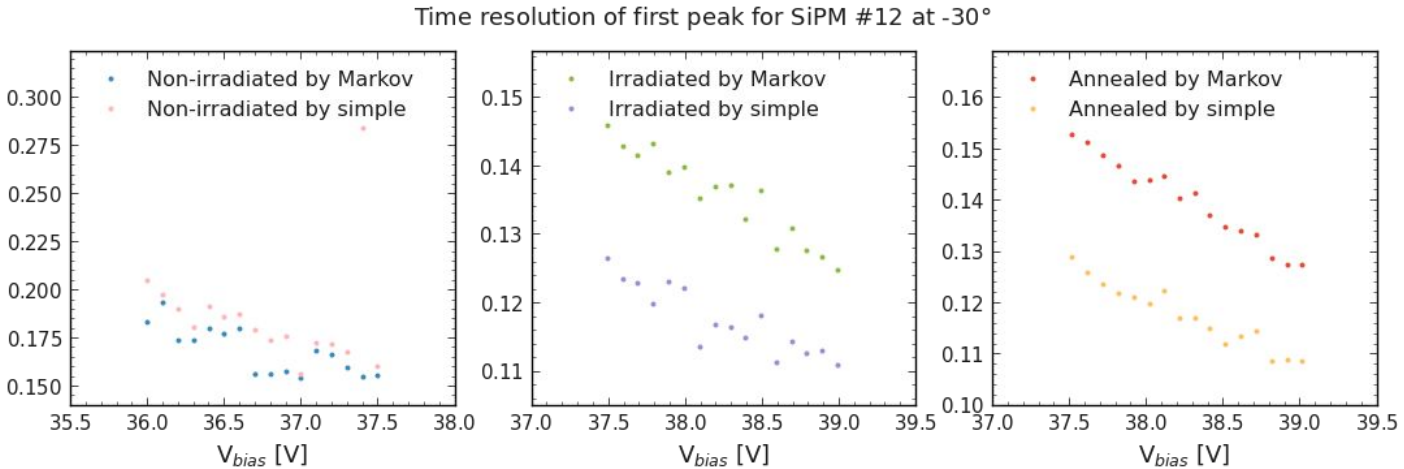


Time resolution for first photon peak

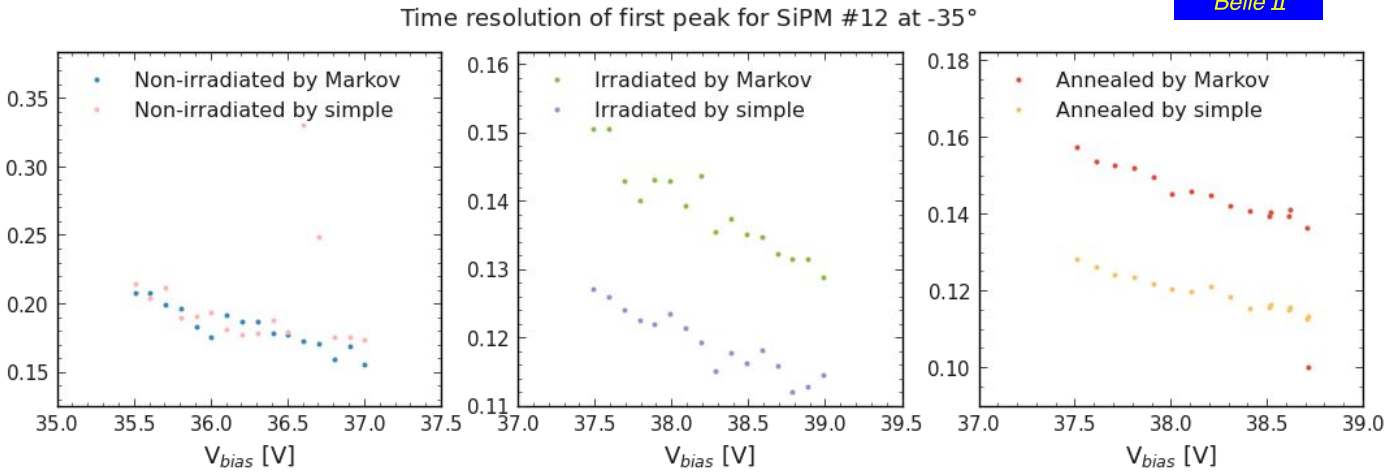


Time resolution for first photon peak



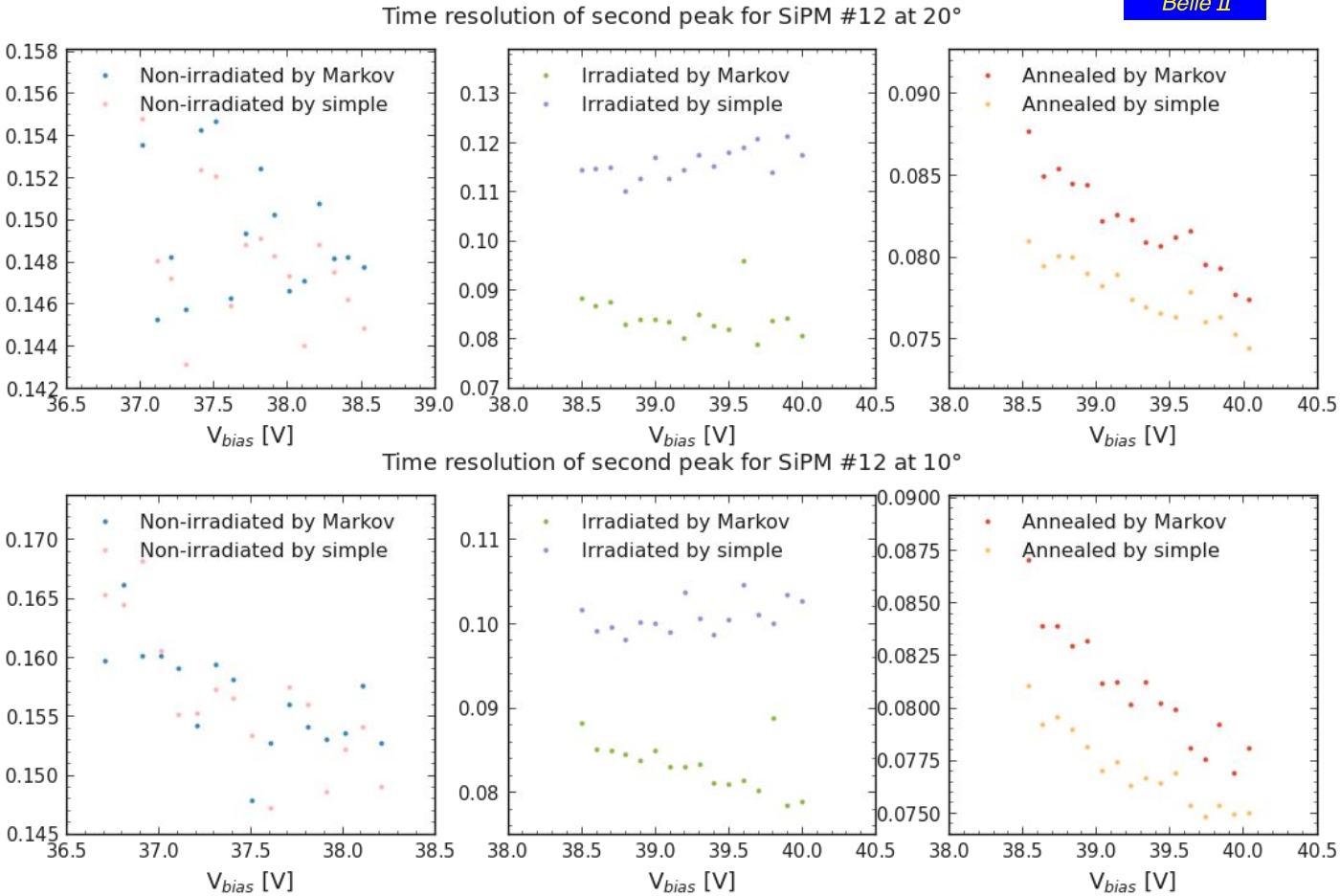


Time resolution for first photon peak

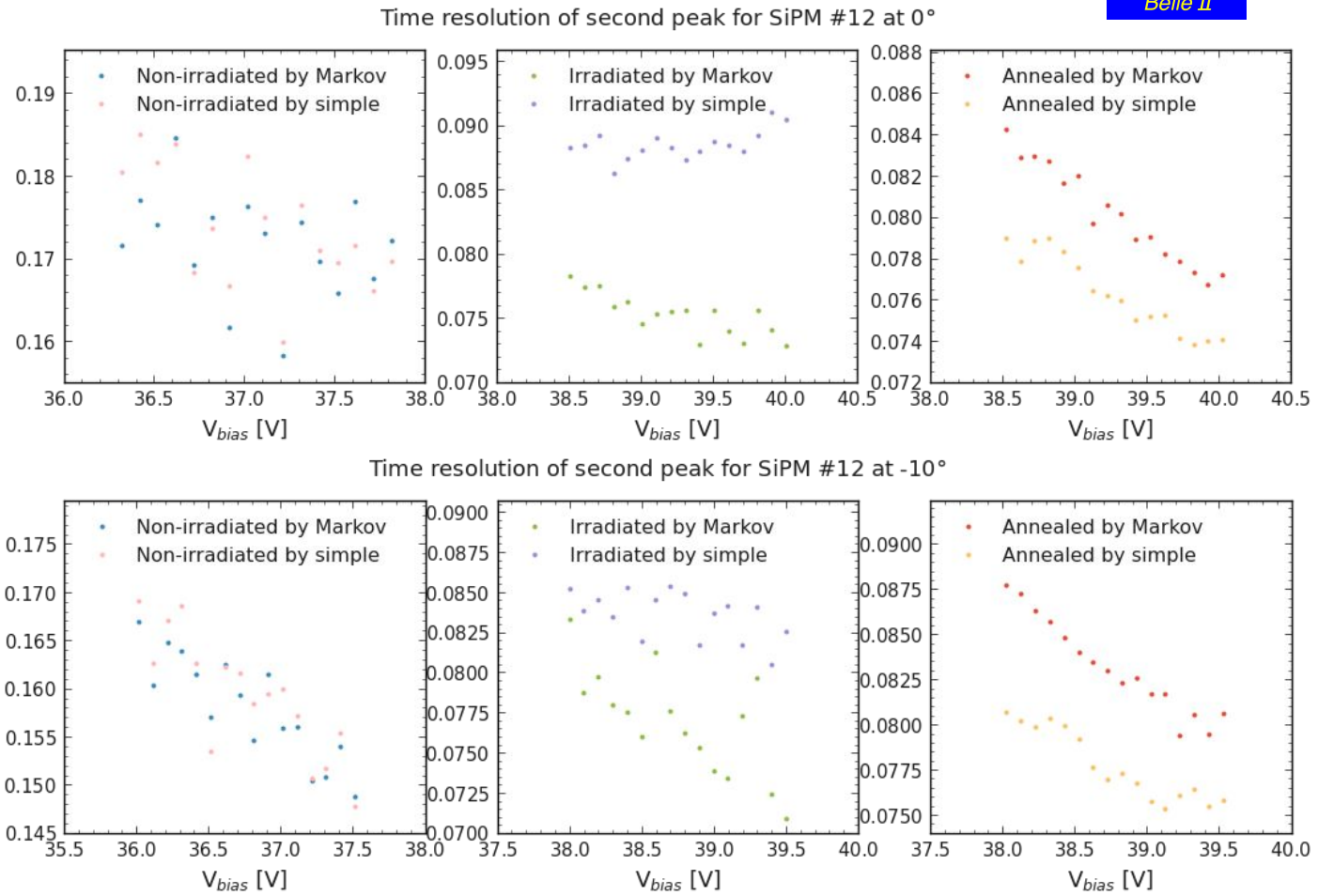


Time resolution for second photon peak for SiPM #12

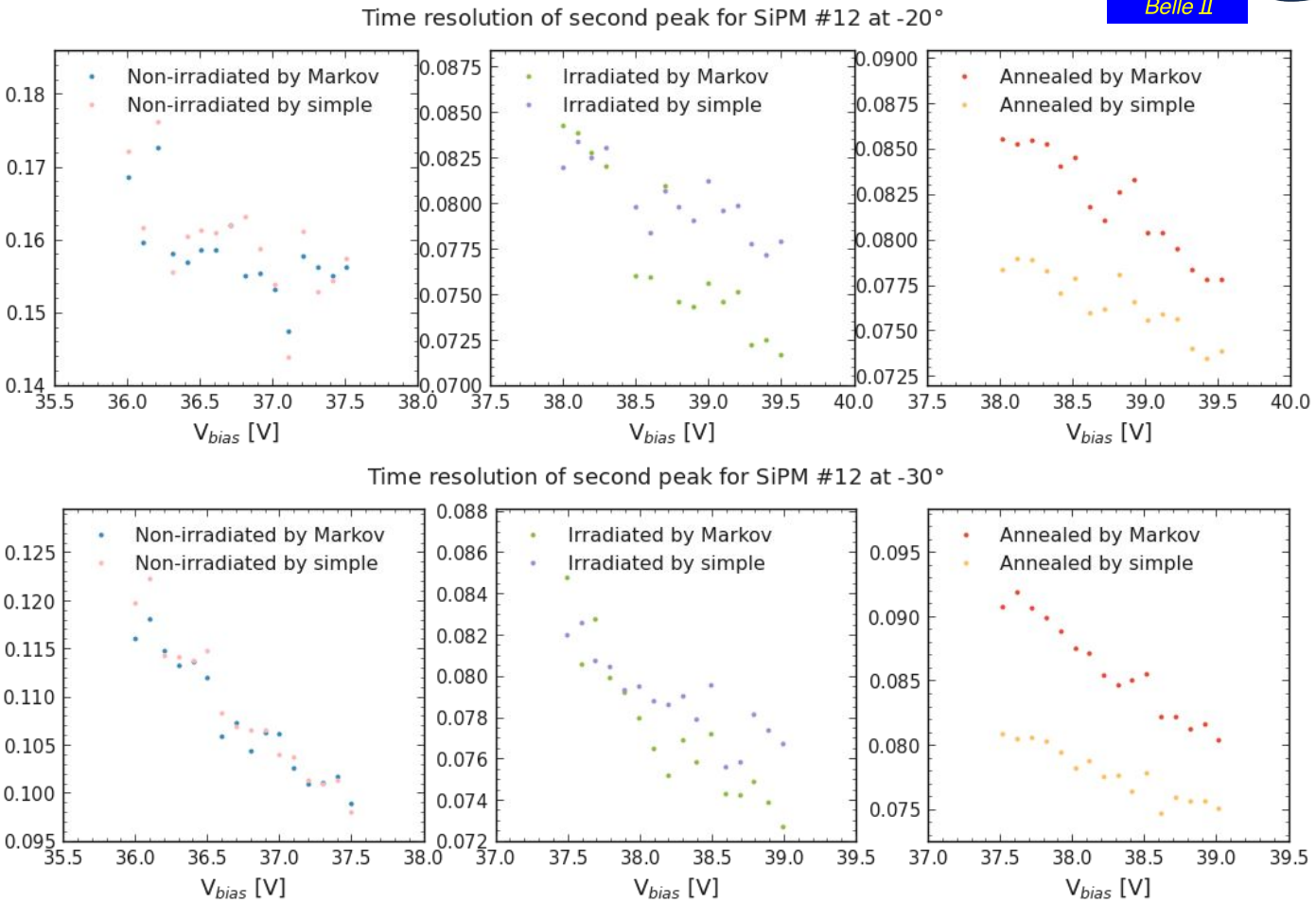
Time resolution for second photon peak



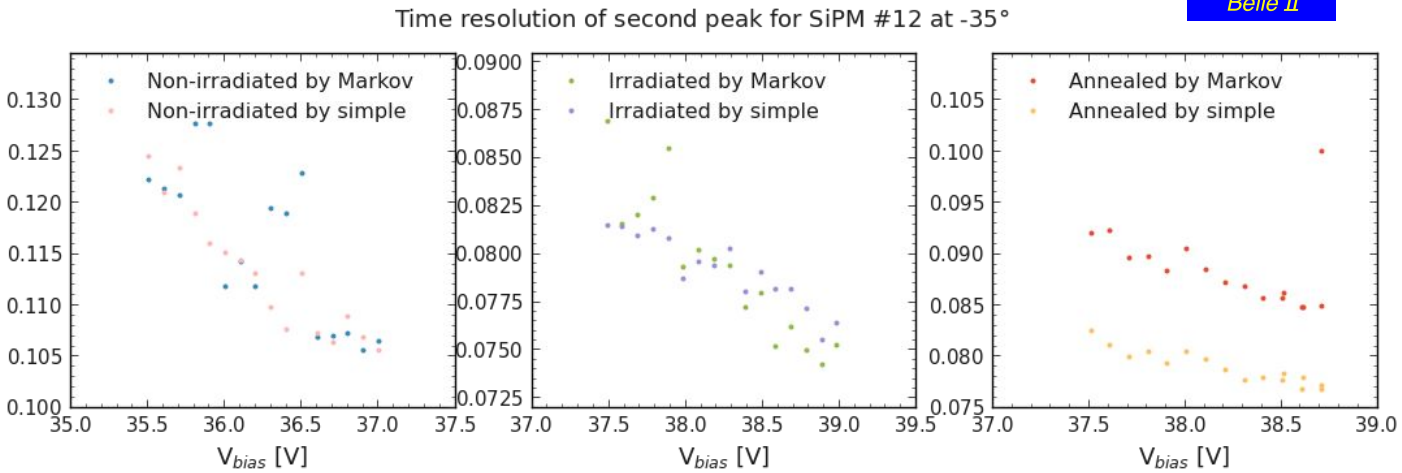
Time resolution for second photon peak



Time resolution for second photon peak

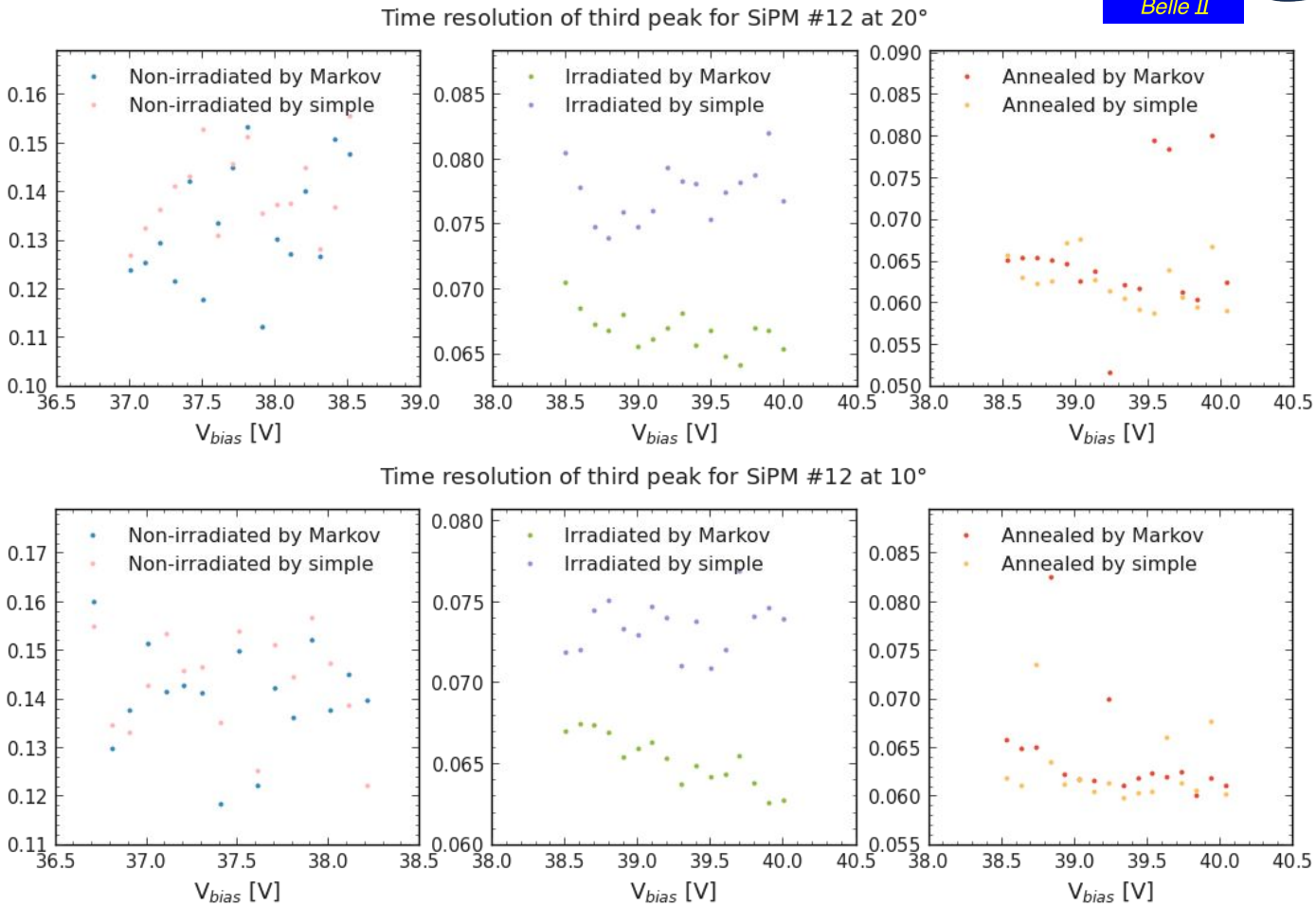


Time resolution for second photon peak

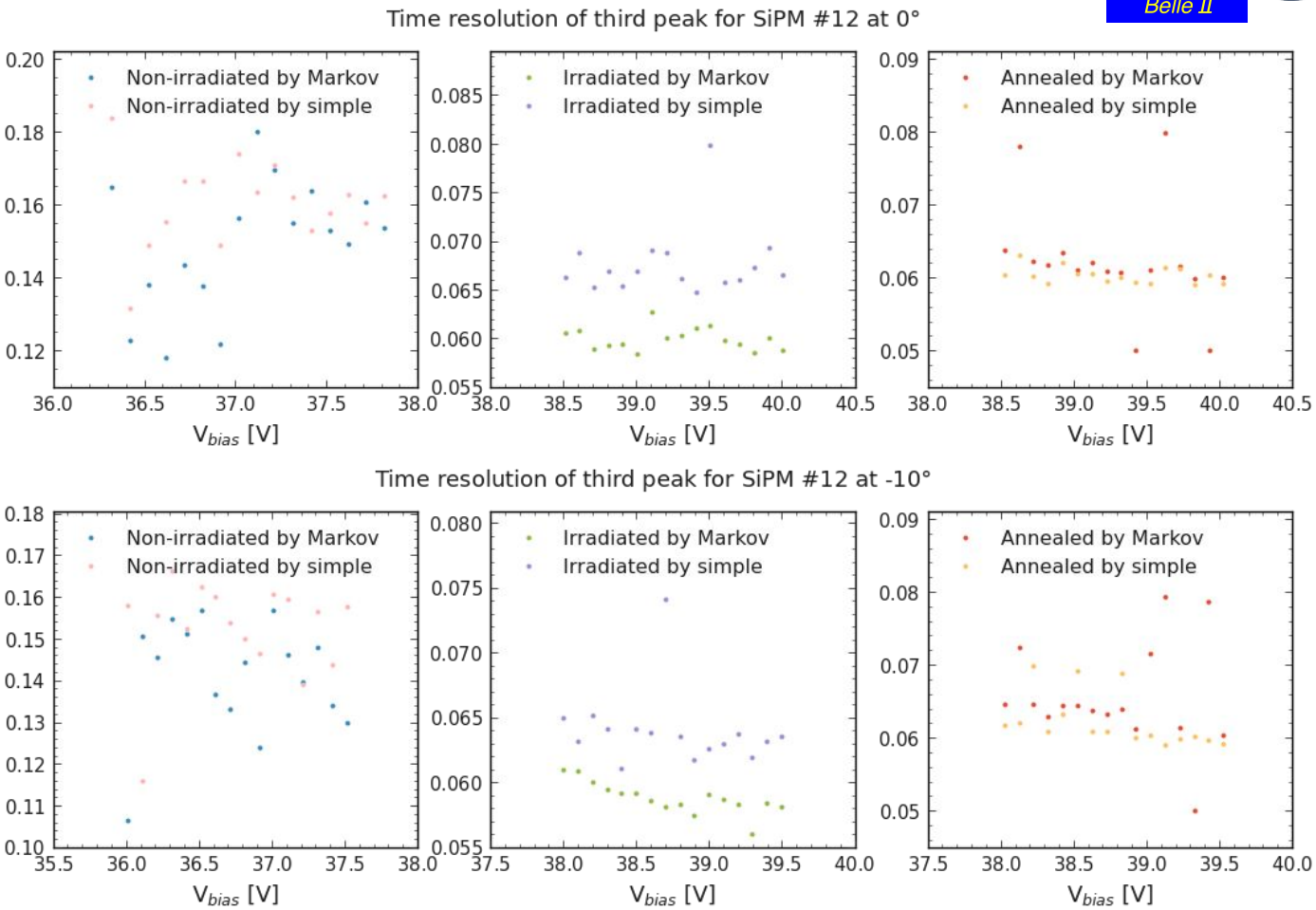


Time resolution for third photon peak for SiPM #12

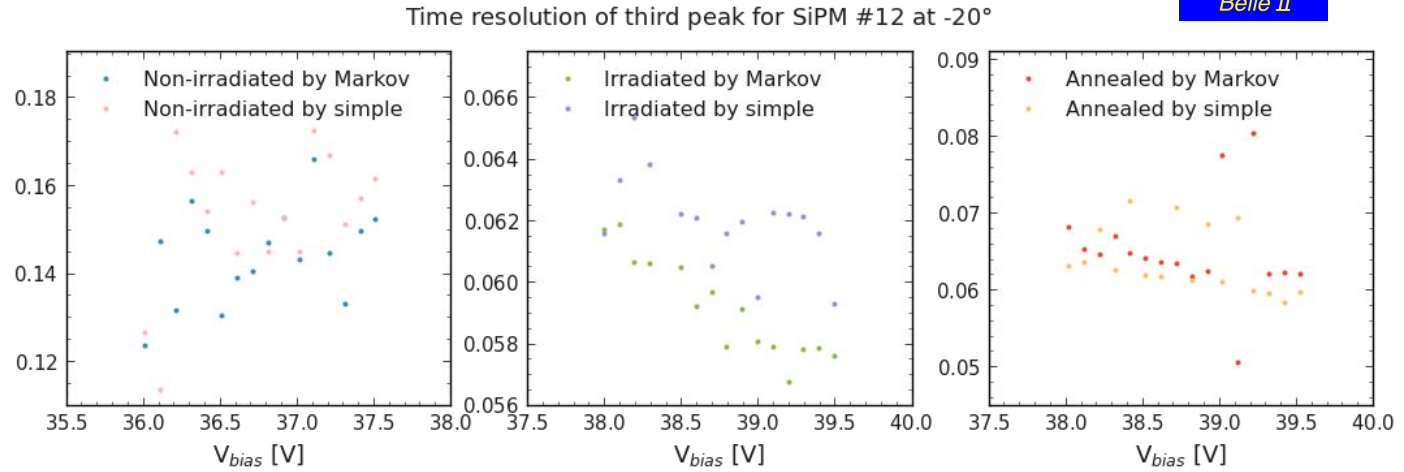
Time resolution for third photon peak

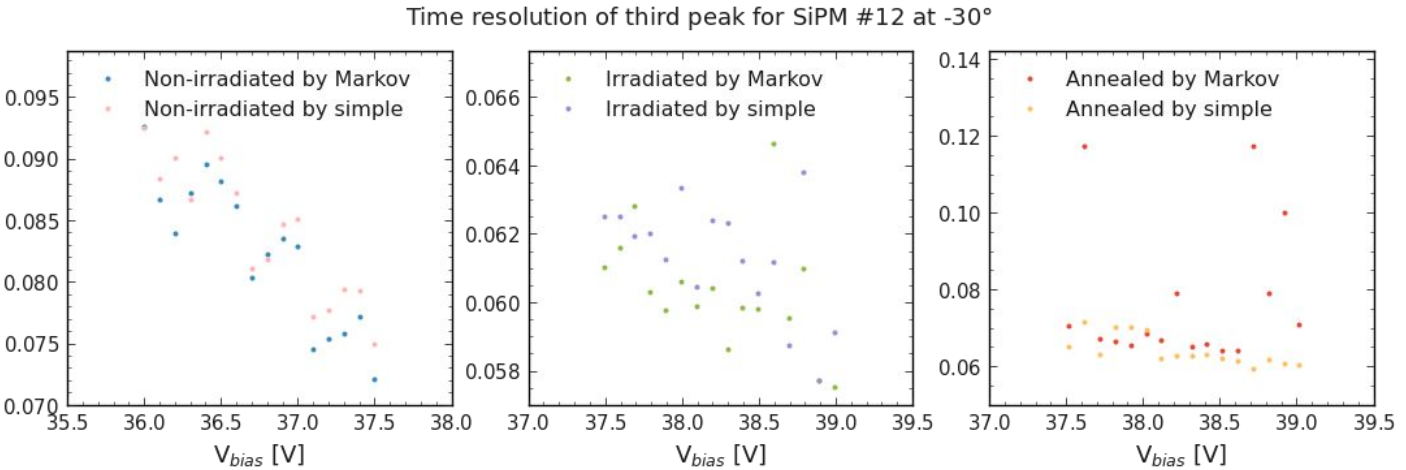


Time resolution for third photon peak

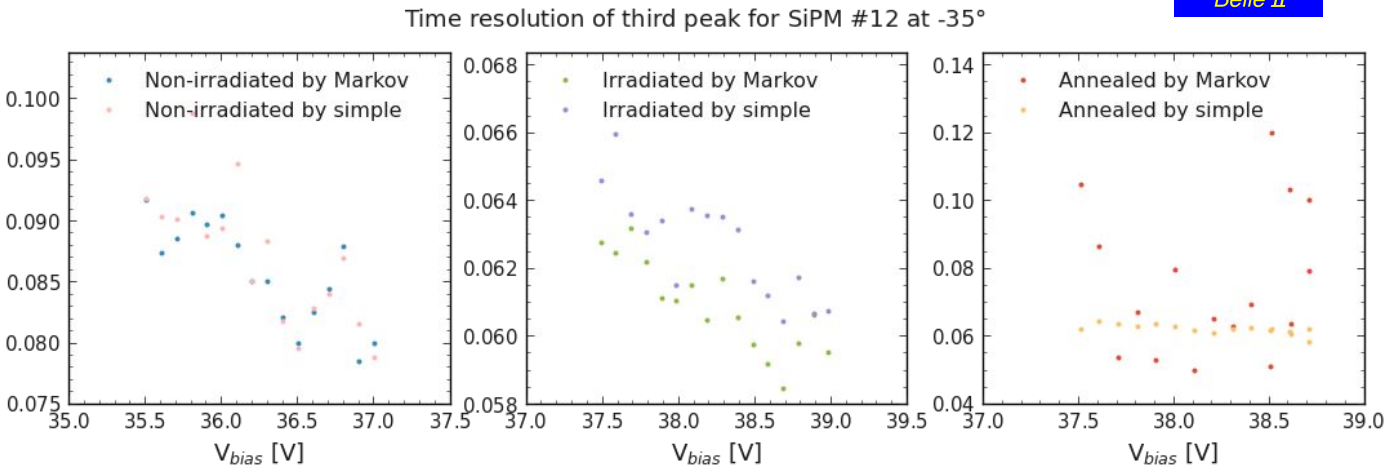


Time resolution for third photon peak



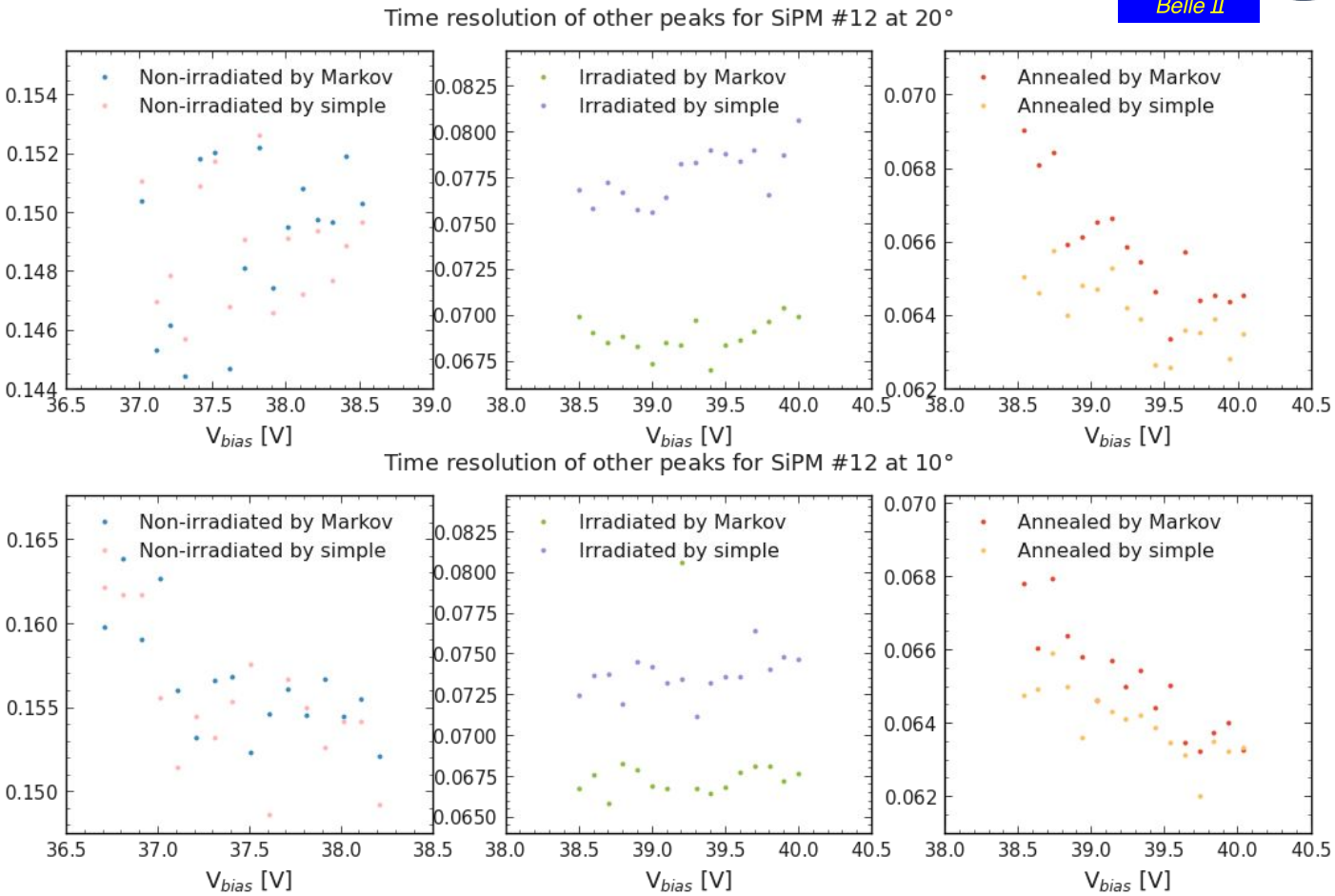


Time resolution for third photon peak

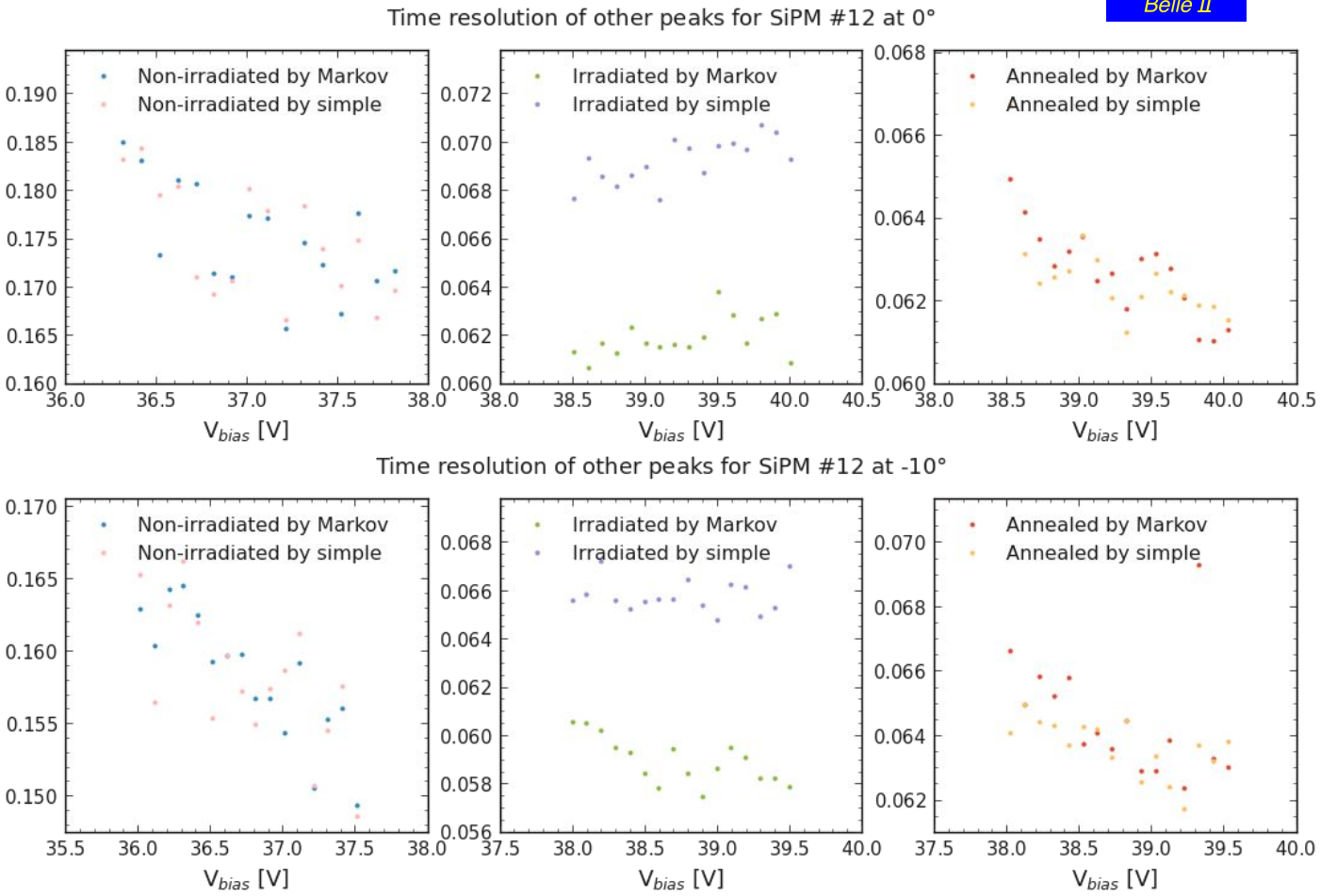


Time resolution for other photon peaks for SiPM #12

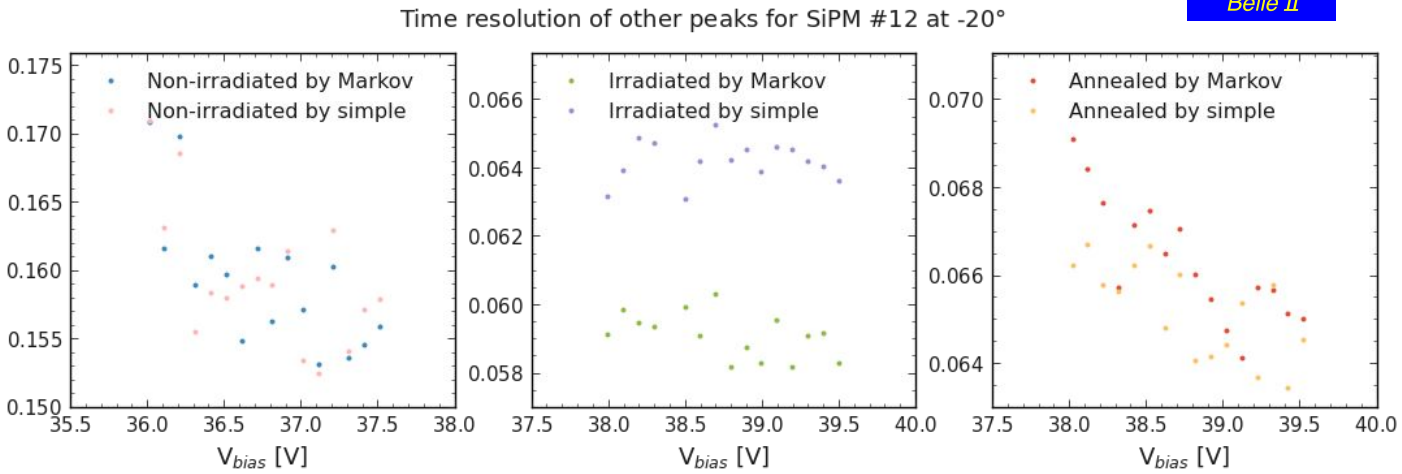
Time resolution for other photon peaks

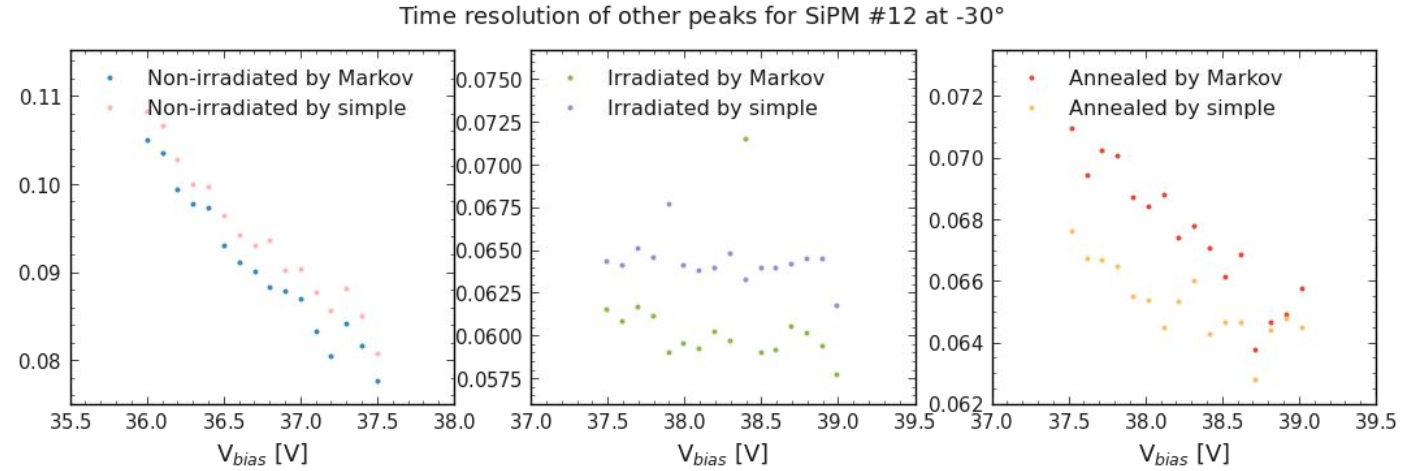


Time resolution for other photon peaks

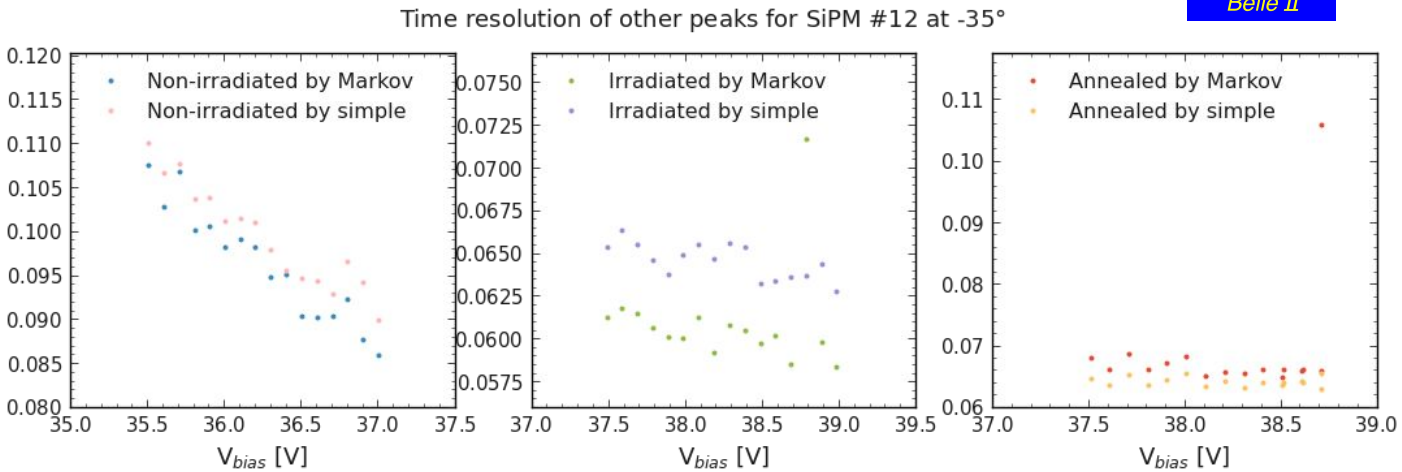


Time resolution for other photon peaks



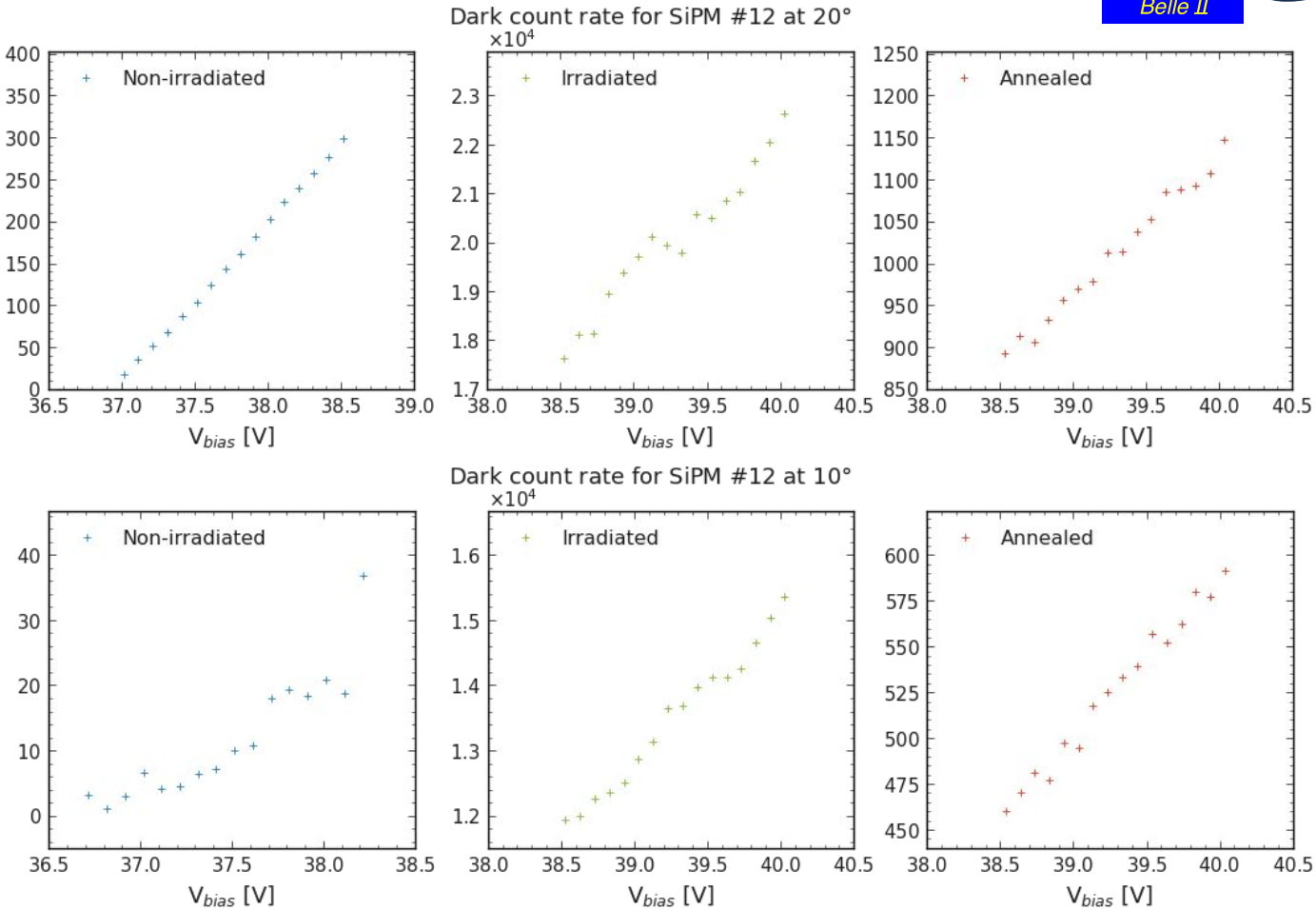


Time resolution for other photon peaks

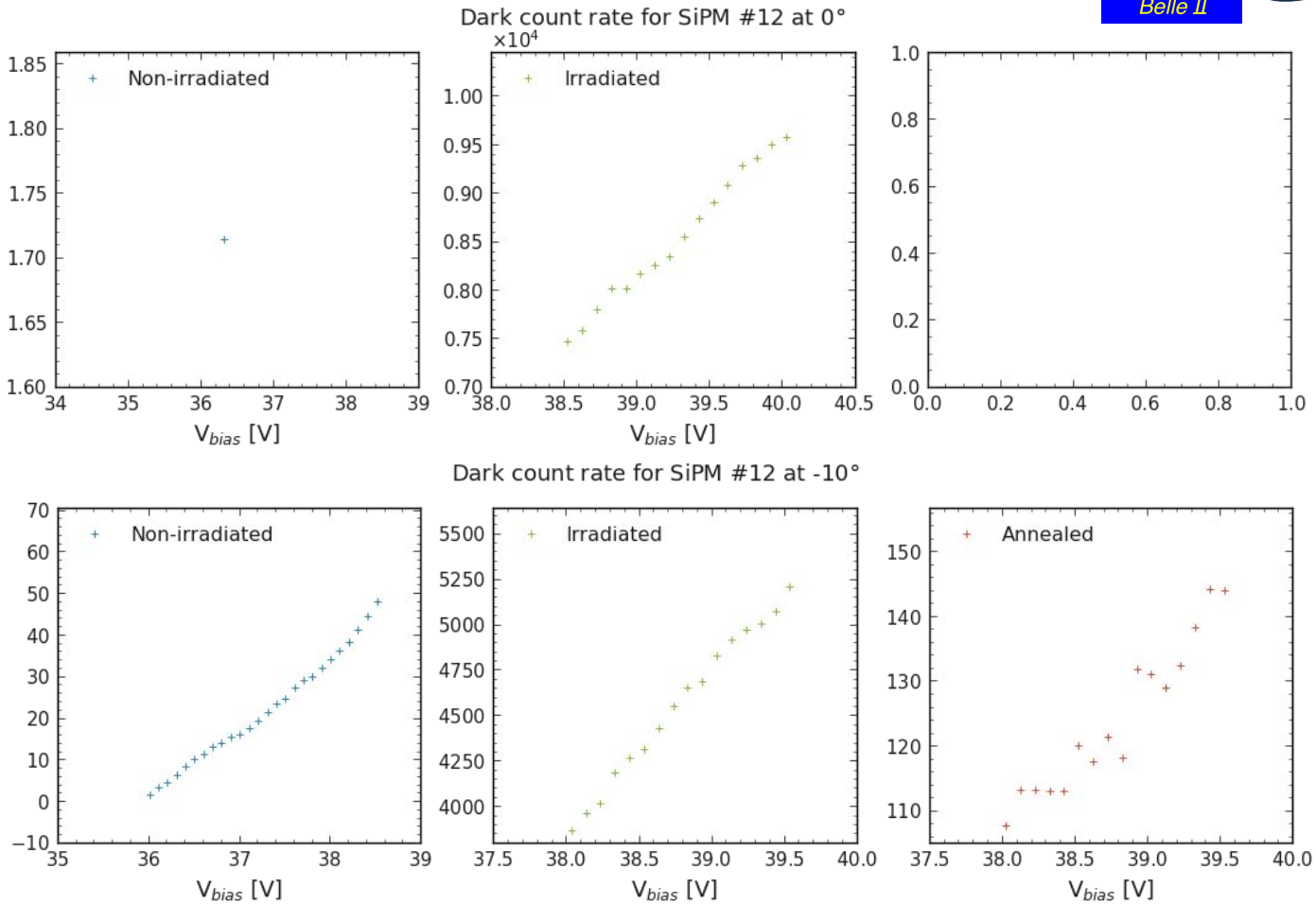


Dark count rate for SiPM #12

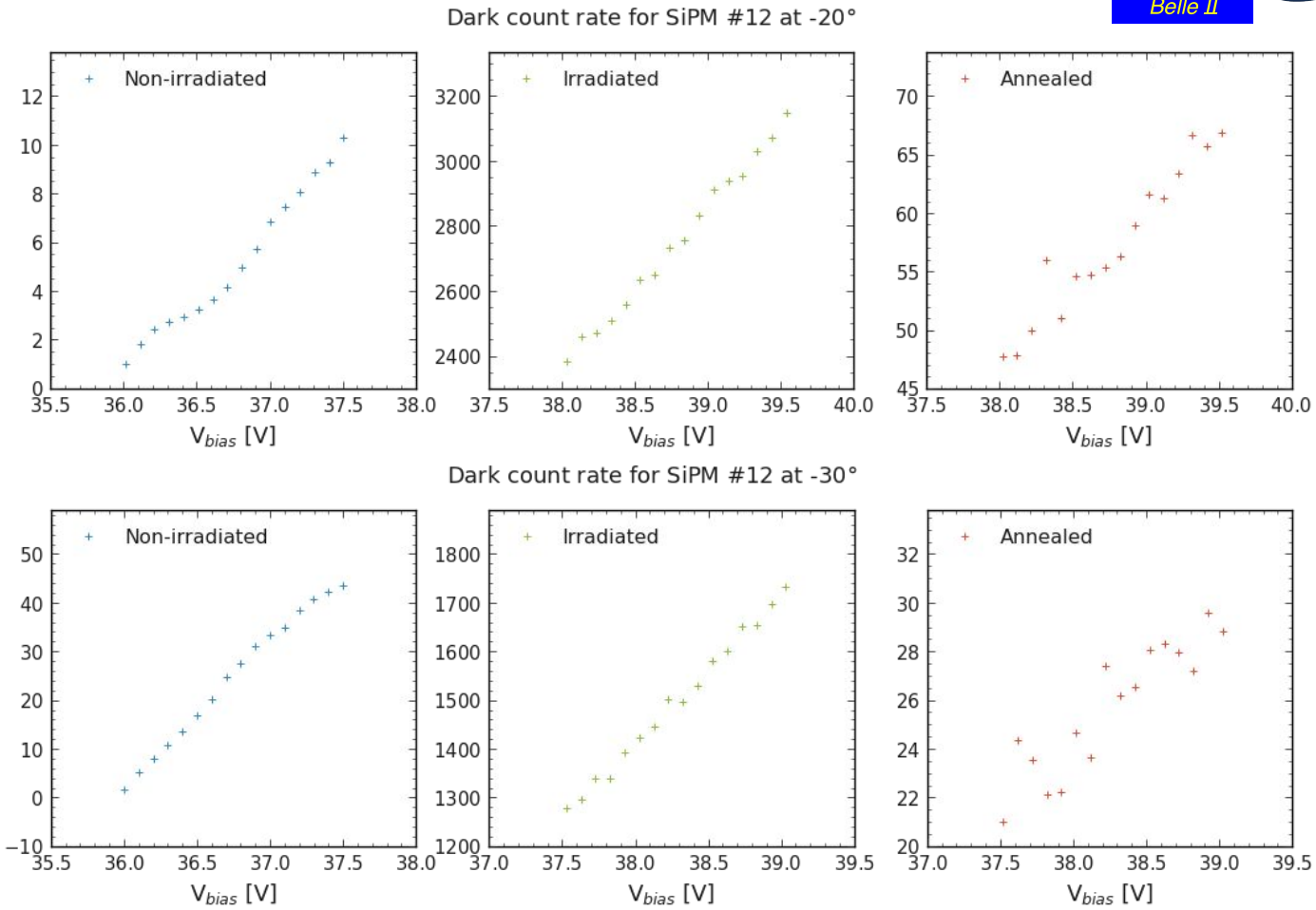
Dark count rate



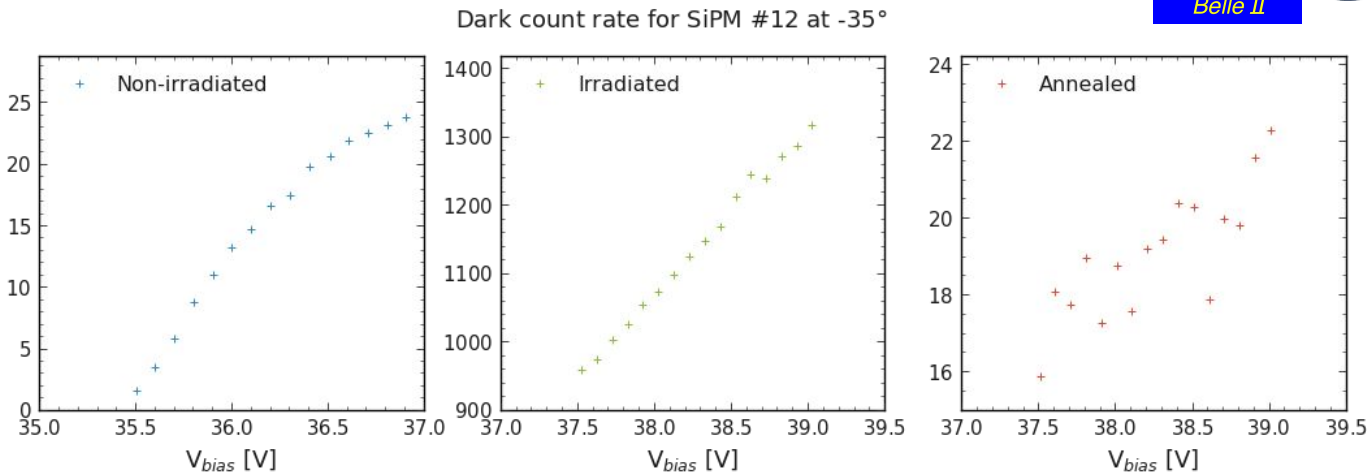
Dark count rate



Dark count rate



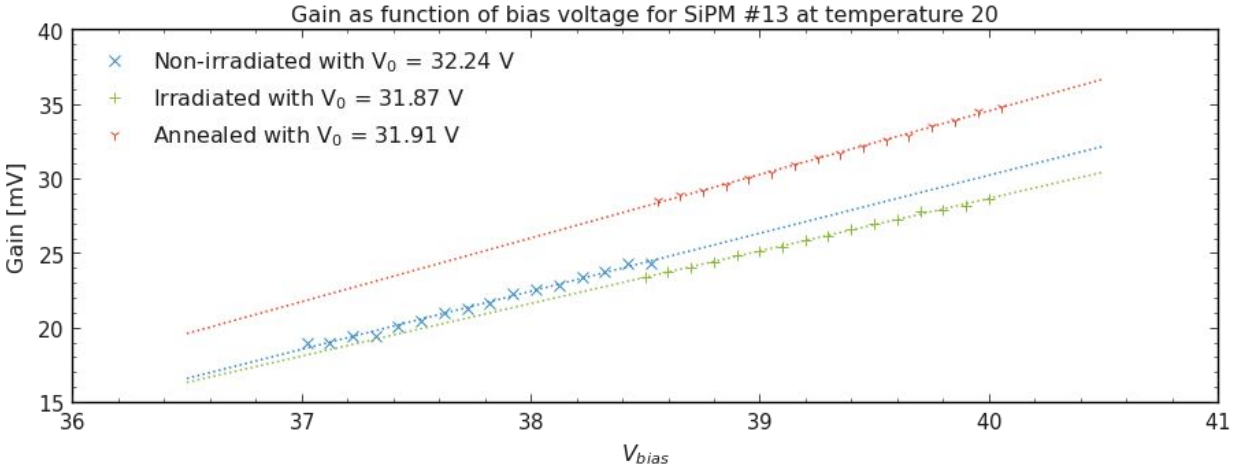
Dark count rate

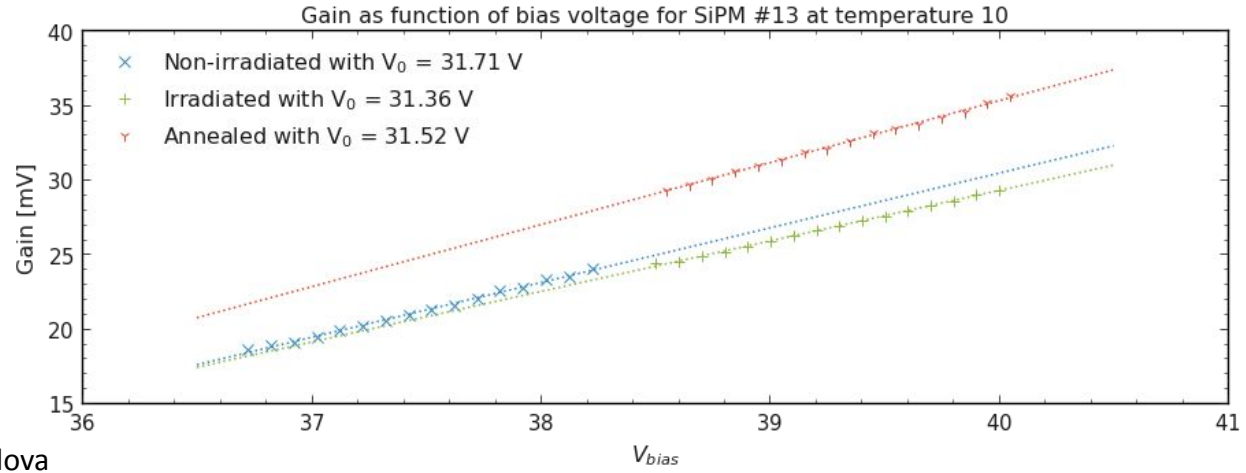


SiMP #13

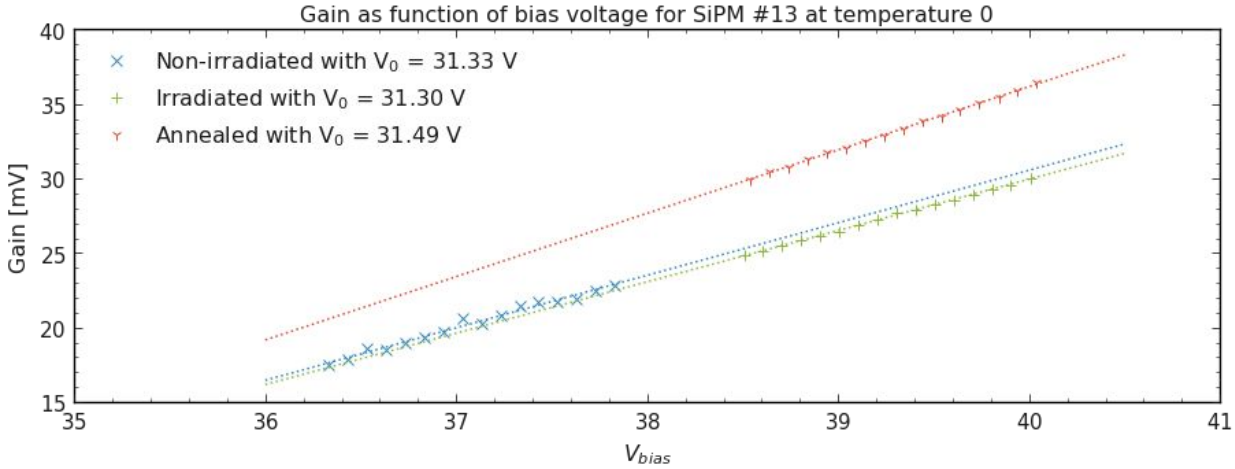
Gain as function of bias voltage for SiPM #13

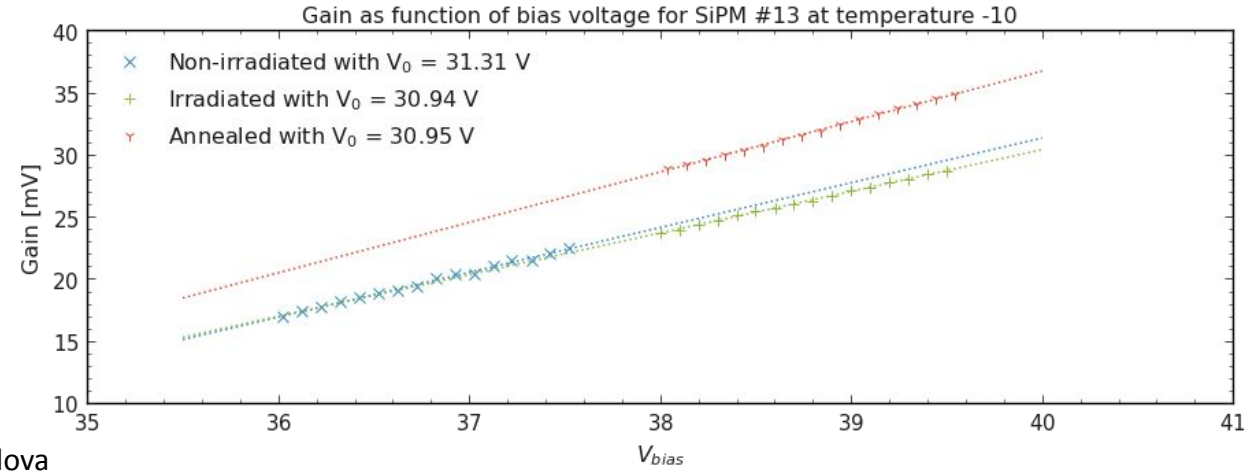
Gain as function of bias voltage



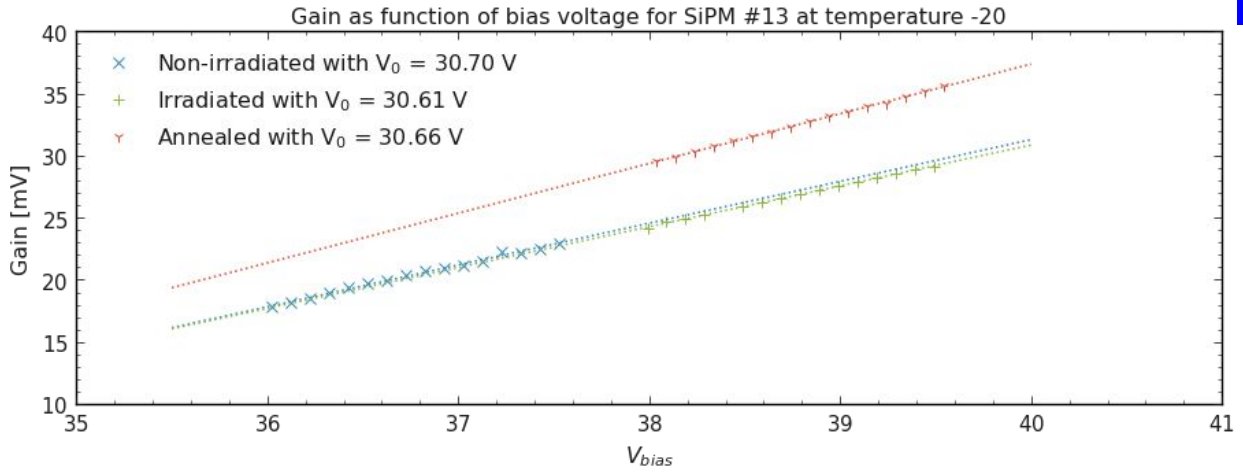


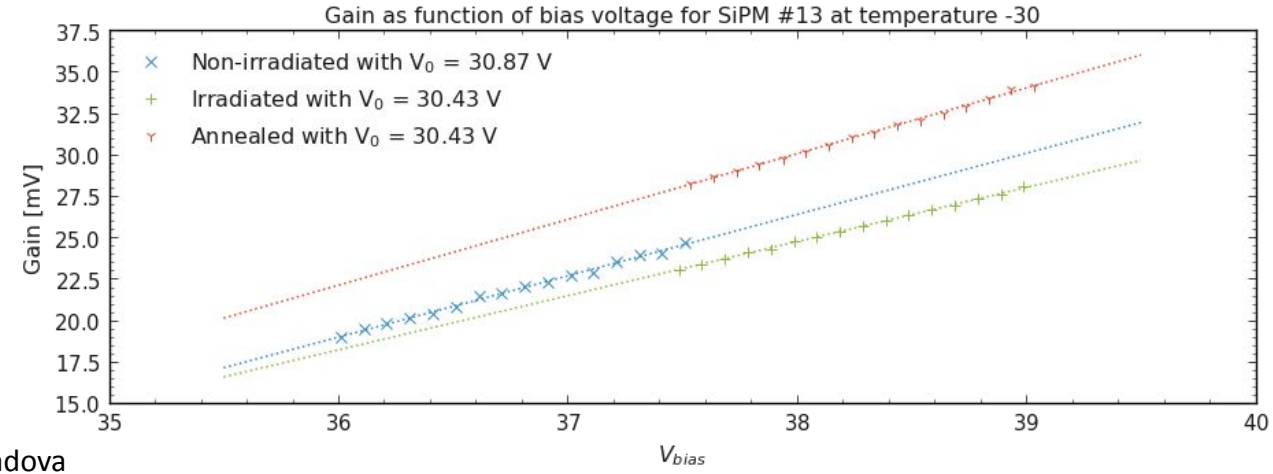
Gain as function of bias voltage



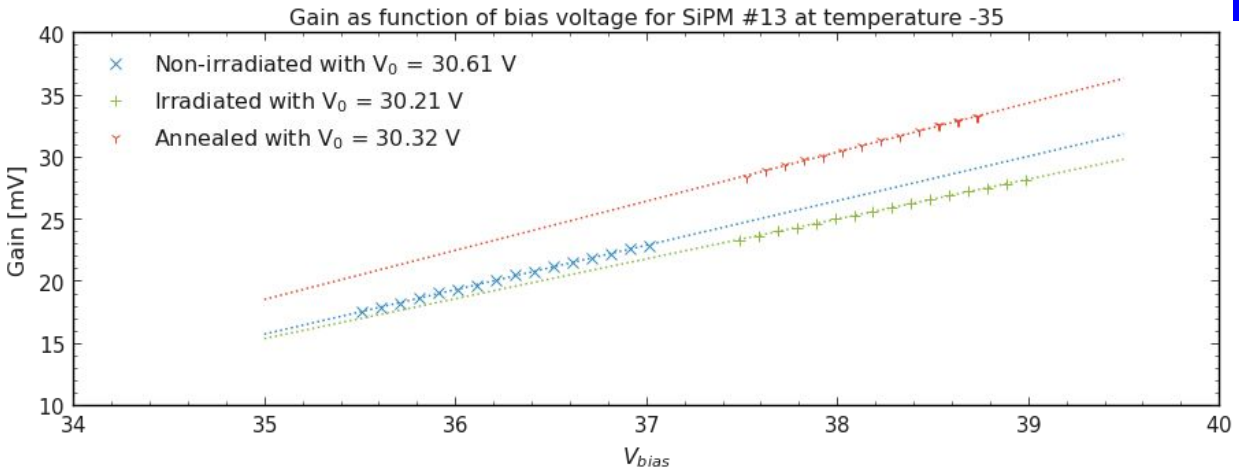


Gain as function of bias voltage



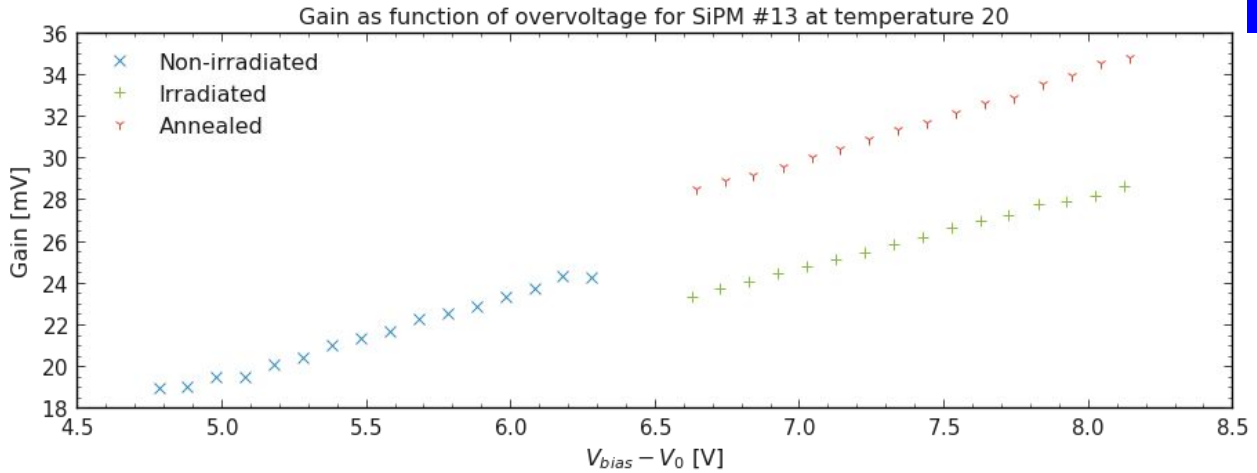


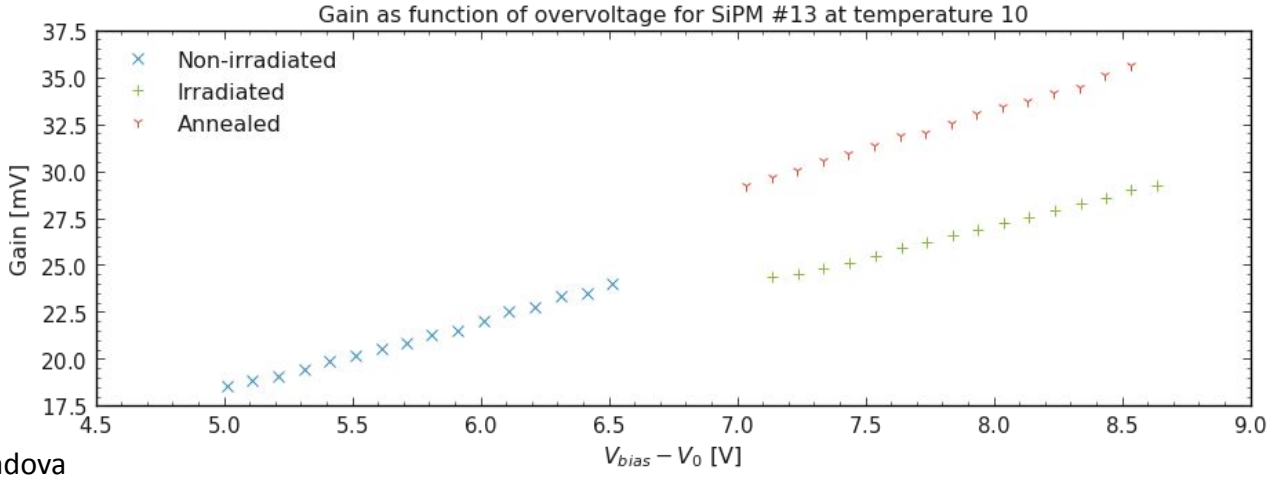
Gain as function of bias voltage



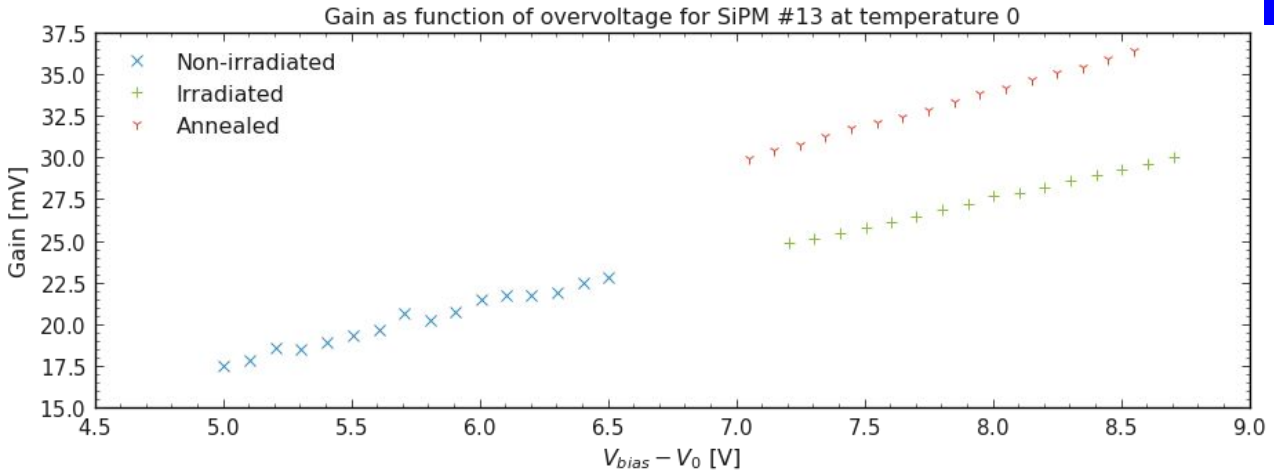
Gain as function of overvoltage for SiPM #13

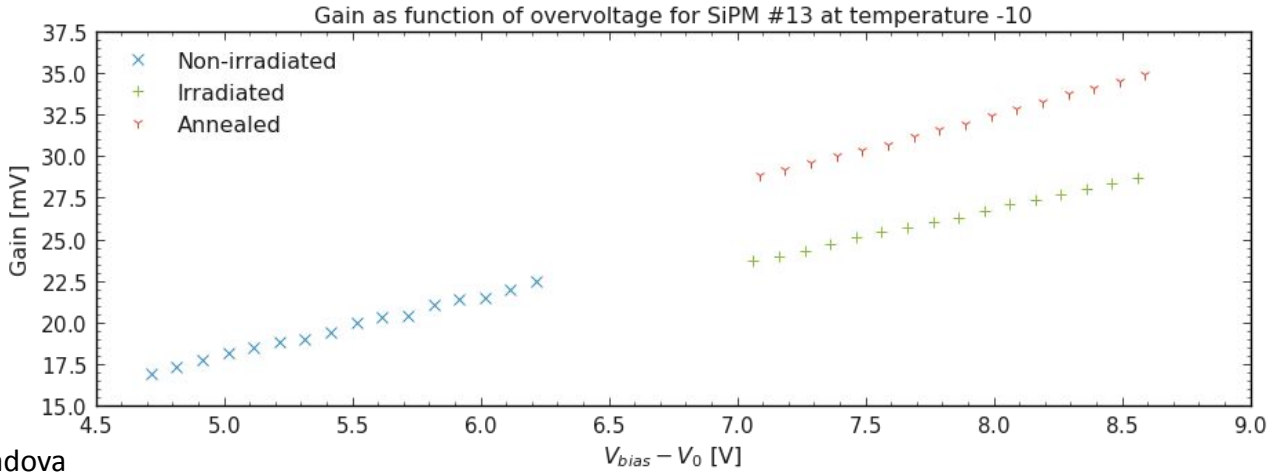
Gain as function of overvoltage



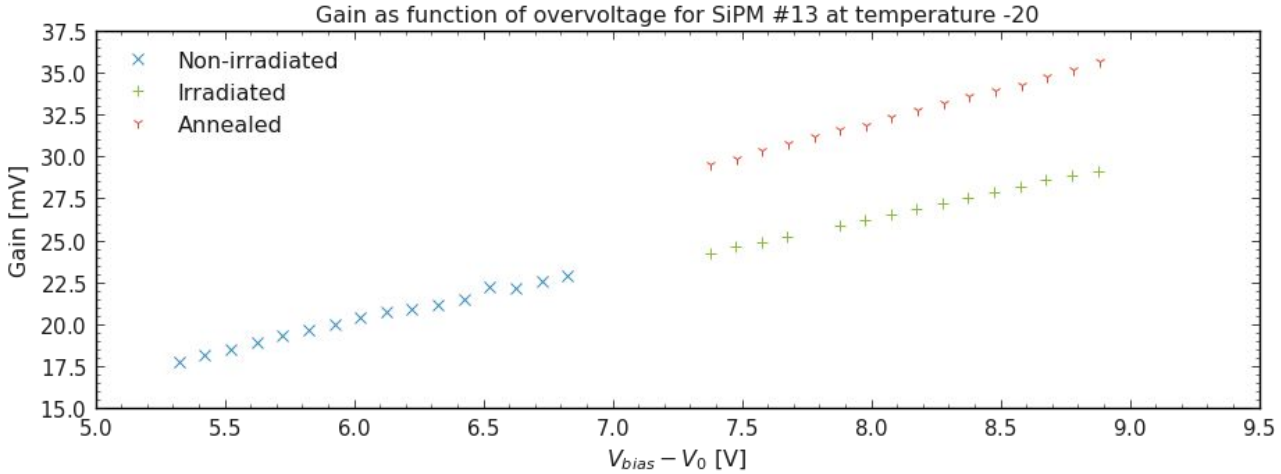


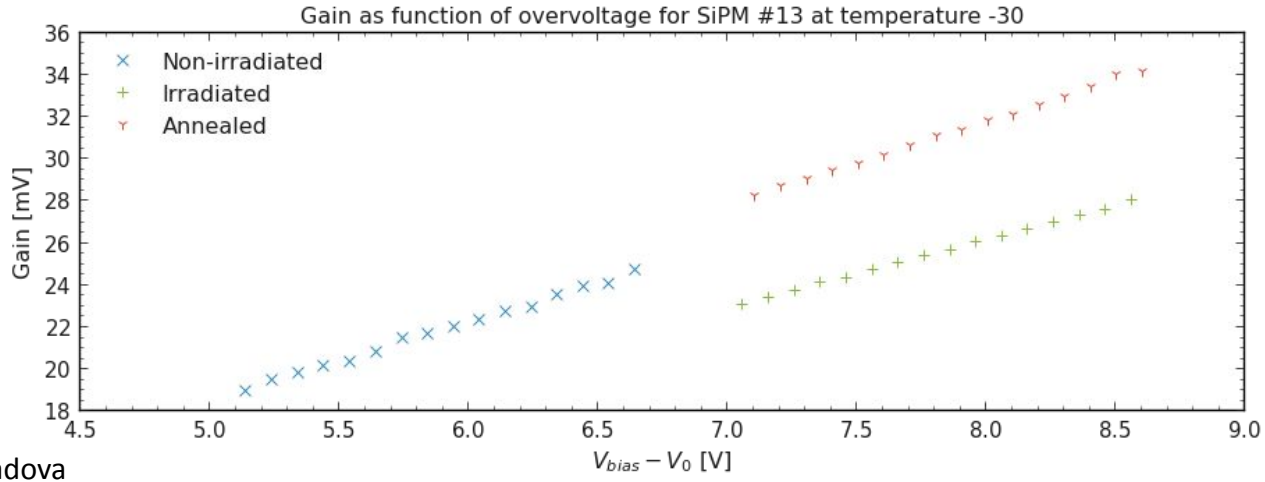
Gain as function of overvoltage



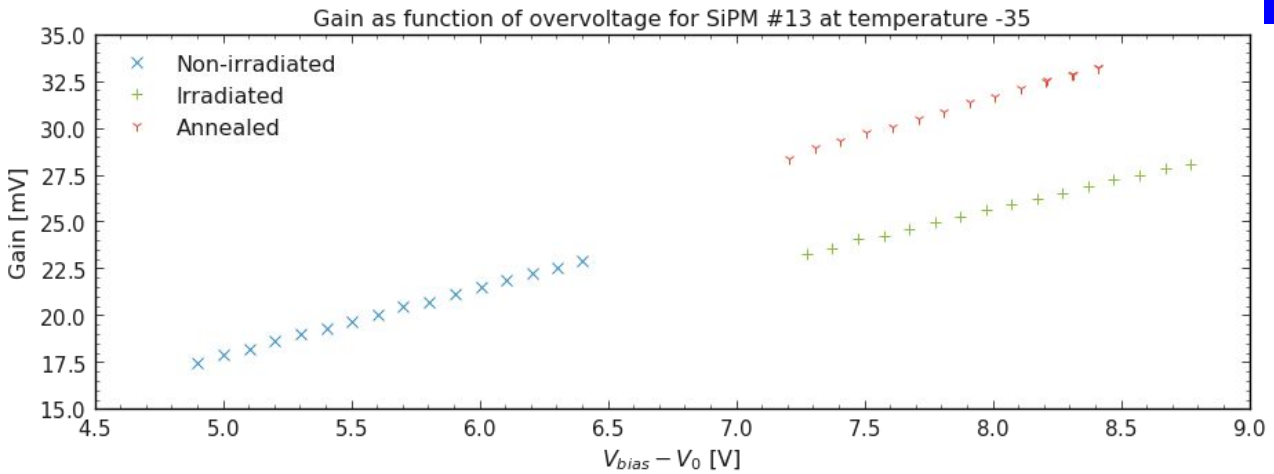


Gain as function of overvoltage



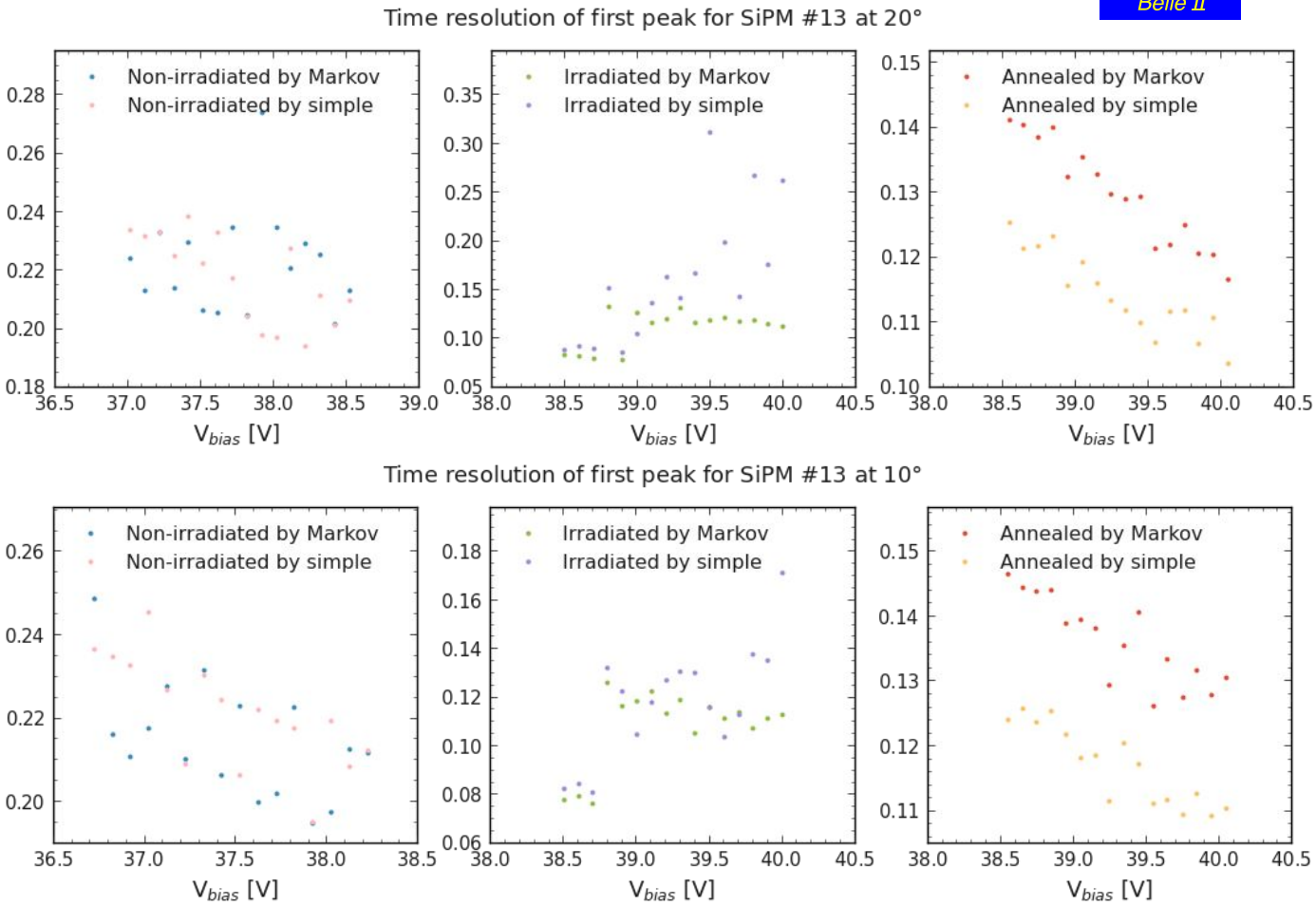


Gain as function of overvoltage

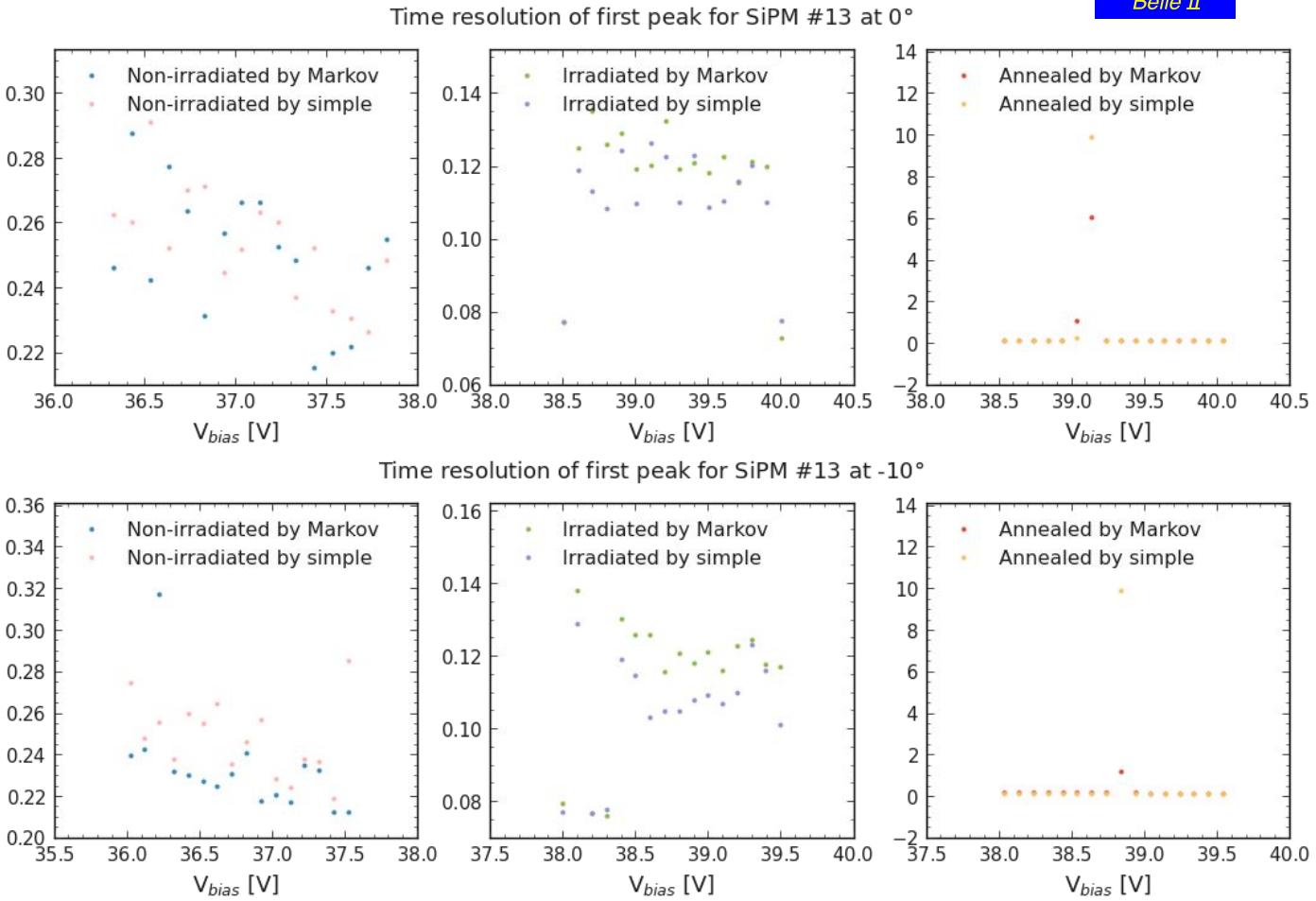


Time resolution for first photon peak for SiPM #13

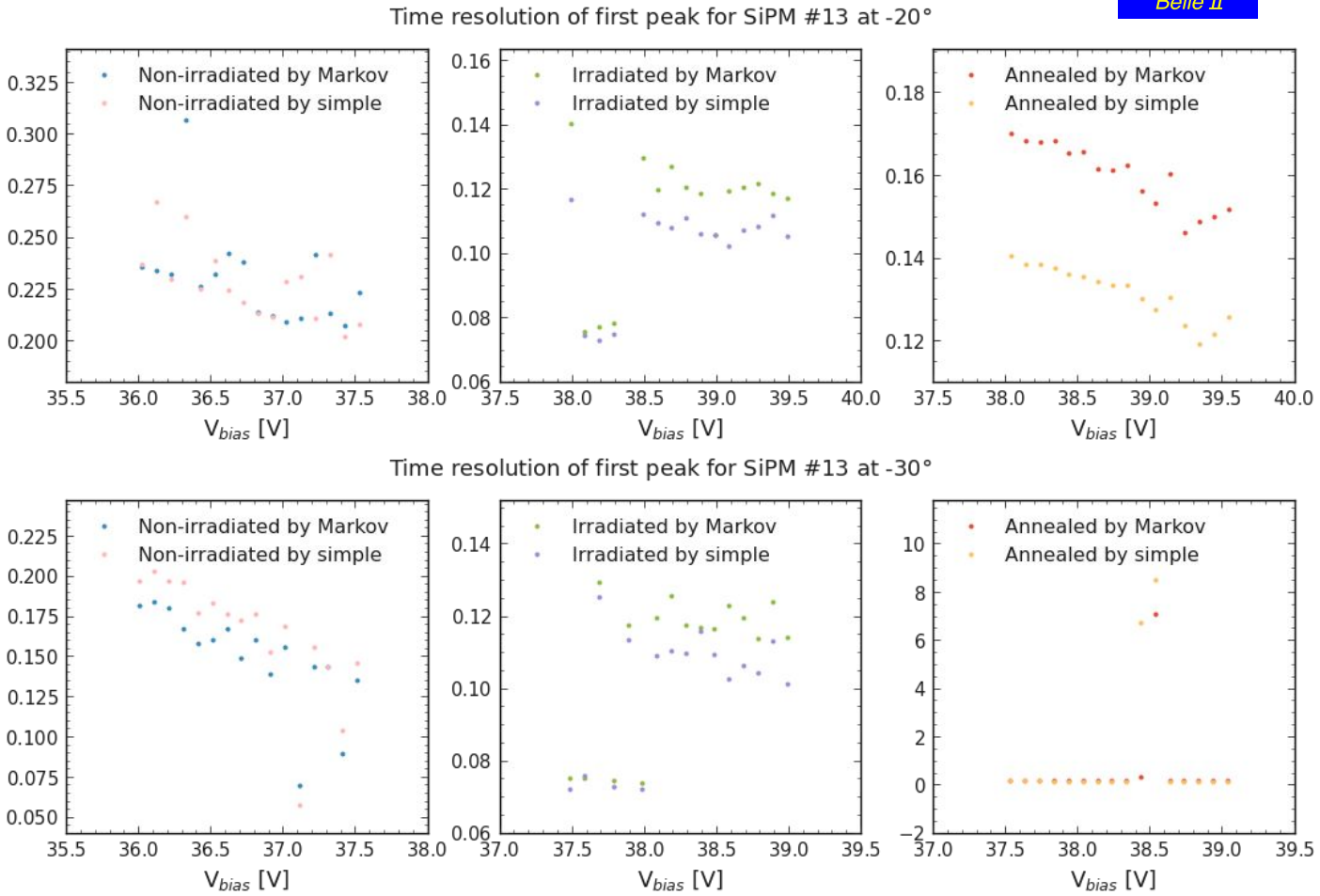
Time resolution for first photon peak



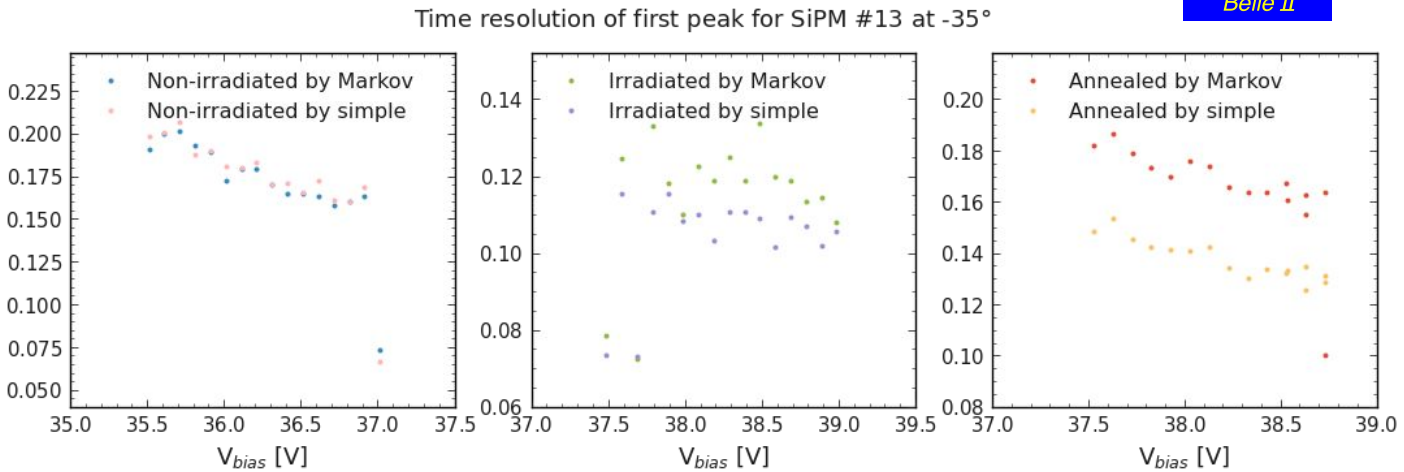
Time resolution for first photon peak



Time resolution for first photon peak

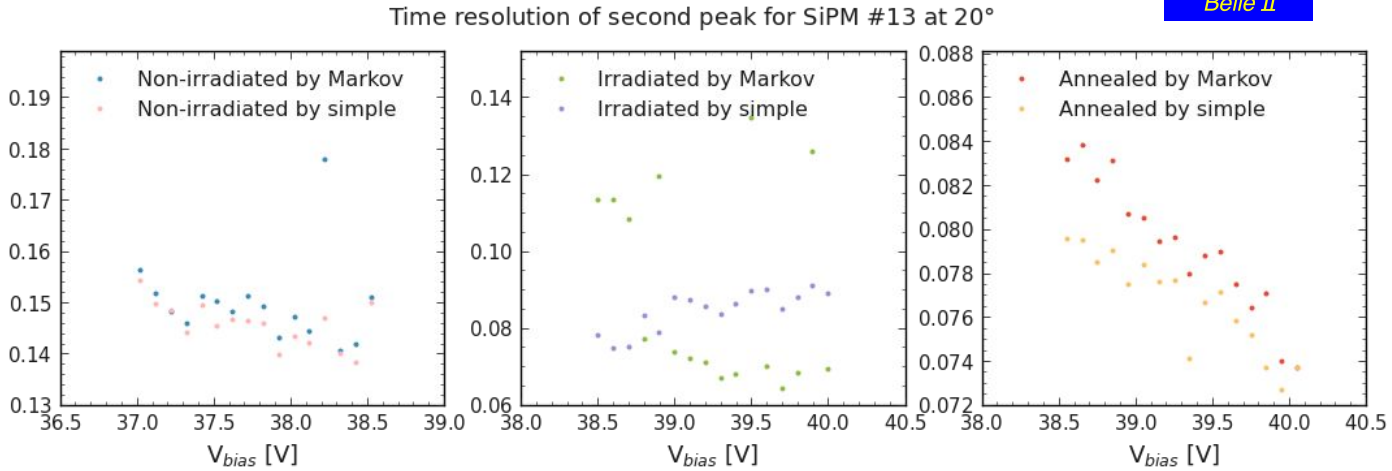


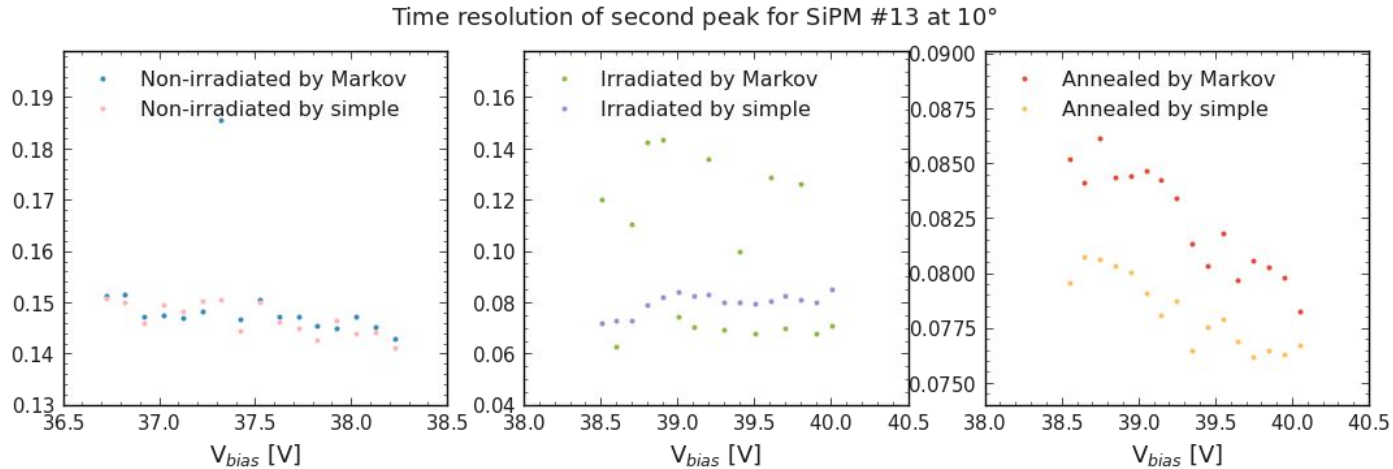
Time resolution for first photon peak



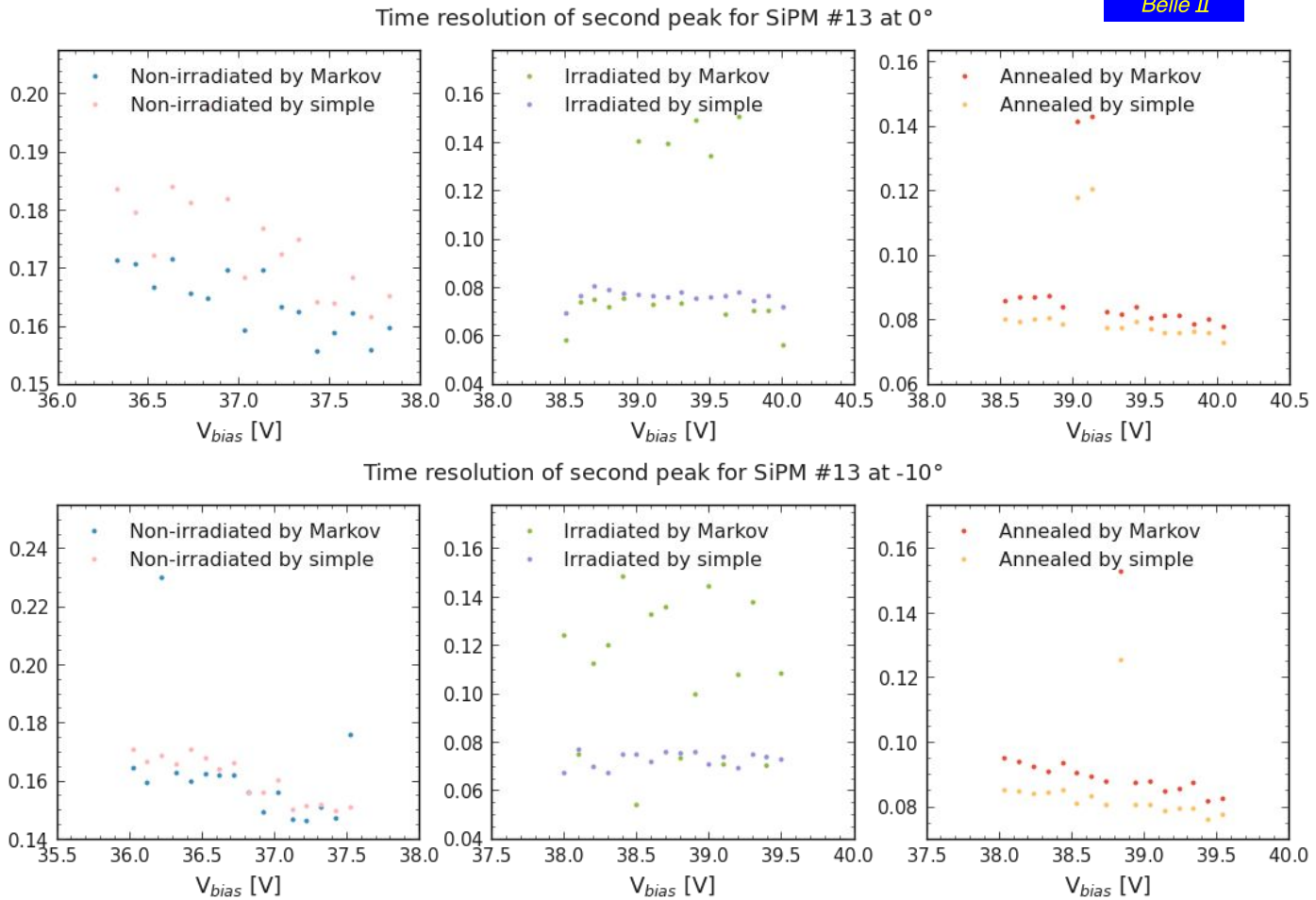
Time resolution for second photon peak for SiPM #13

Time resolution for second photon peak

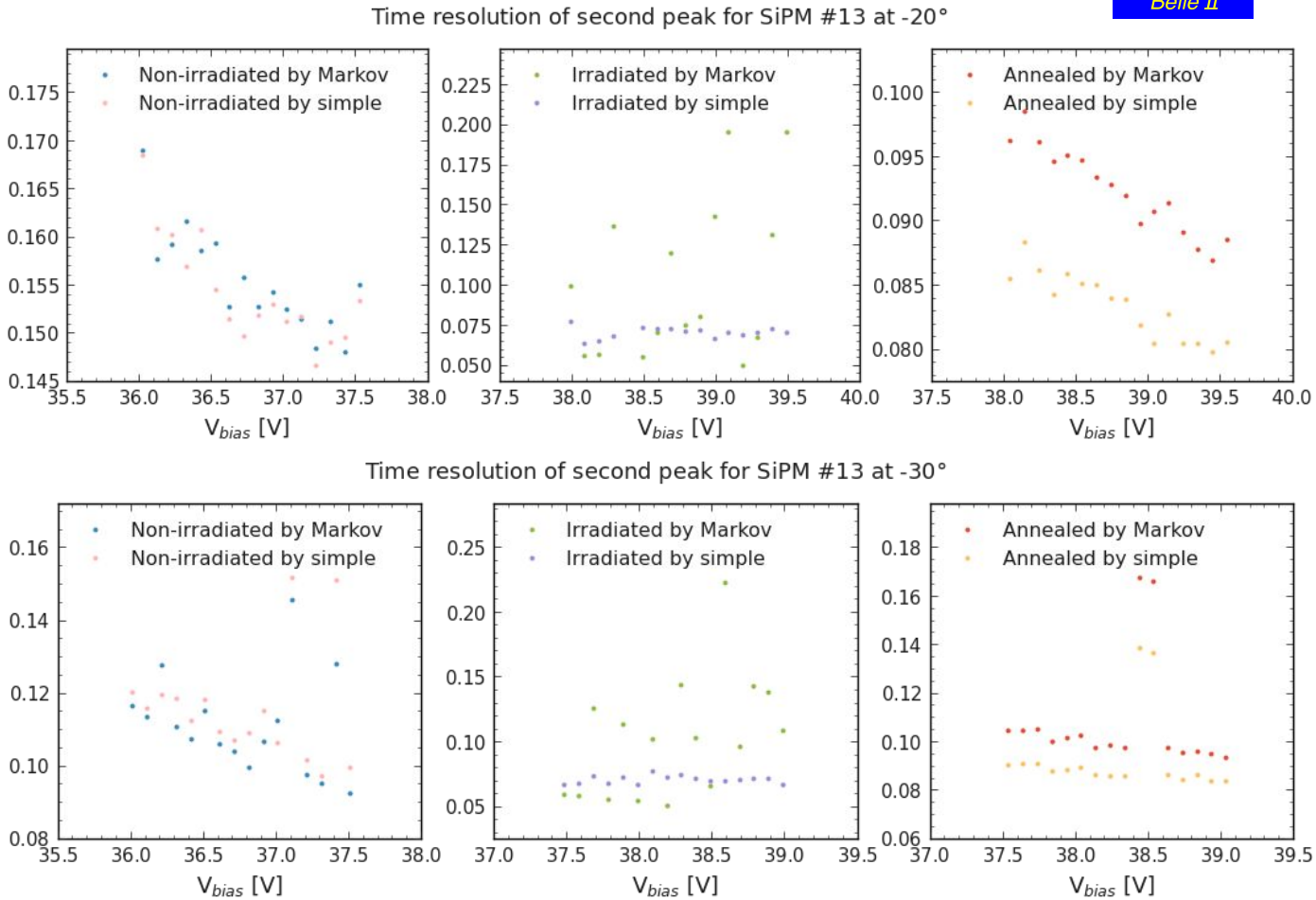




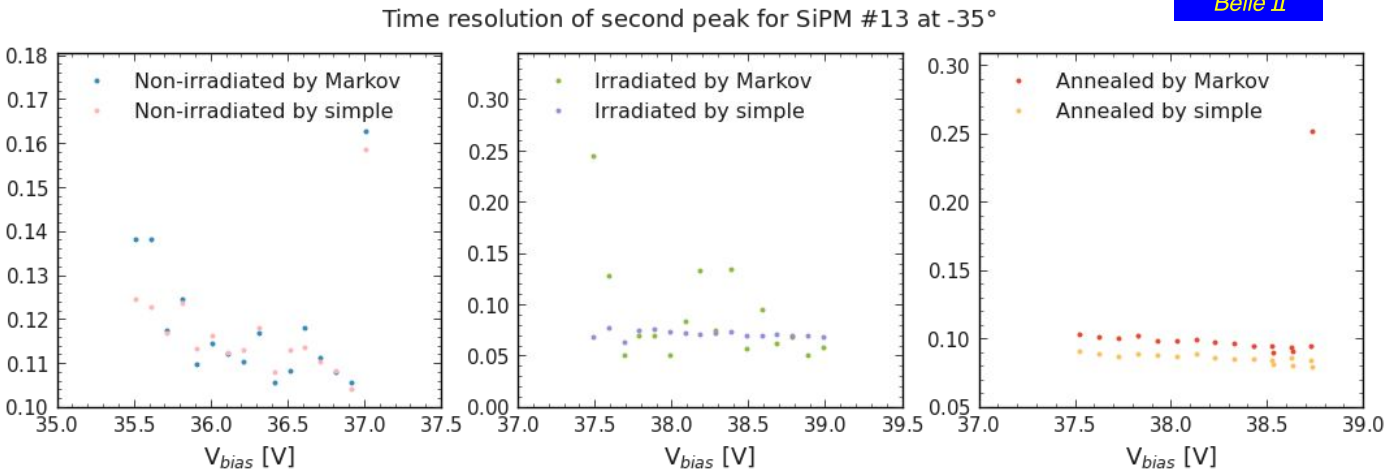
Time resolution for second photon peak



Time resolution for second photon peak

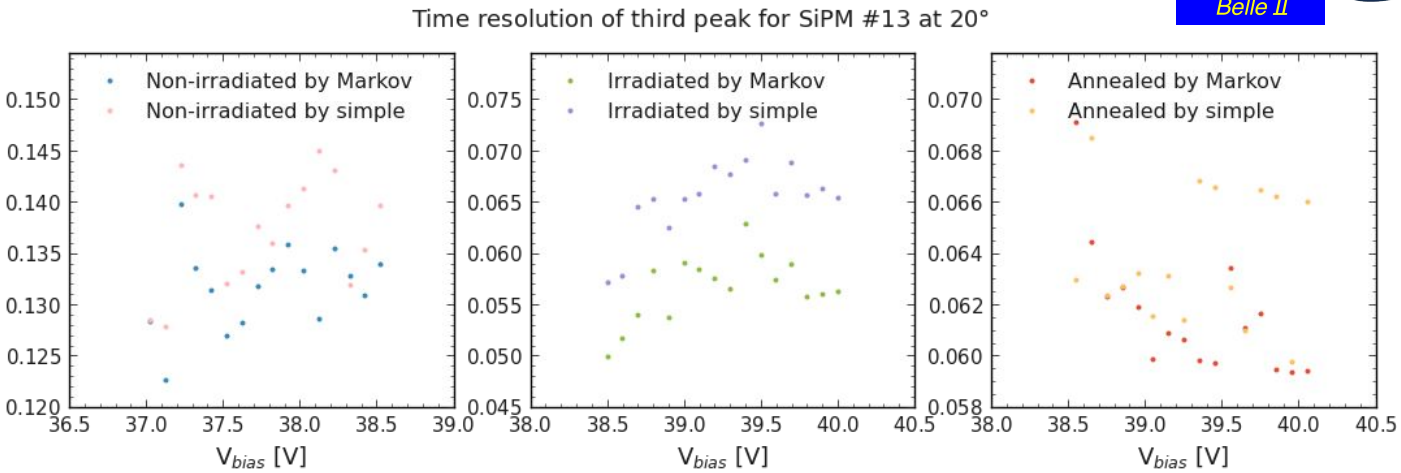


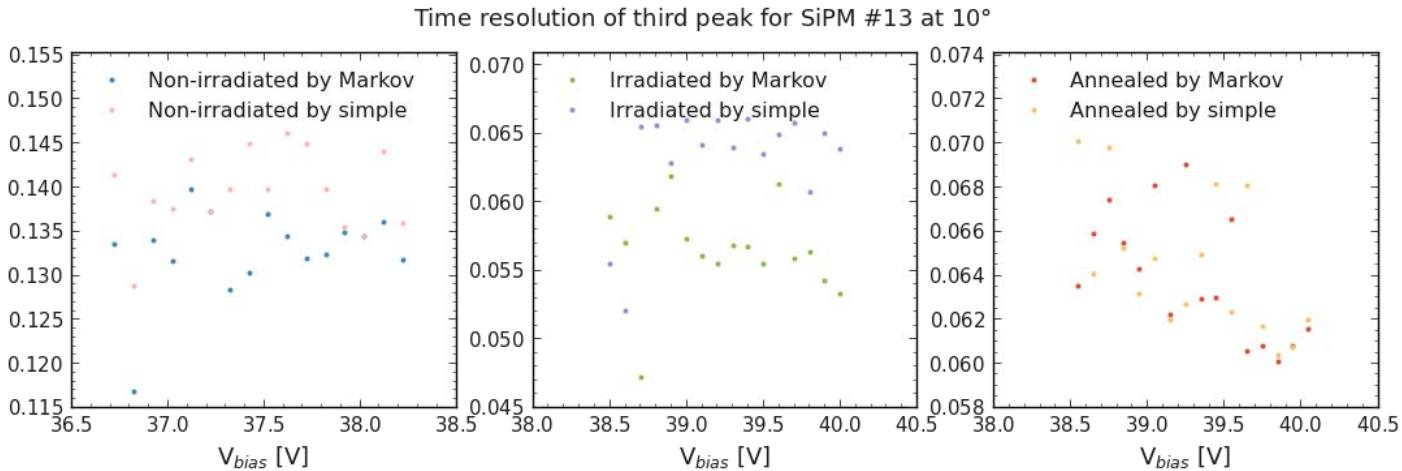
Time resolution for second photon peak



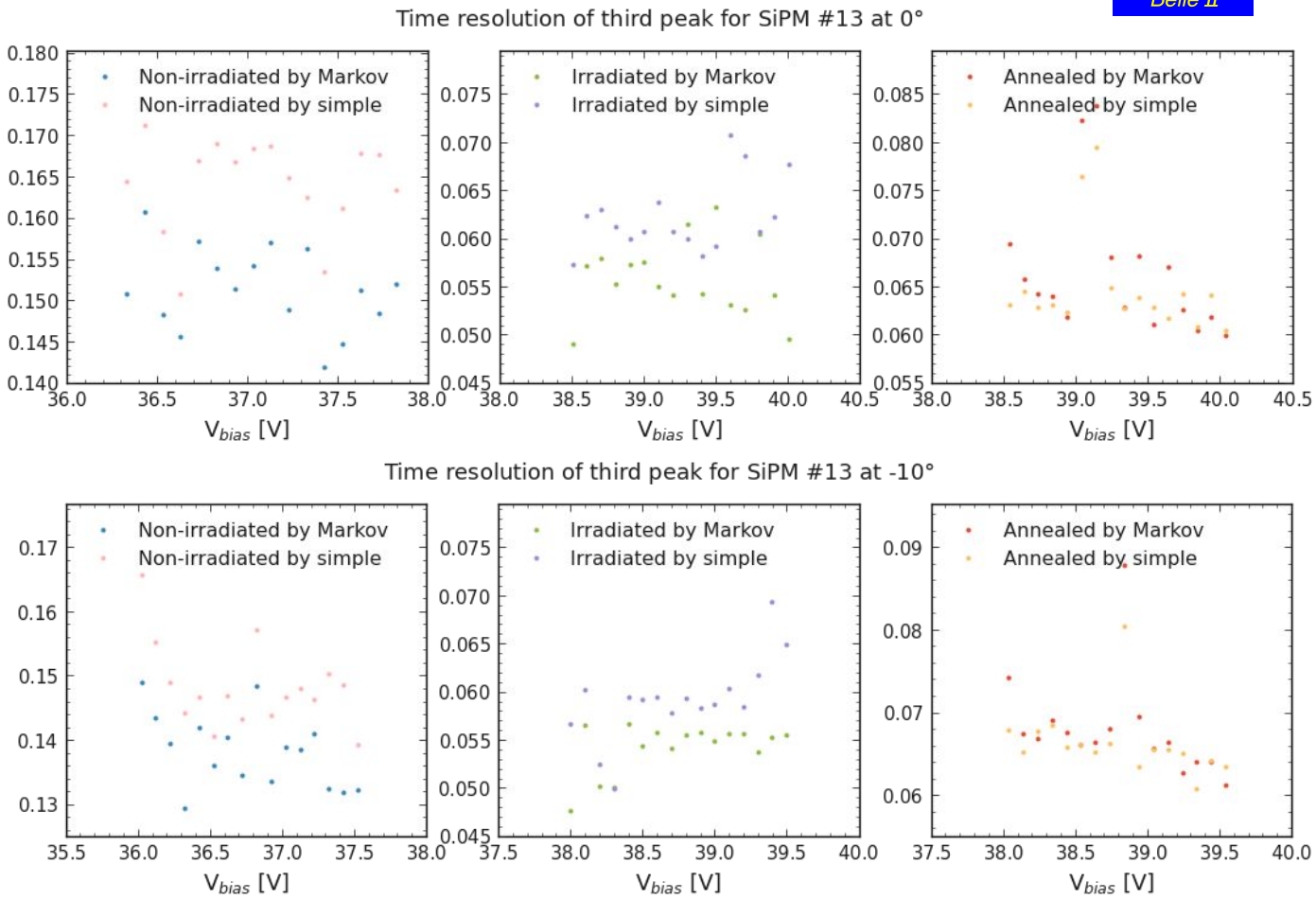
Time resolution for third photon peak for SiPM #13

Time resolution for third photon peak

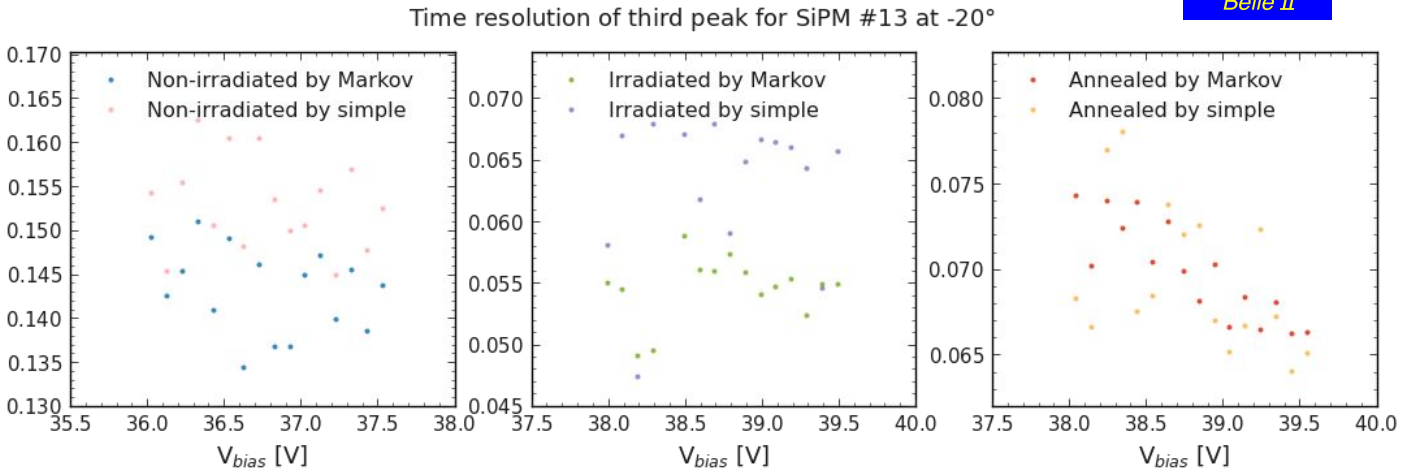


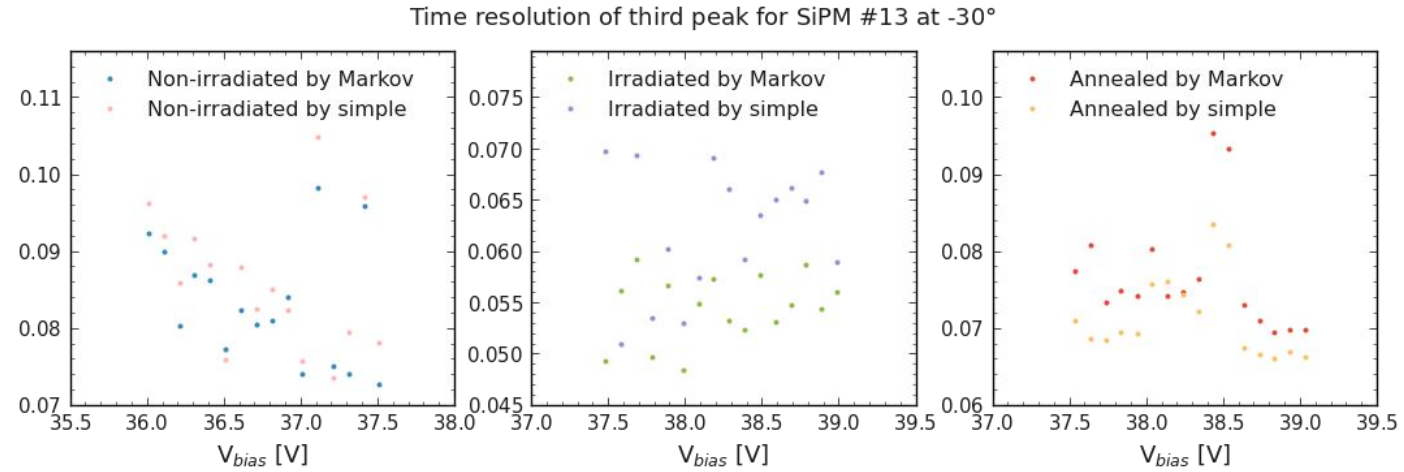


Time resolution for third photon peak

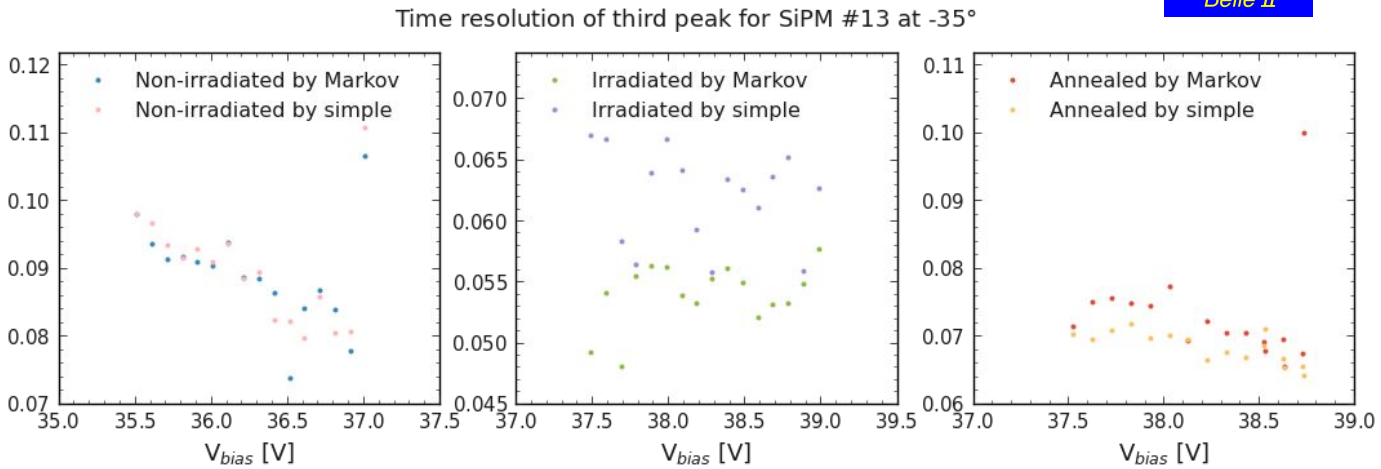


Time resolution for third photon peak



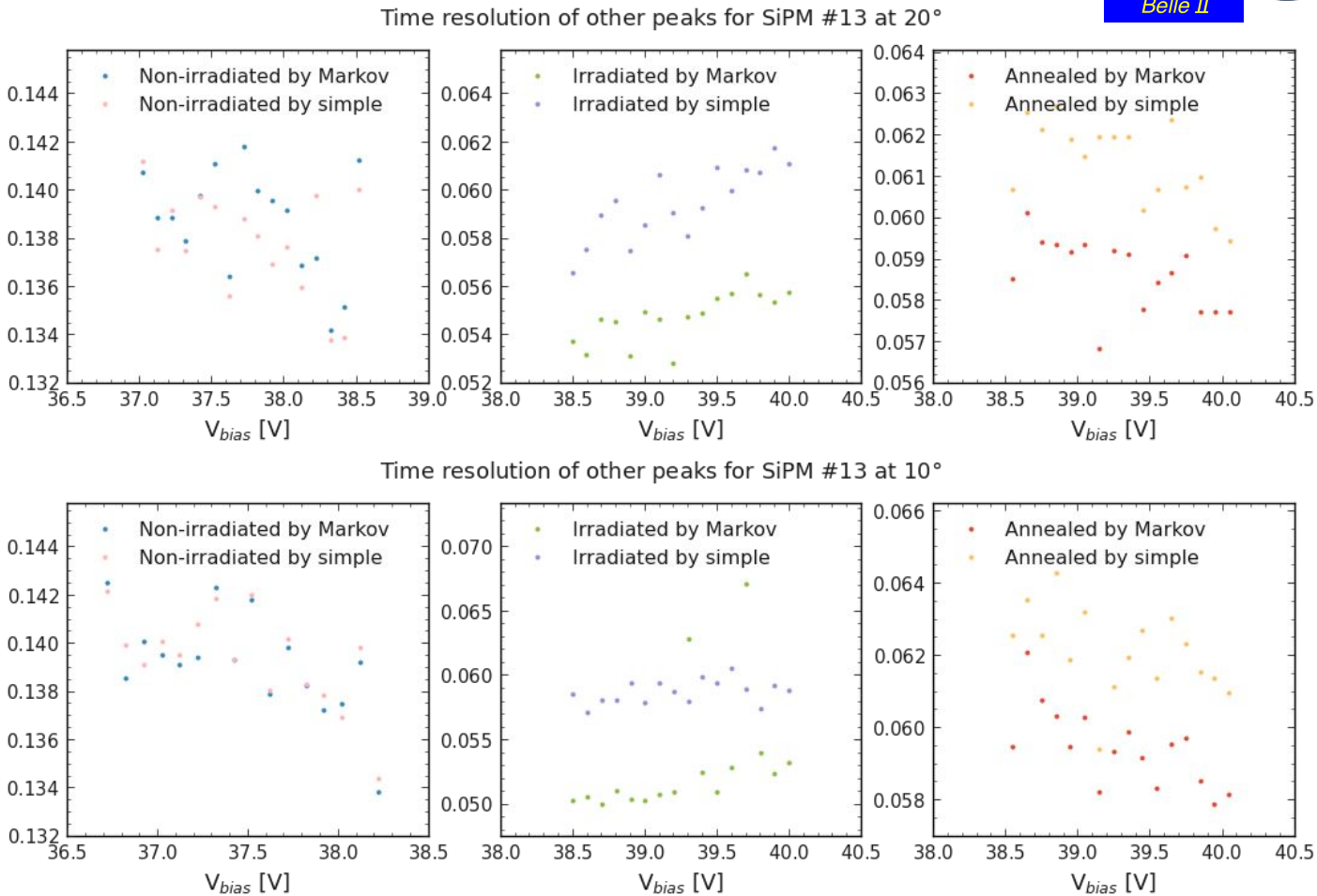


Time resolution for third photon peak

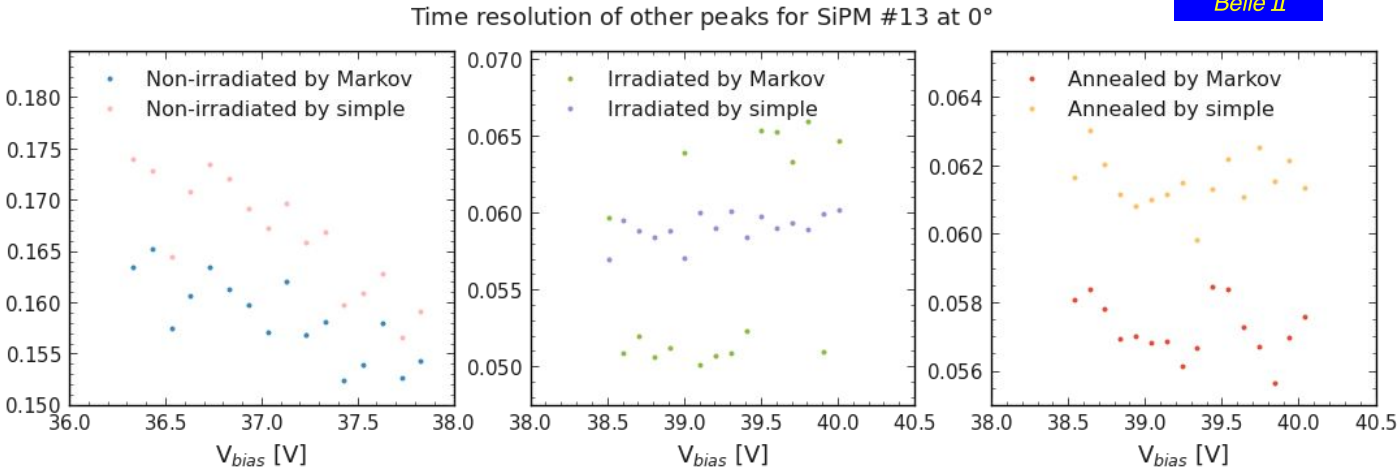


Time resolution for other photon peaks for SiPM #13

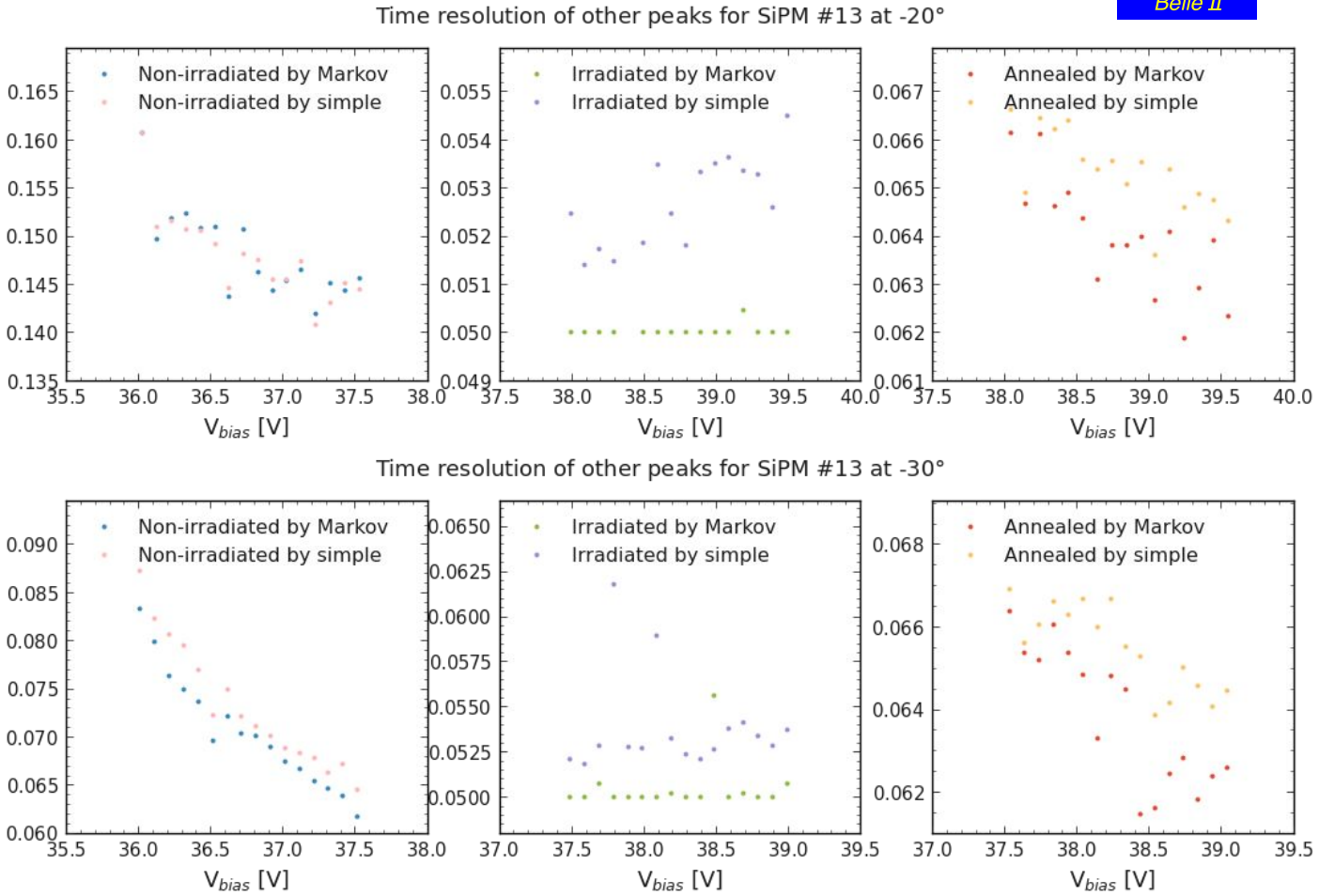
Time resolution for other photon peaks



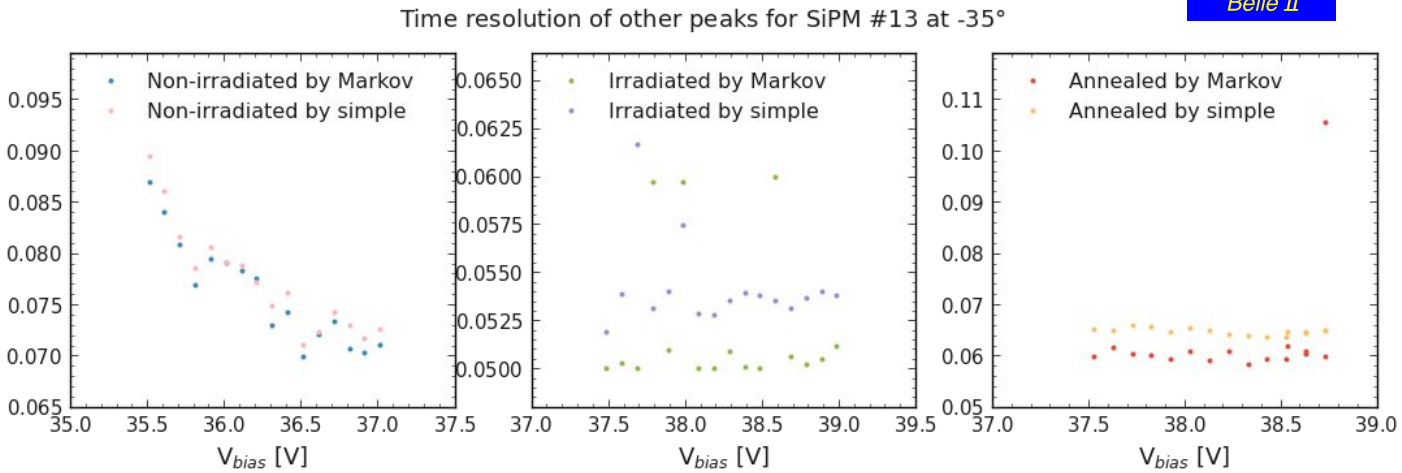
Time resolution for other photon peaks



Time resolution for other photon peaks

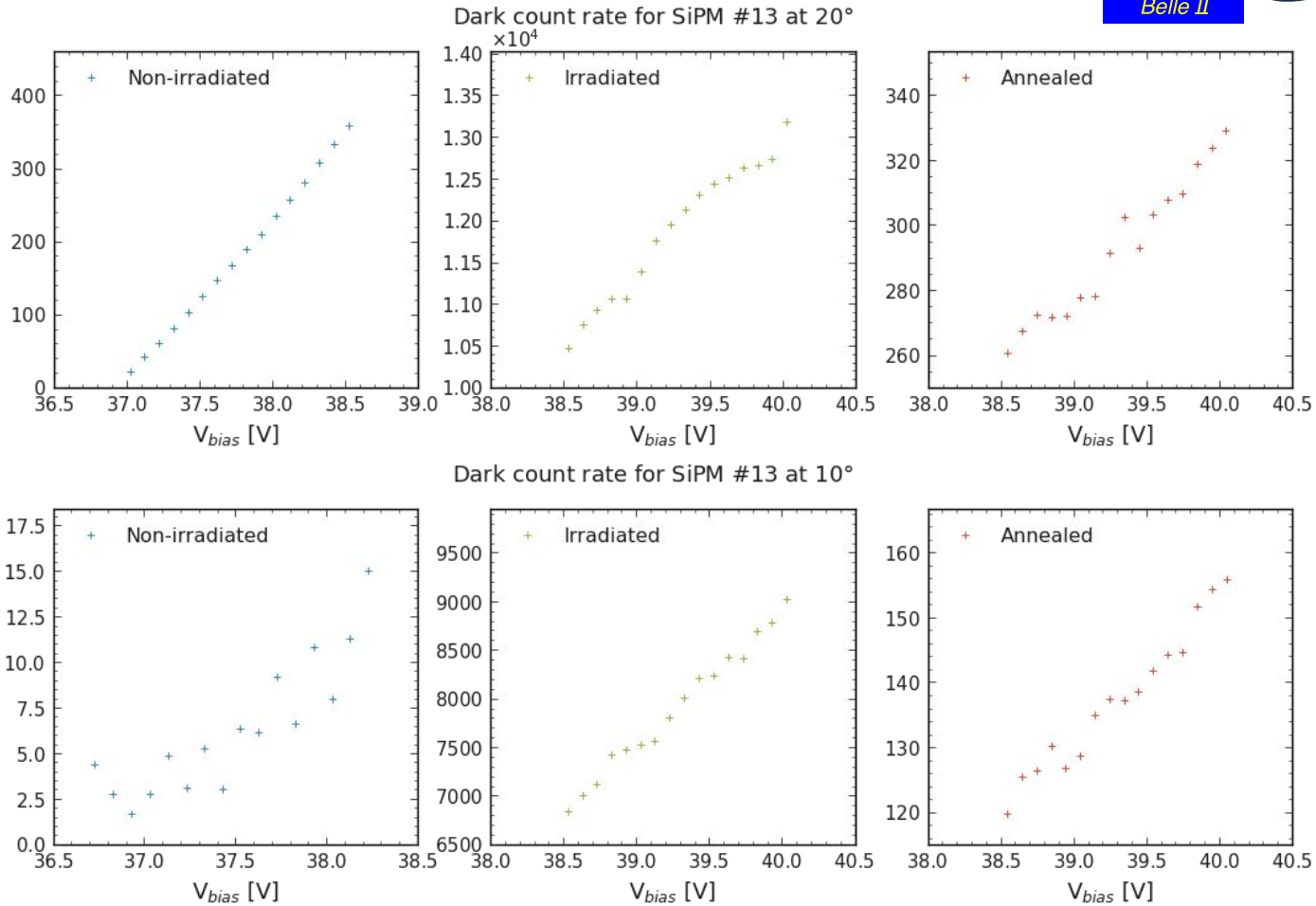


Time resolution for other photon peaks

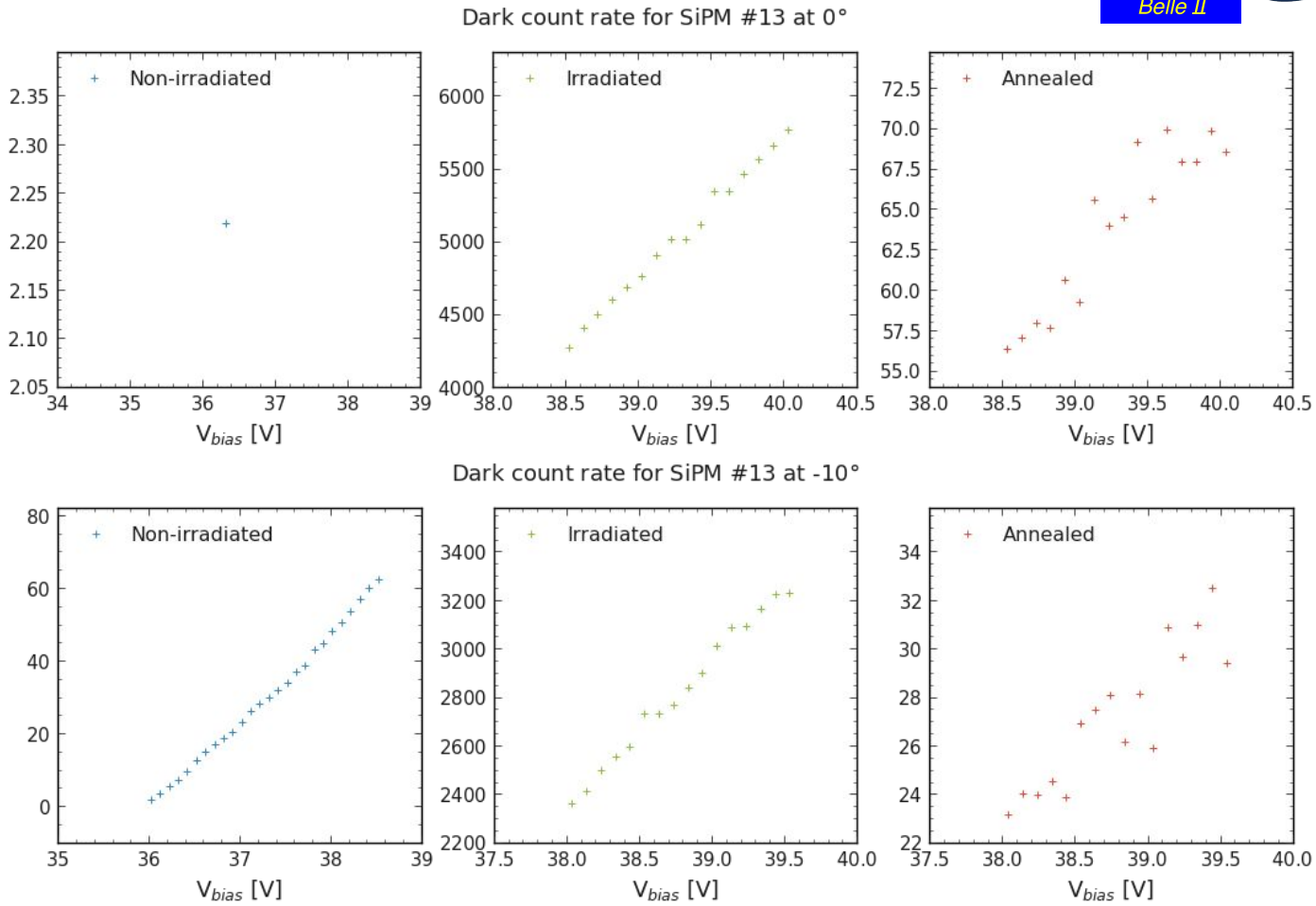


Dark count rate for SiPM #13

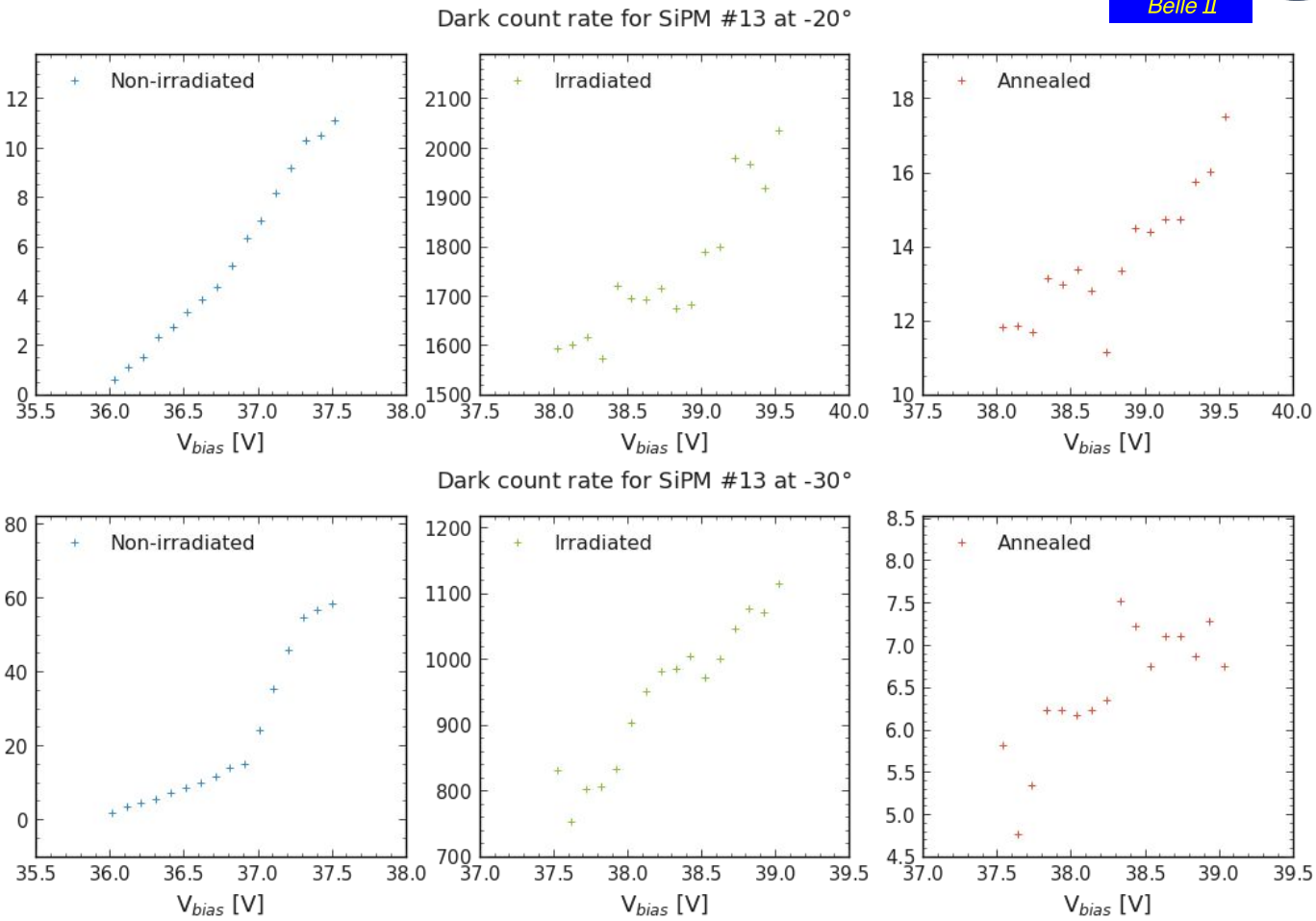
Dark count rate



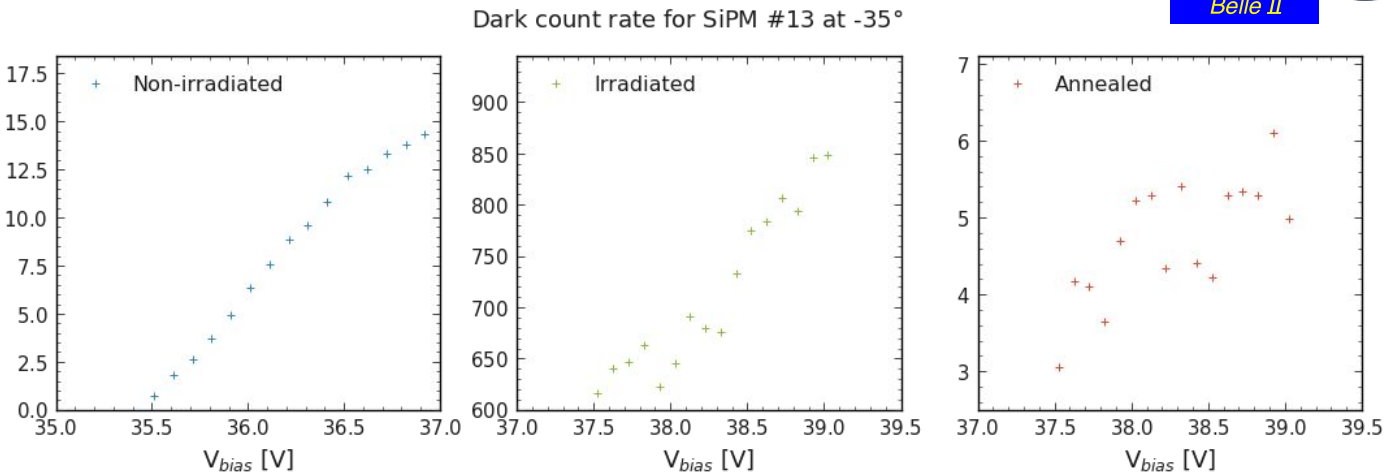
Dark count rate



Dark count rate



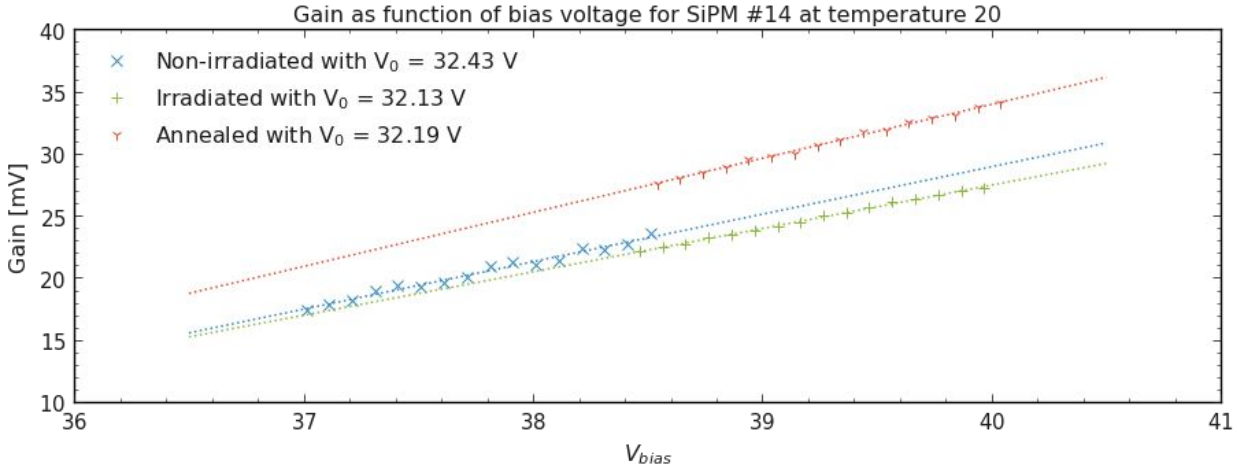
Dark count rate

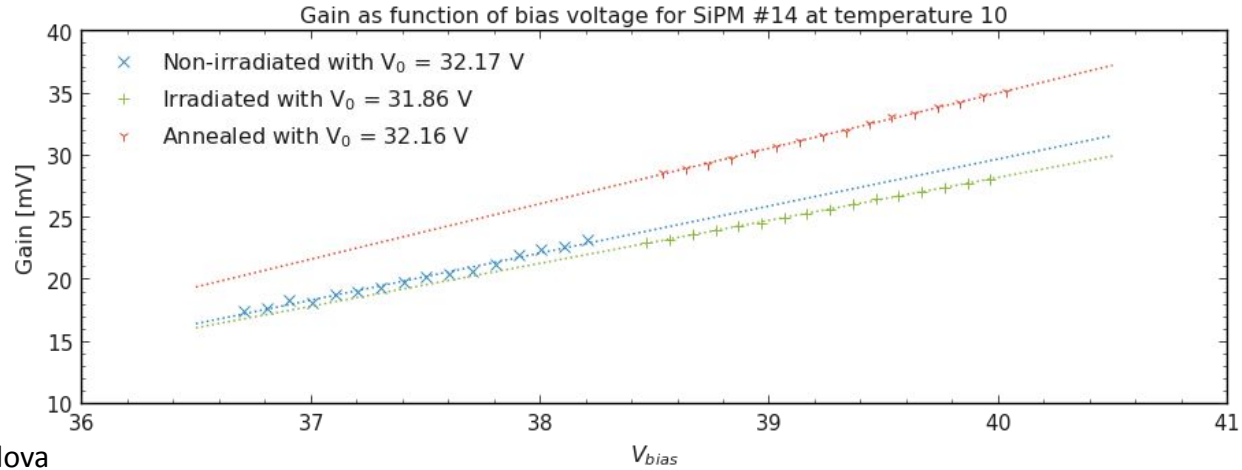


SiMP #14

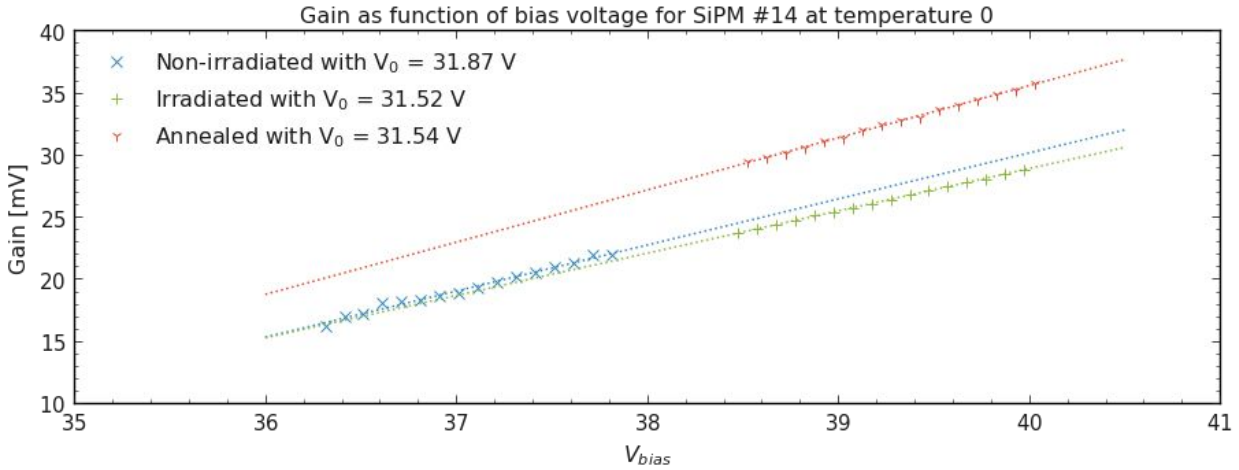
Gain as function of bias voltage for SiPM #14

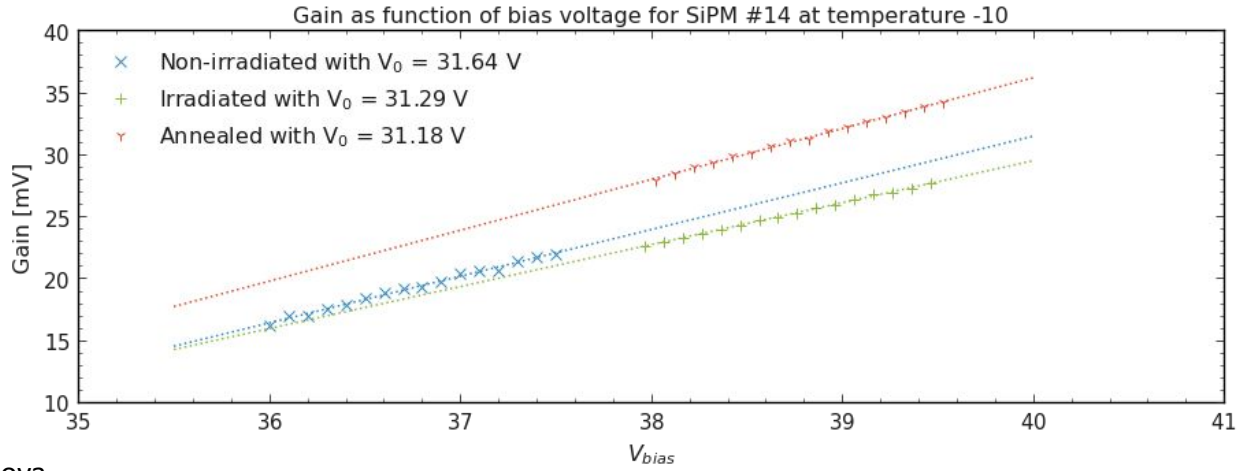
Gain as function of bias voltage



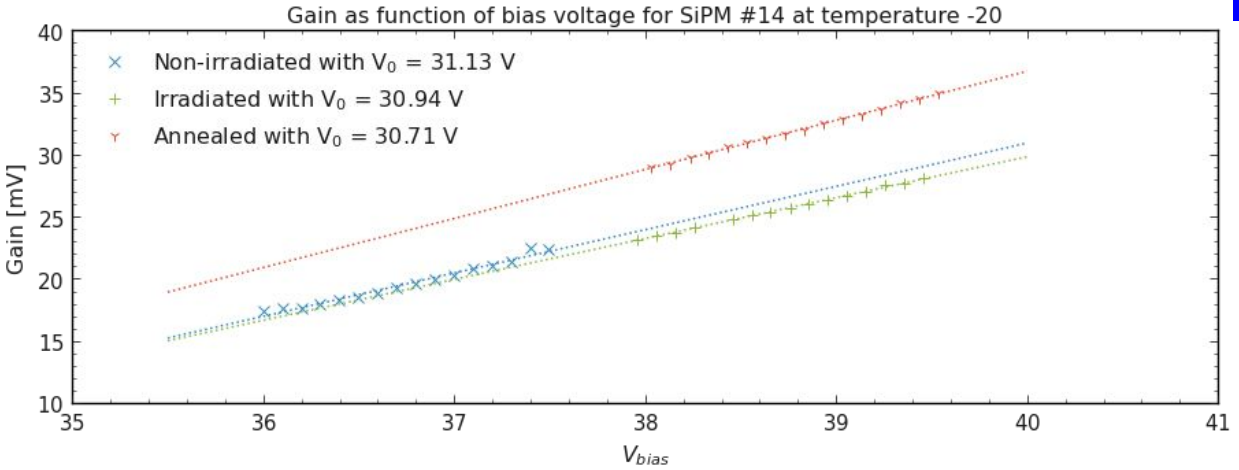


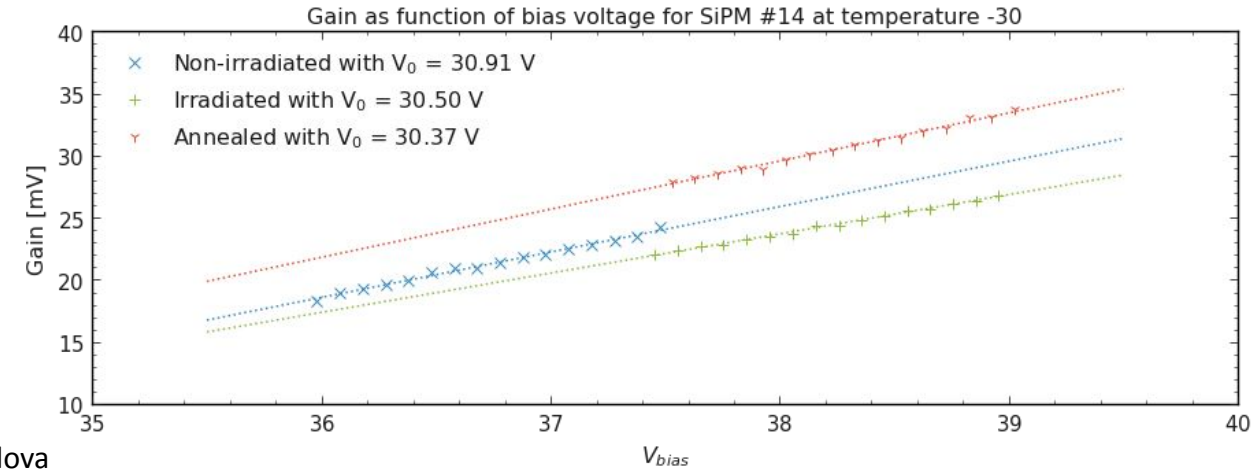
Gain as function of bias voltage



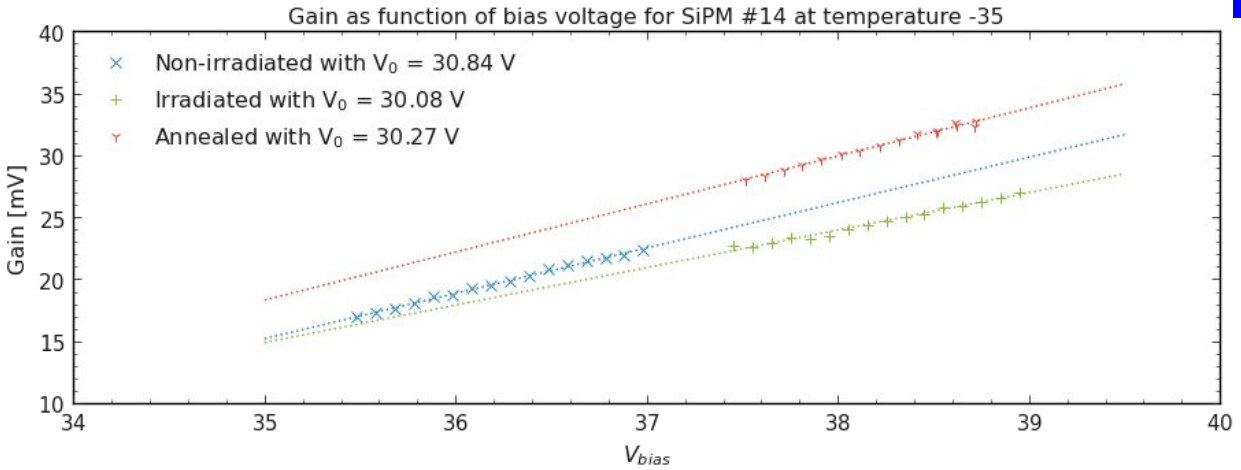


Gain as function of bias voltage



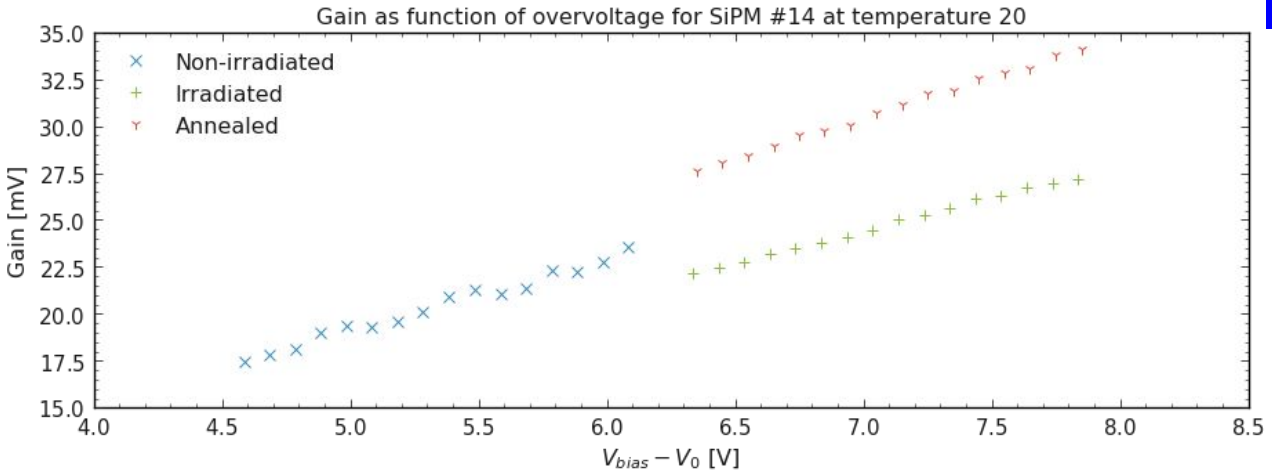


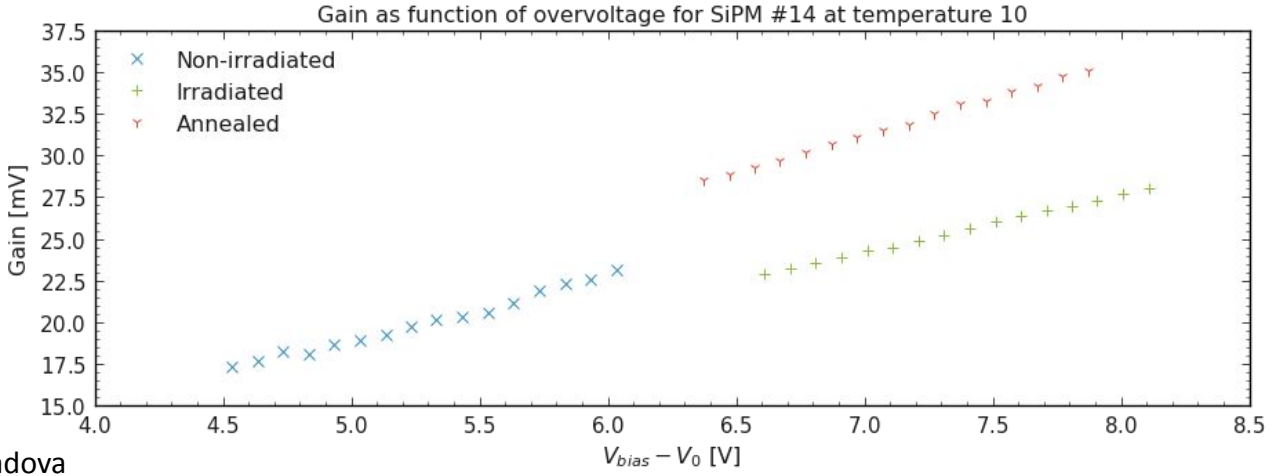
Gain as function of bias voltage



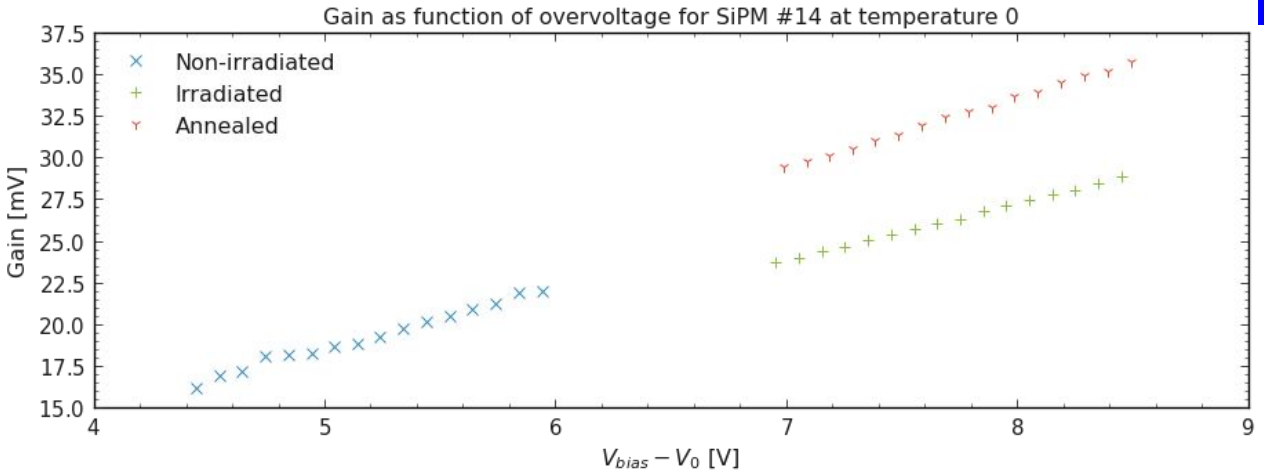
Gain as function of overvoltage for SiPM #14

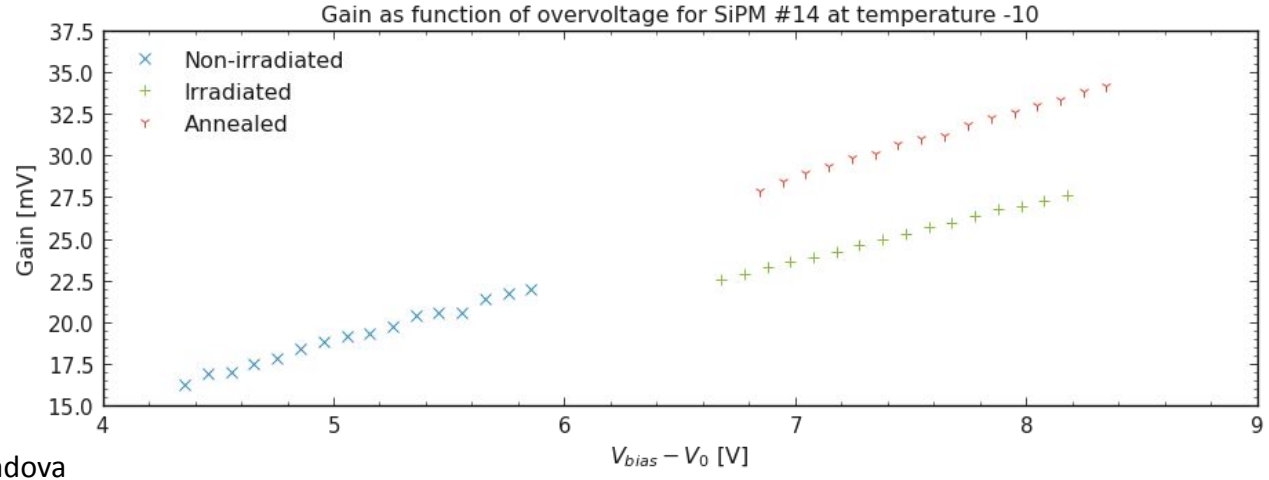
Gain as function of overvoltage



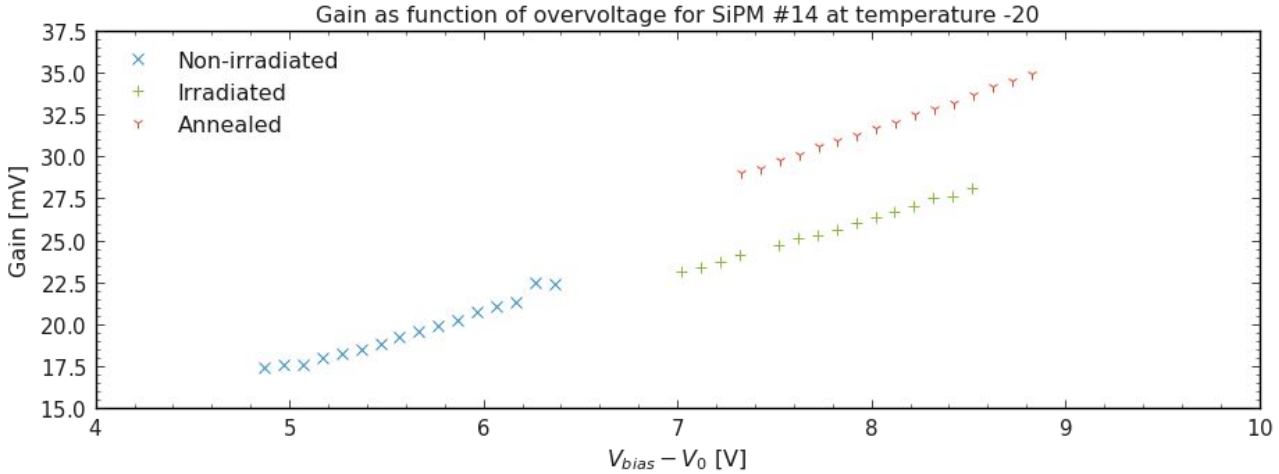


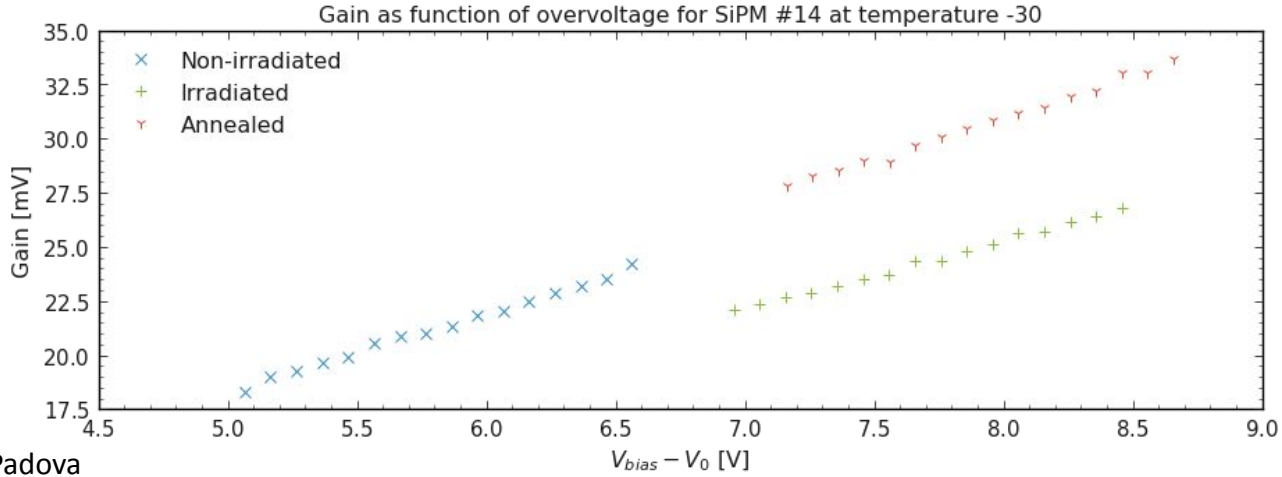
Gain as function of overvoltage



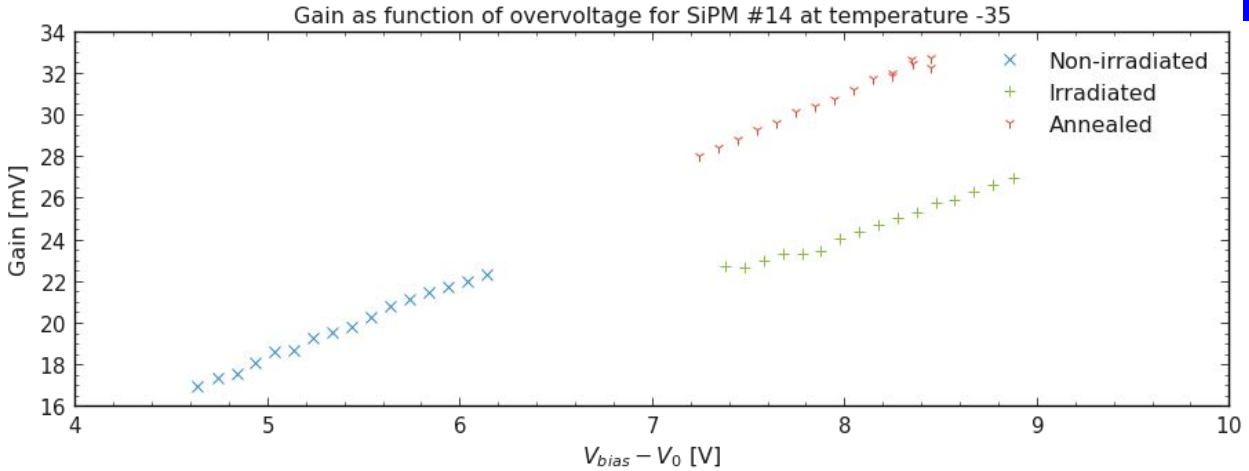


Gain as function of overvoltage



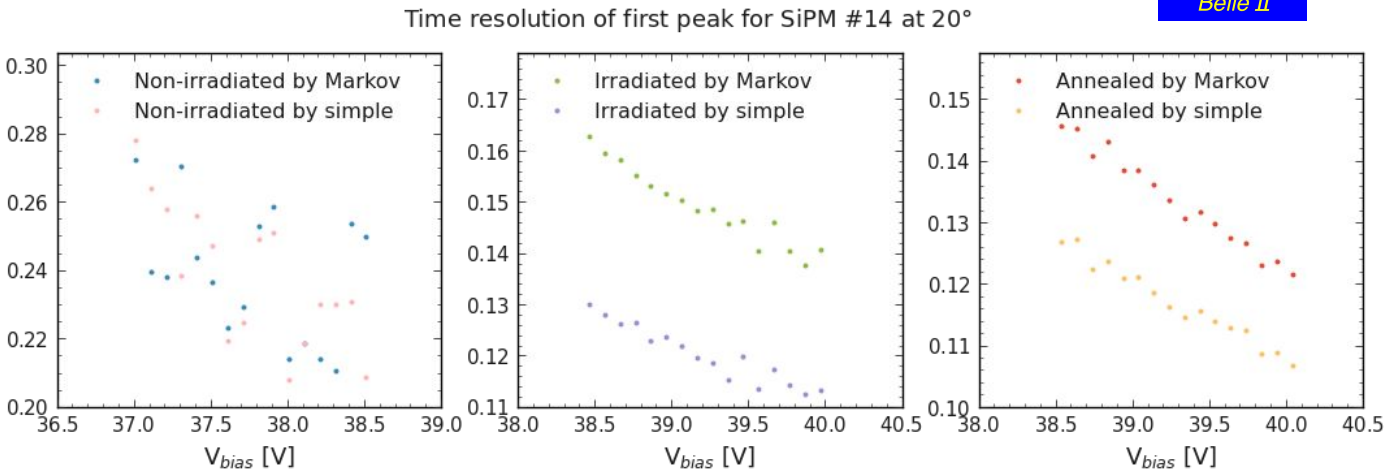


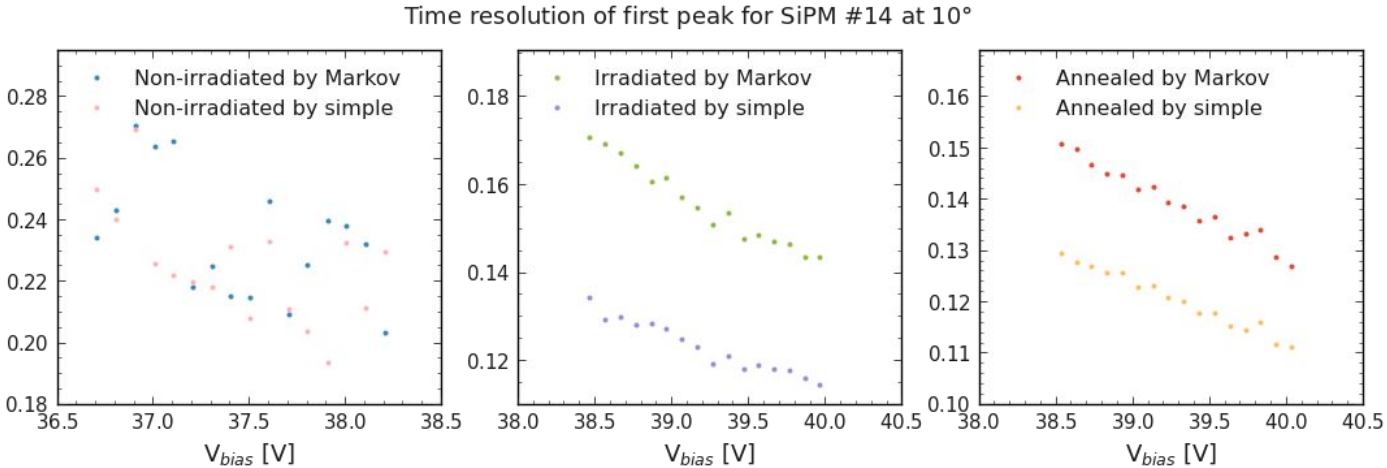
Gain as function of overvoltage



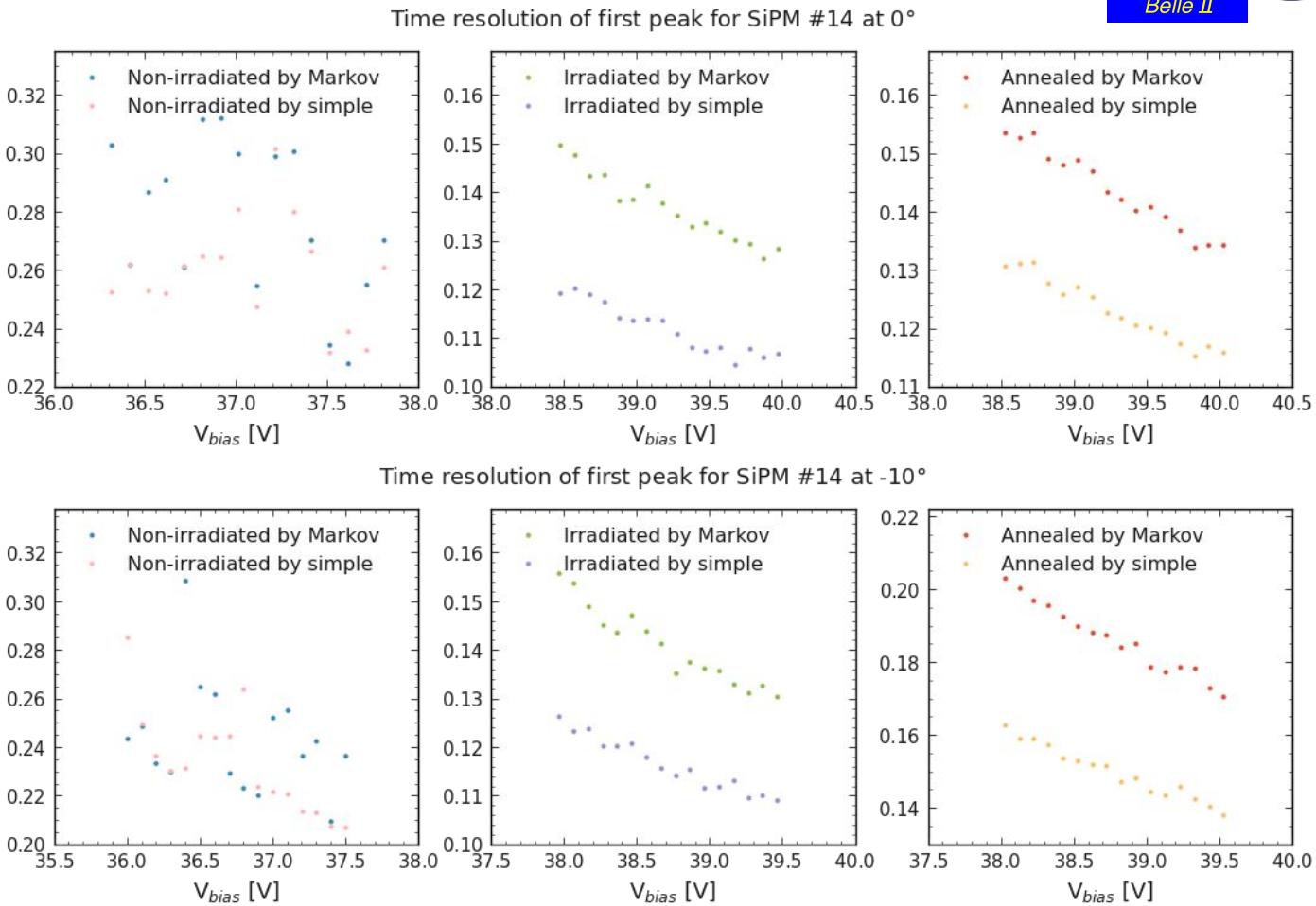
Time resolution for first photon peak for SiPM #14

Time resolution for first photon peak

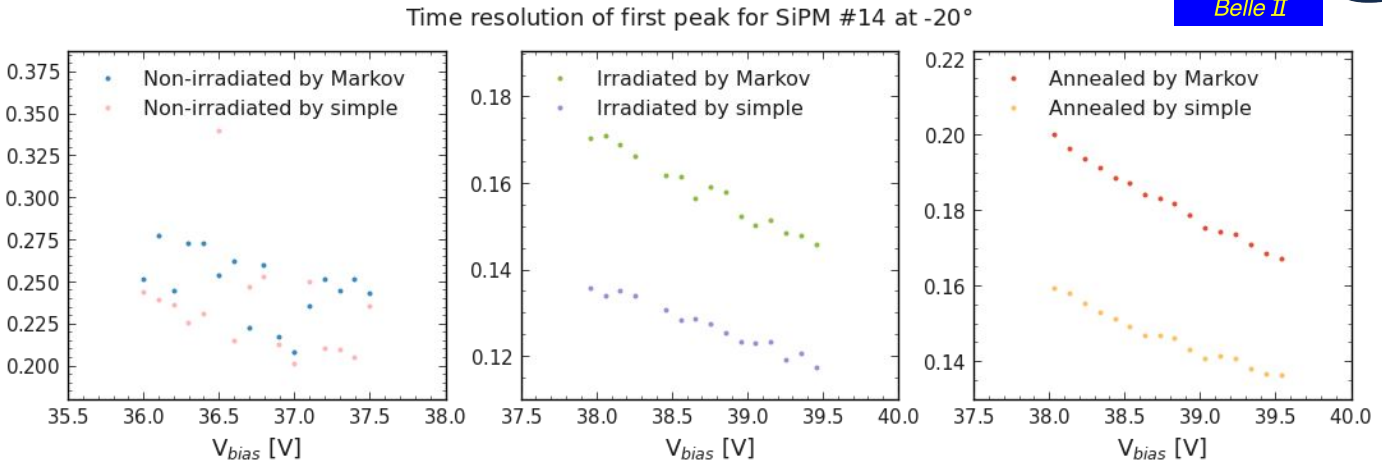


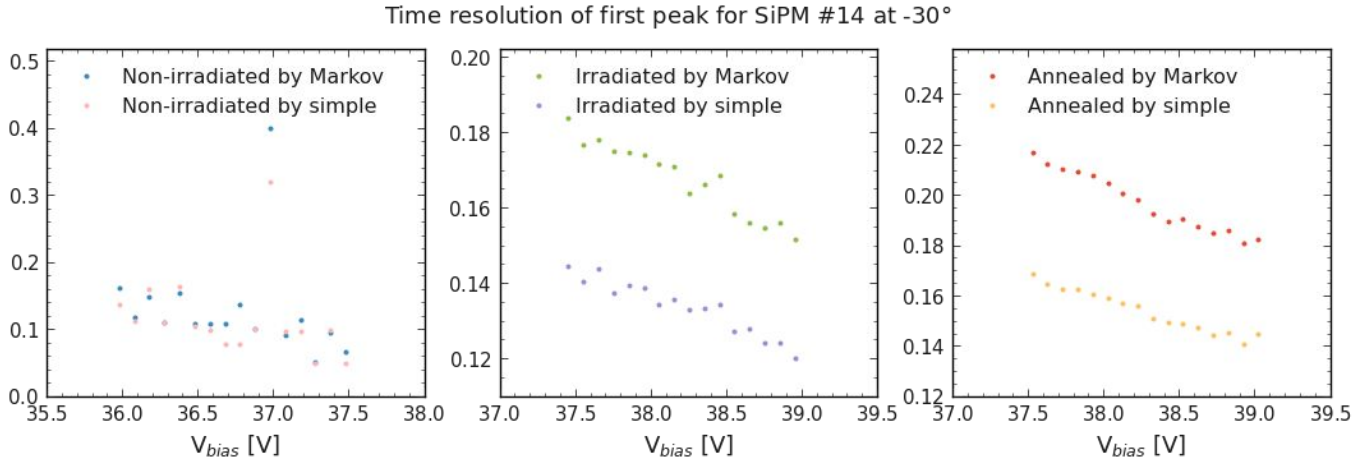


Time resolution for first photon peak

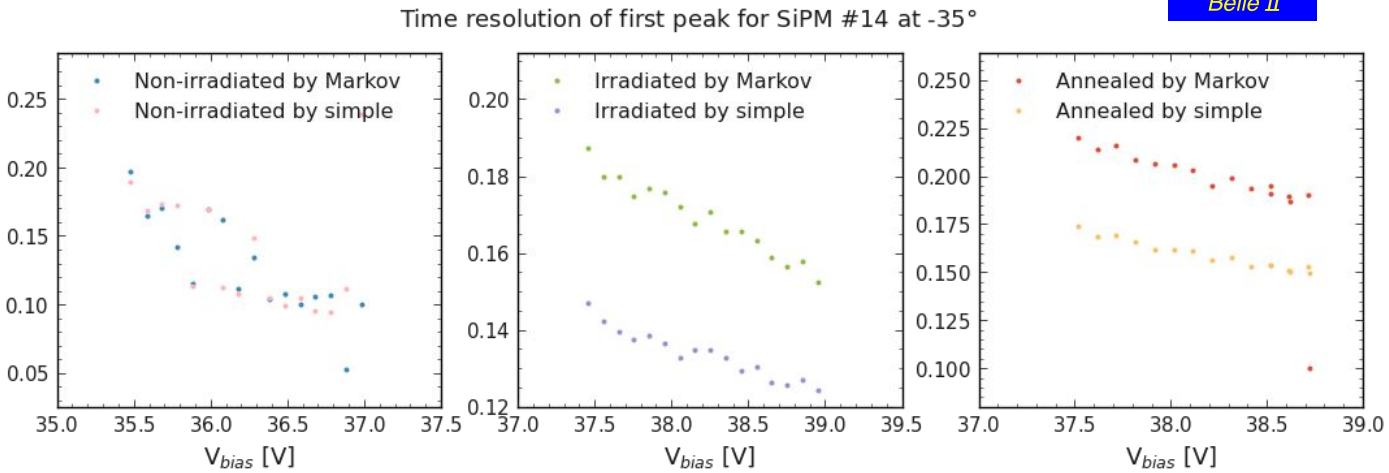


Time resolution for first photon peak



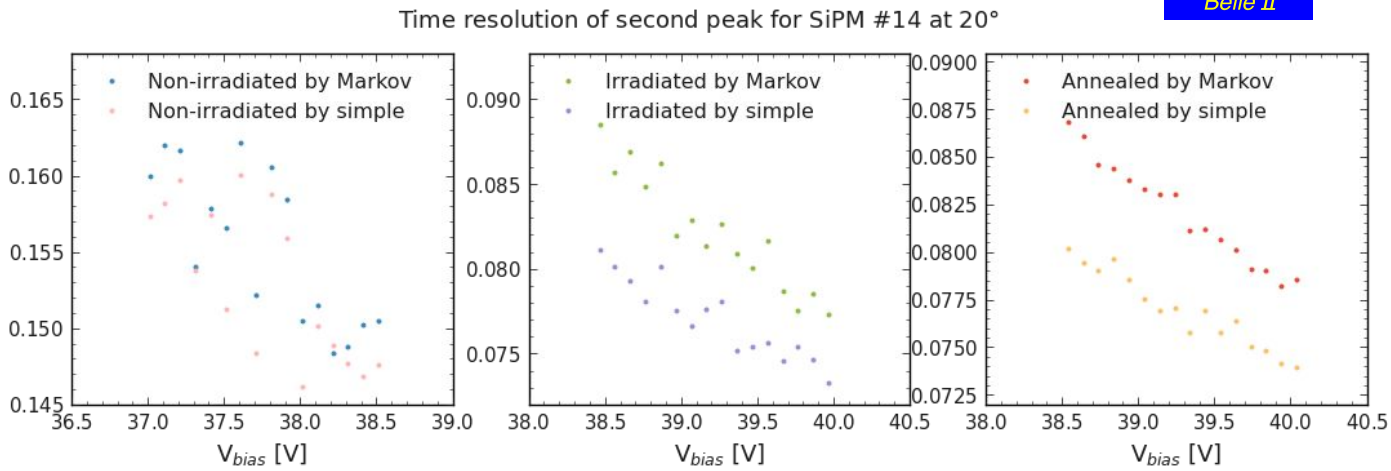


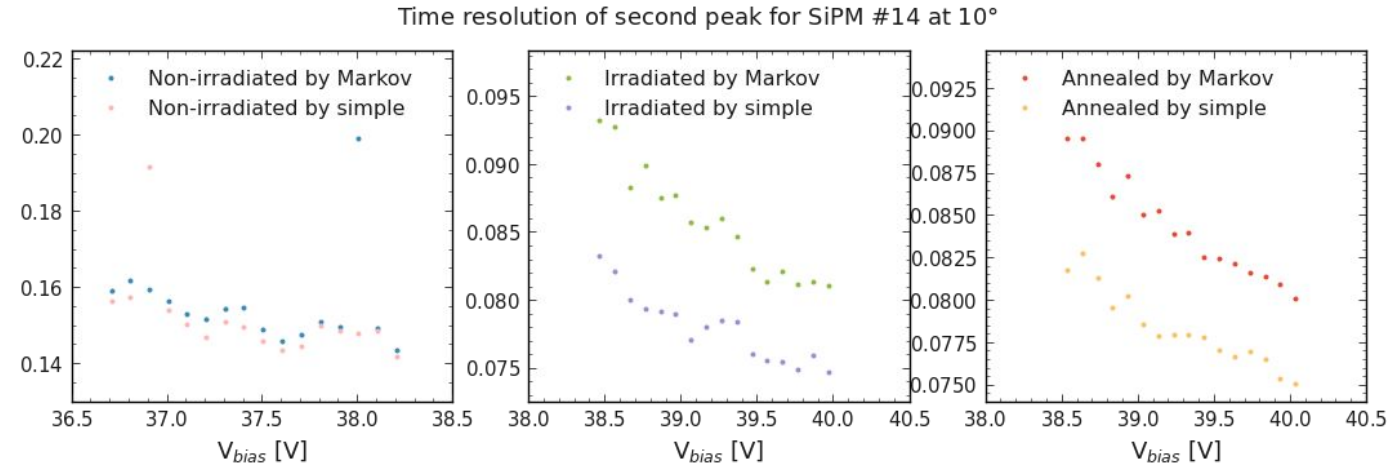
Time resolution for first photon peak



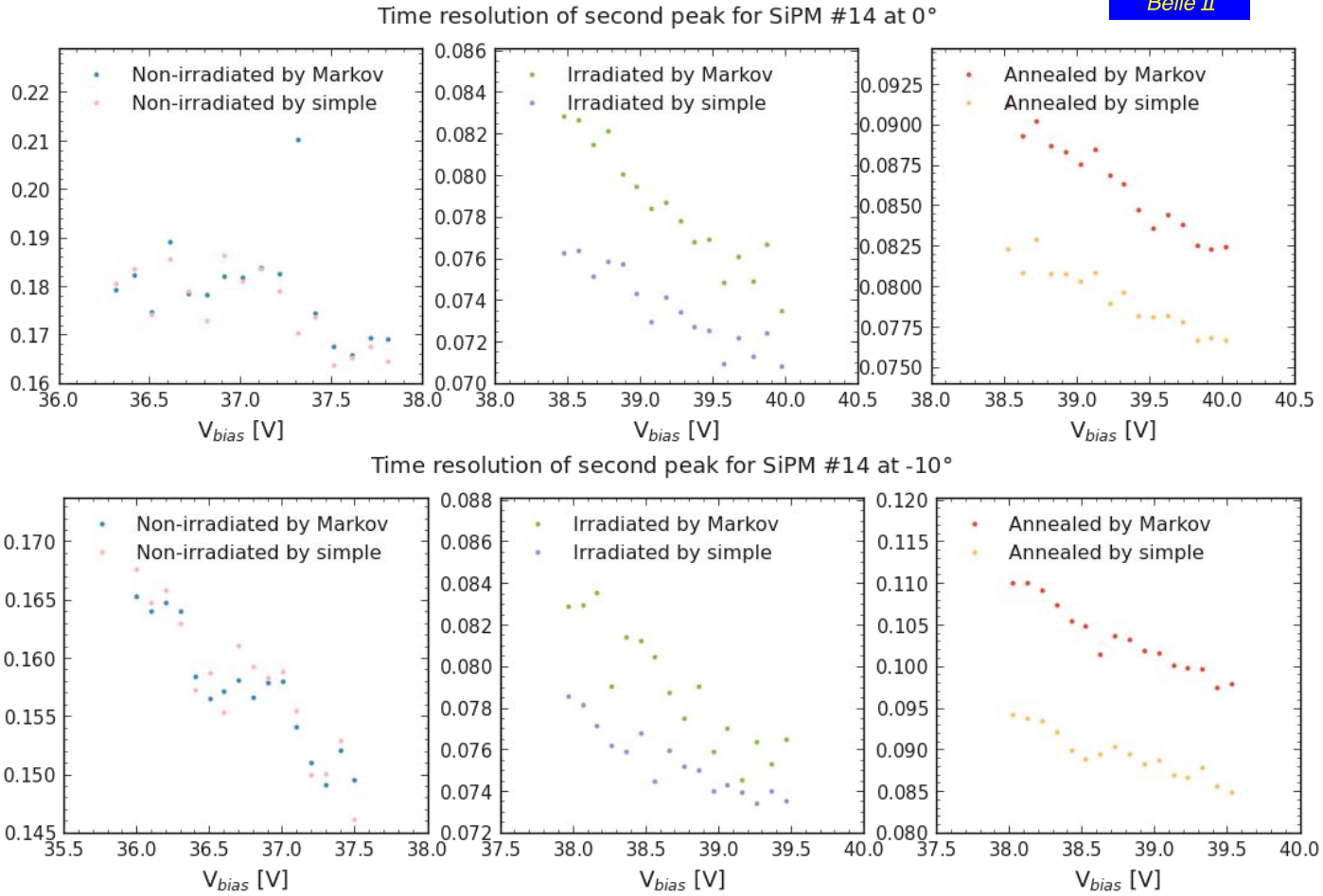
Time resolution for second photon peak for SiPM #14

Time resolution for second photon peak

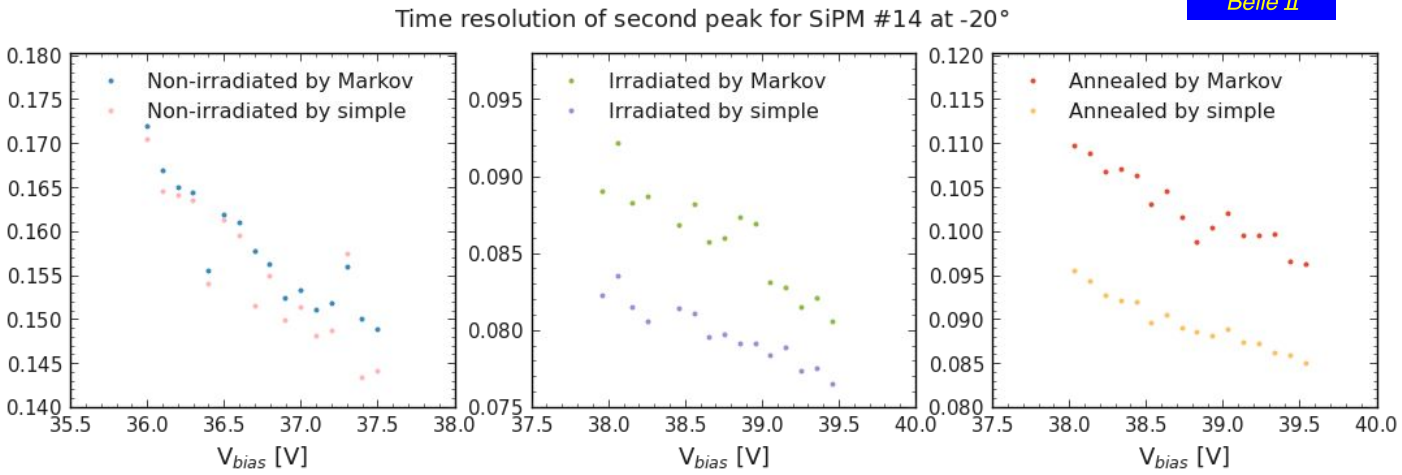


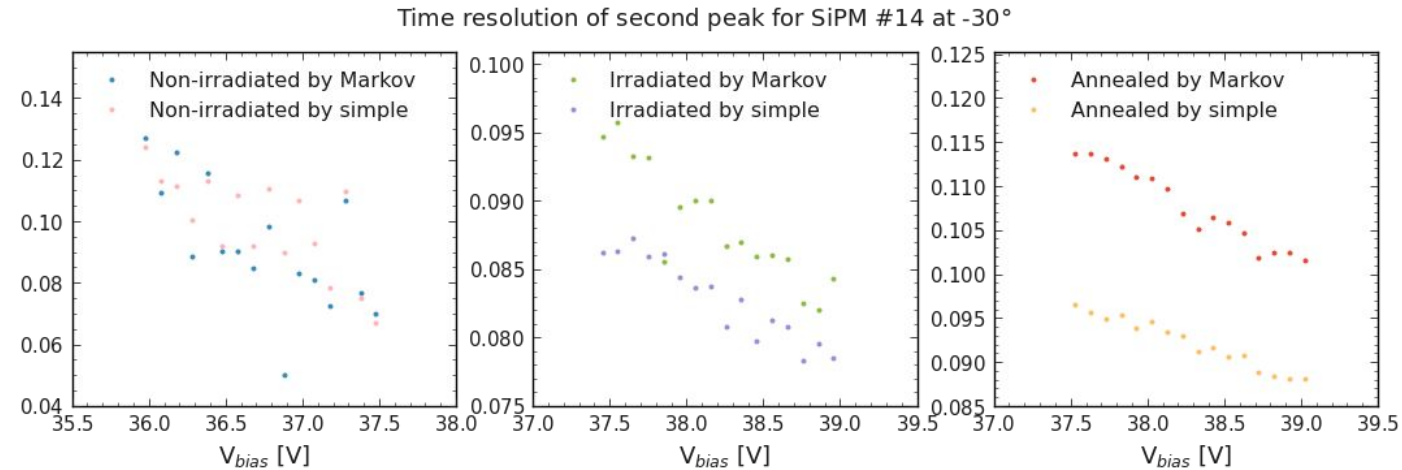


Time resolution for second photon peak

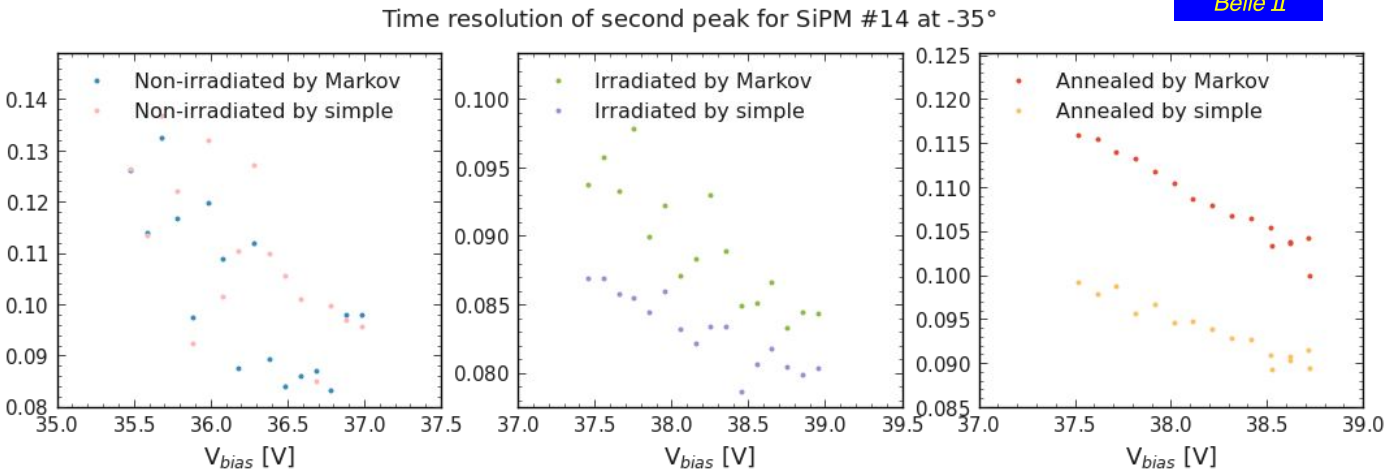


Time resolution for second photon peak



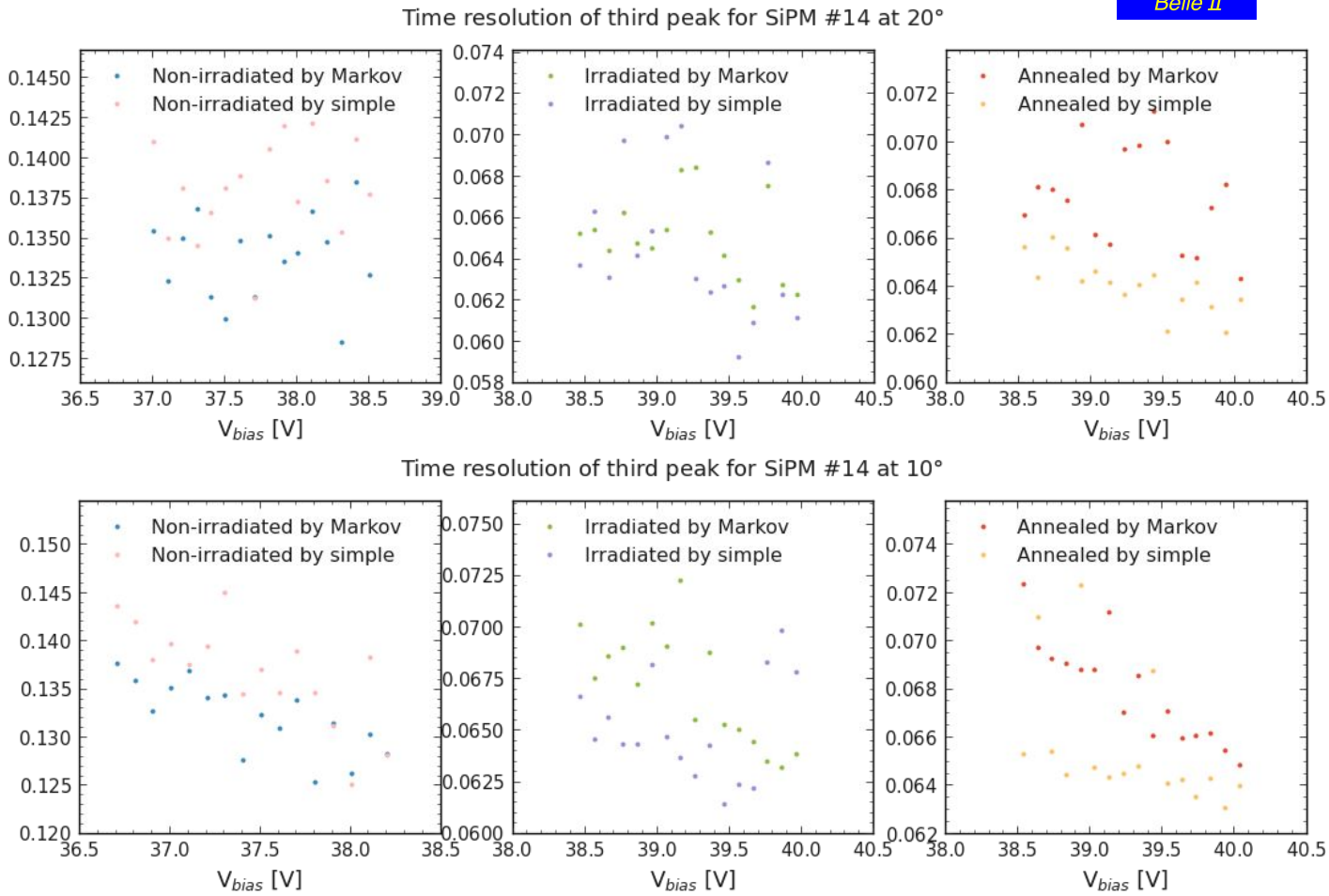


Time resolution for second photon peak

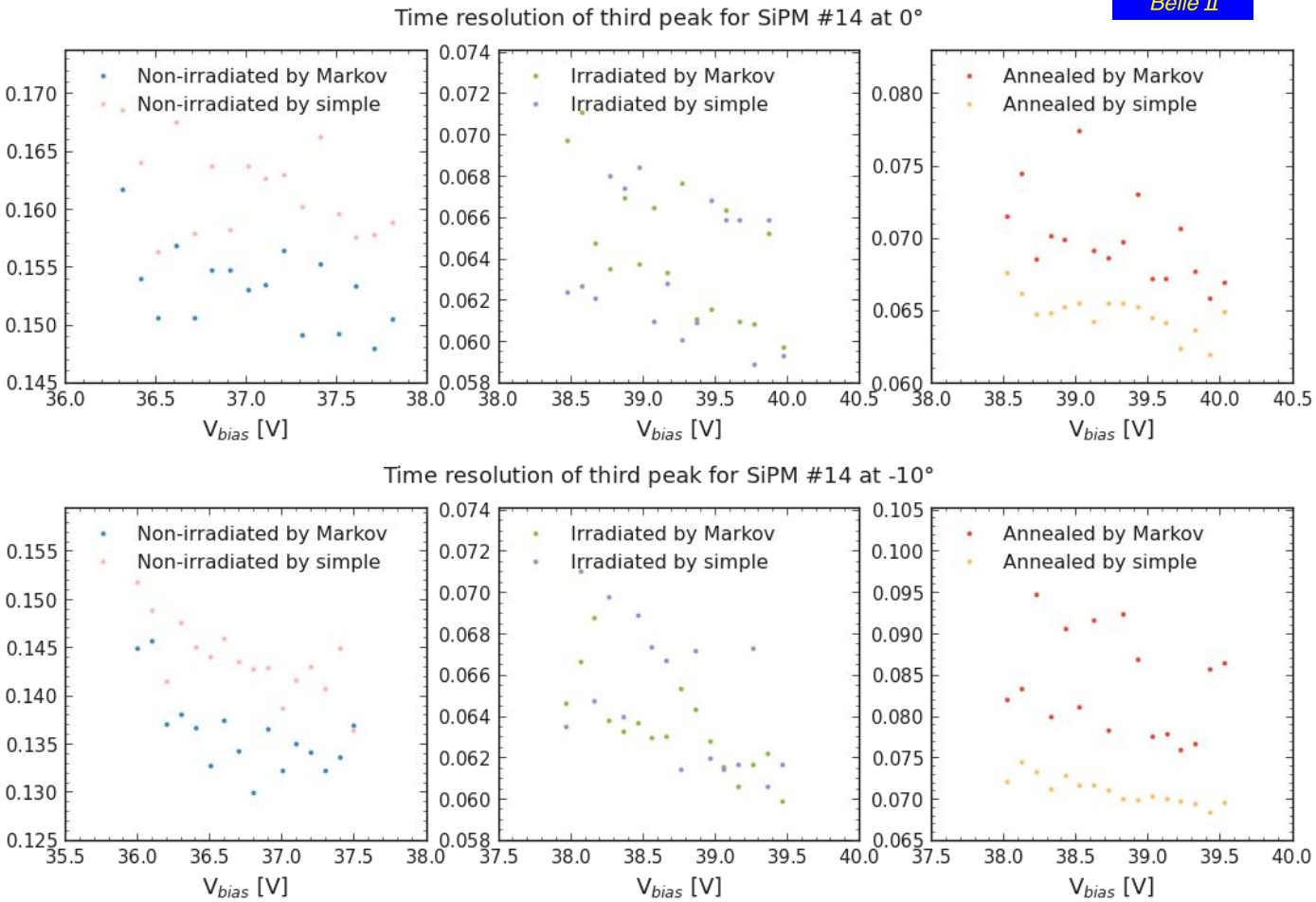


Time resolution for third photon peak for SiPM #14

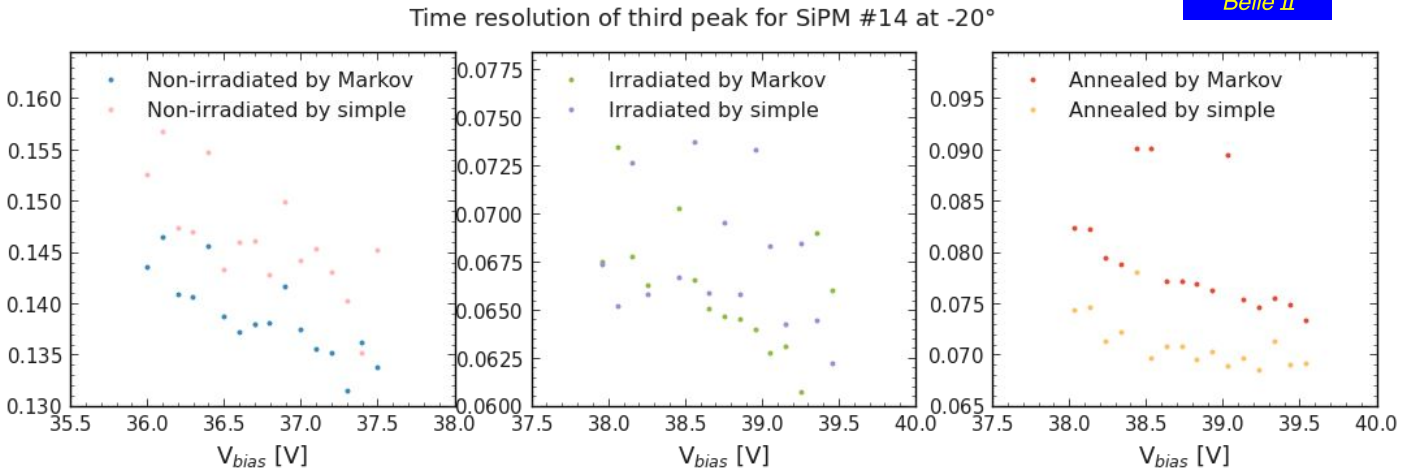
Time resolution for third photon peak

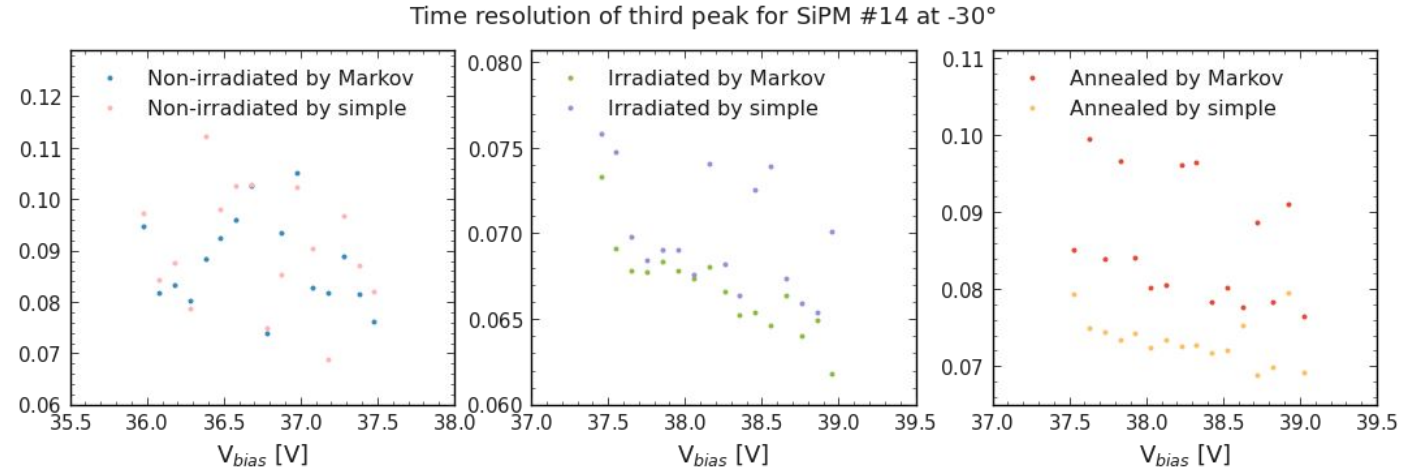


Time resolution for third photon peak

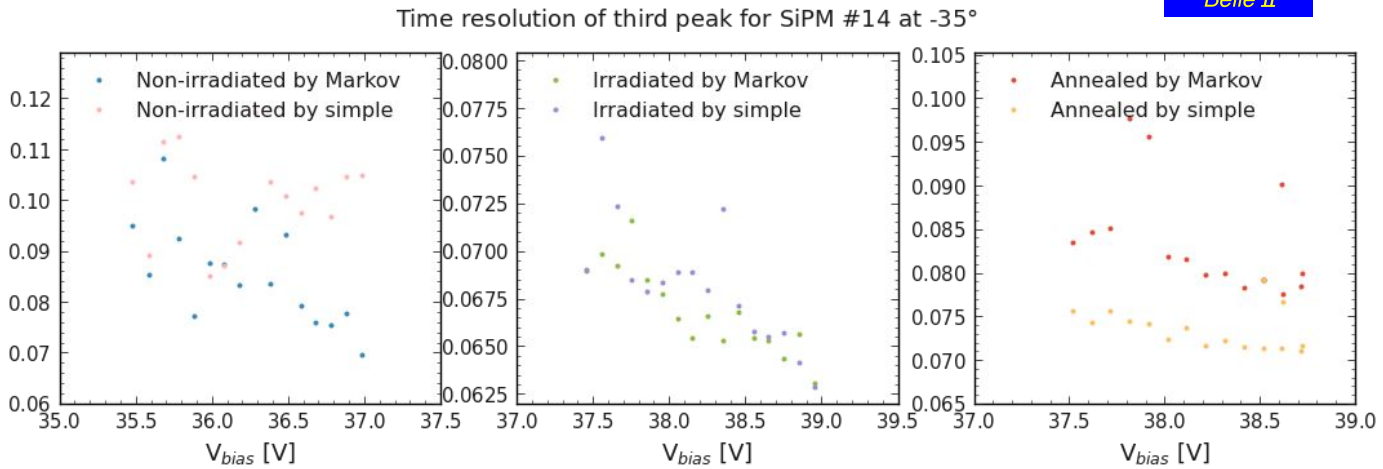


Time resolution for third photon peak



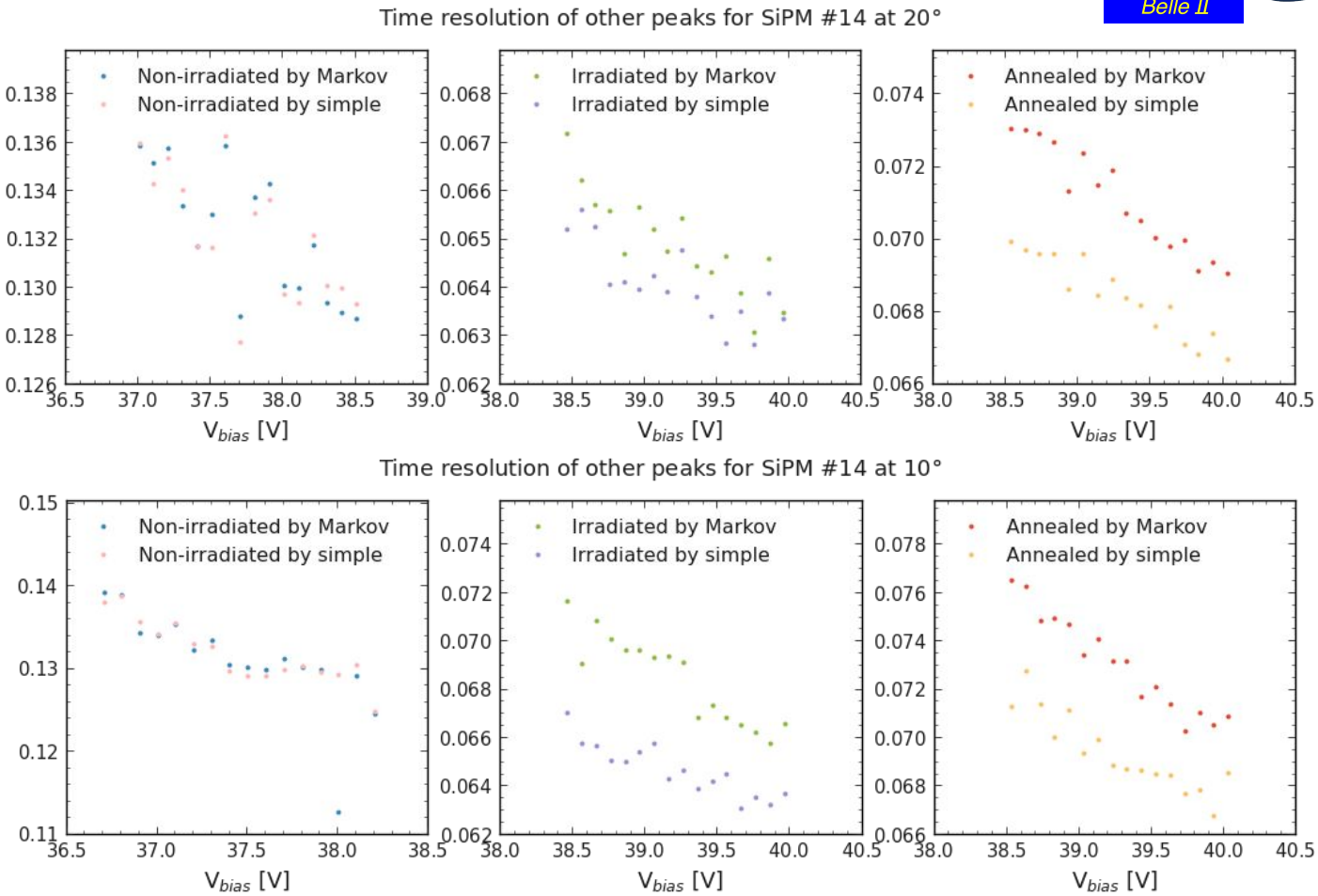


Time resolution for third photon peak

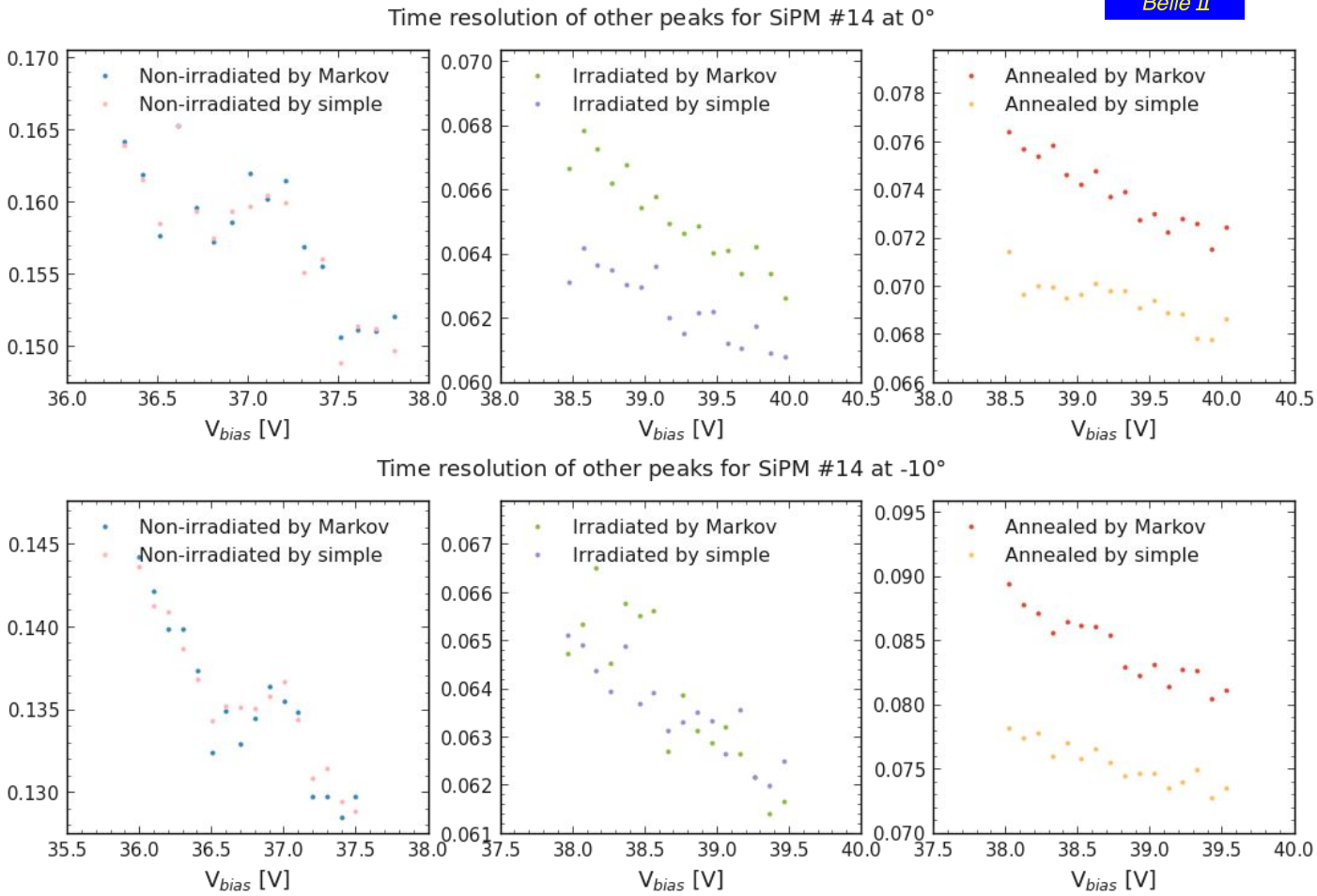


Time resolution for other photon peaks for SiPM #14

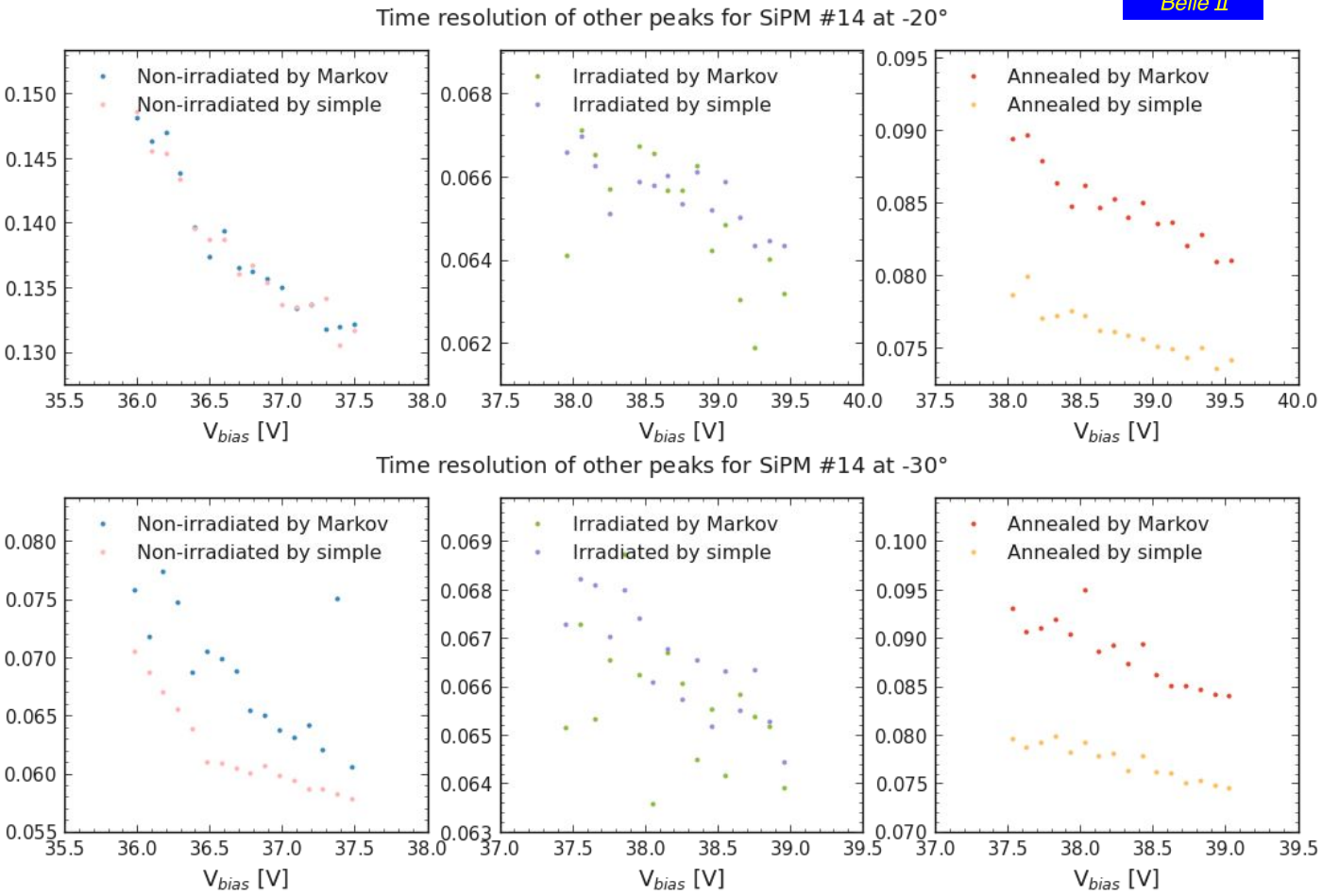
Time resolution for other photon peaks



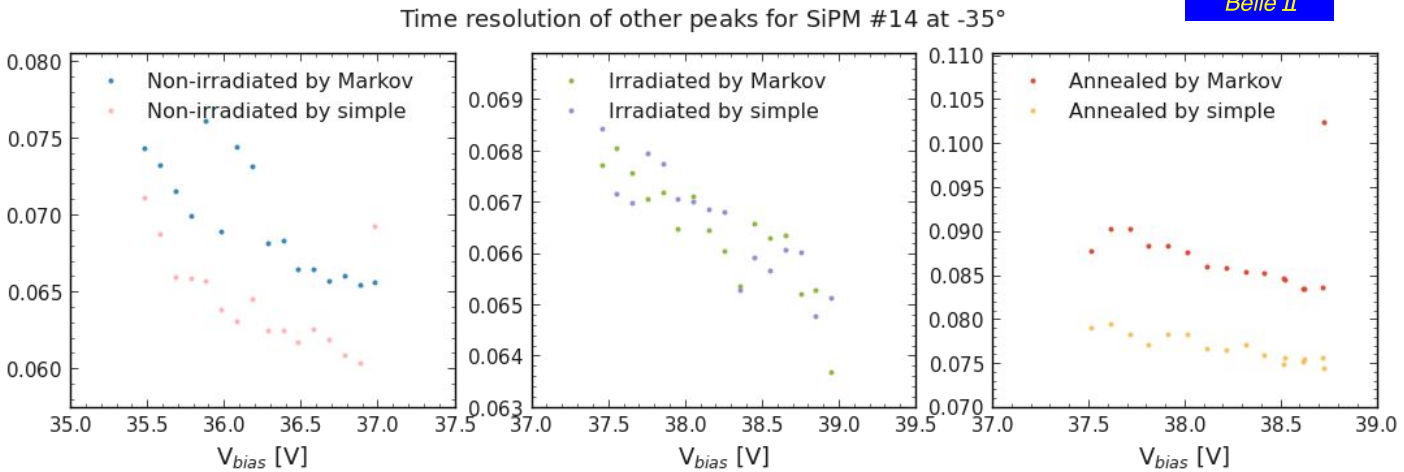
Time resolution for other photon peaks



Time resolution for other photon peaks

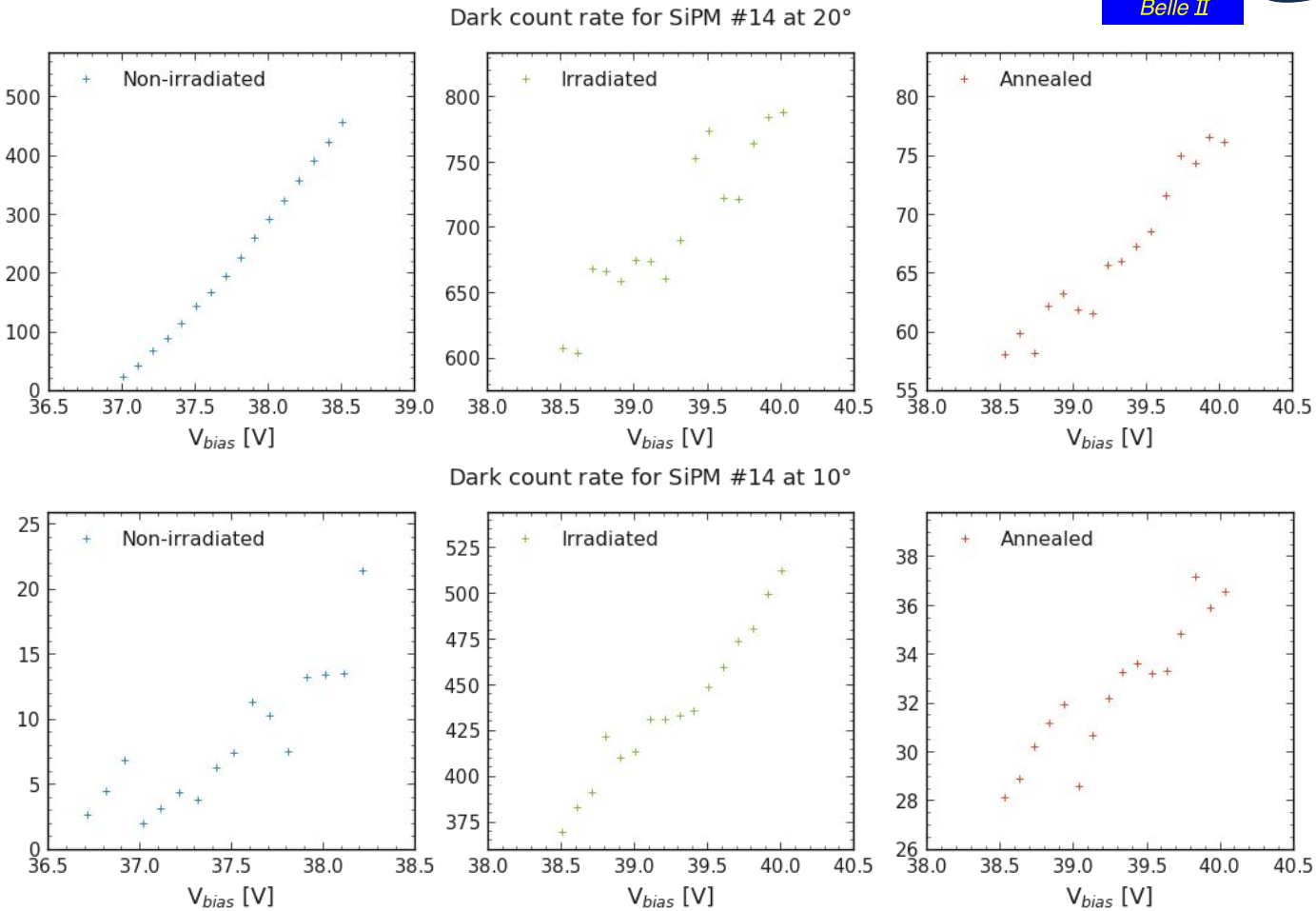


Time resolution for other photon peaks

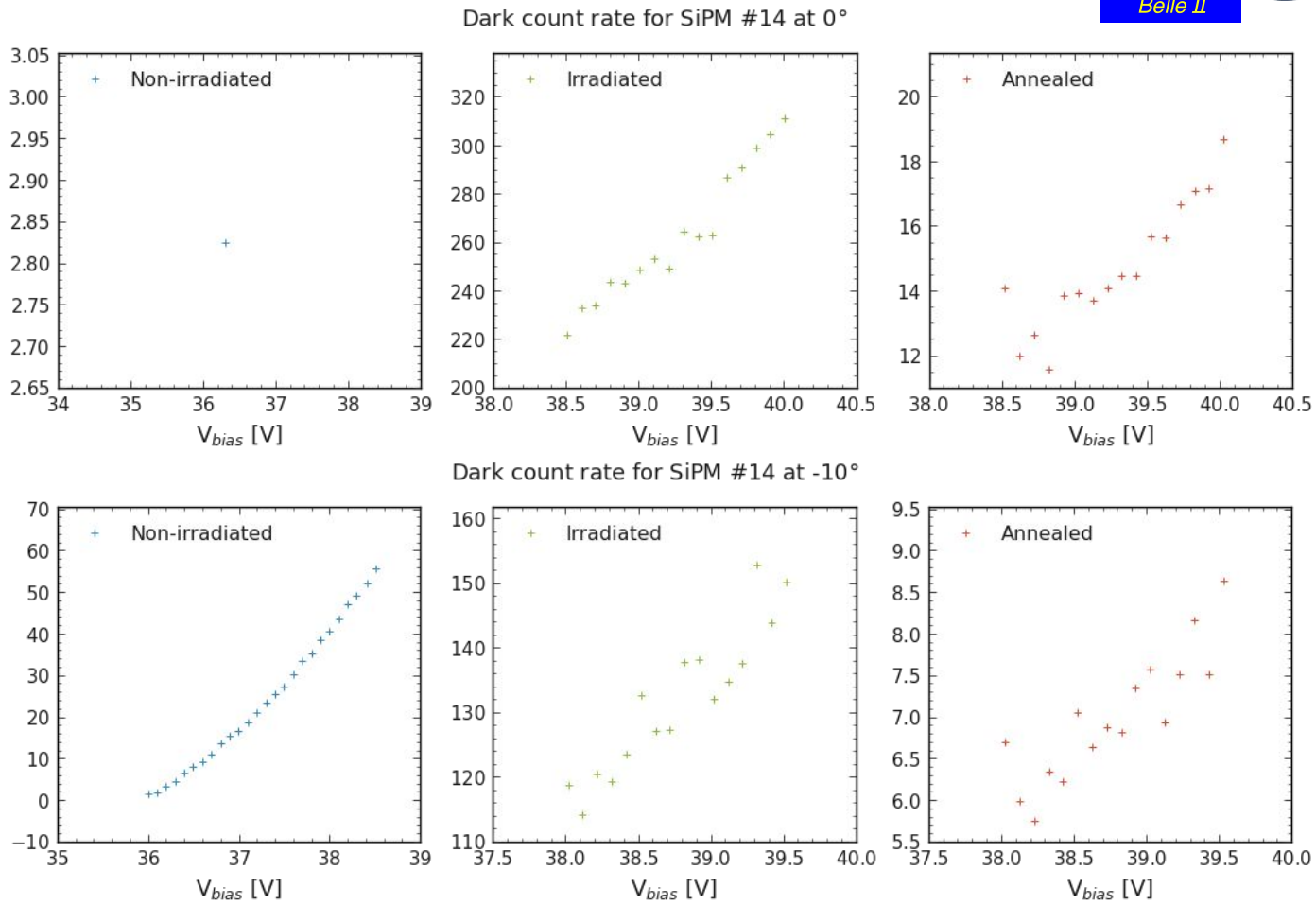


Dark count rate for SiPM #14

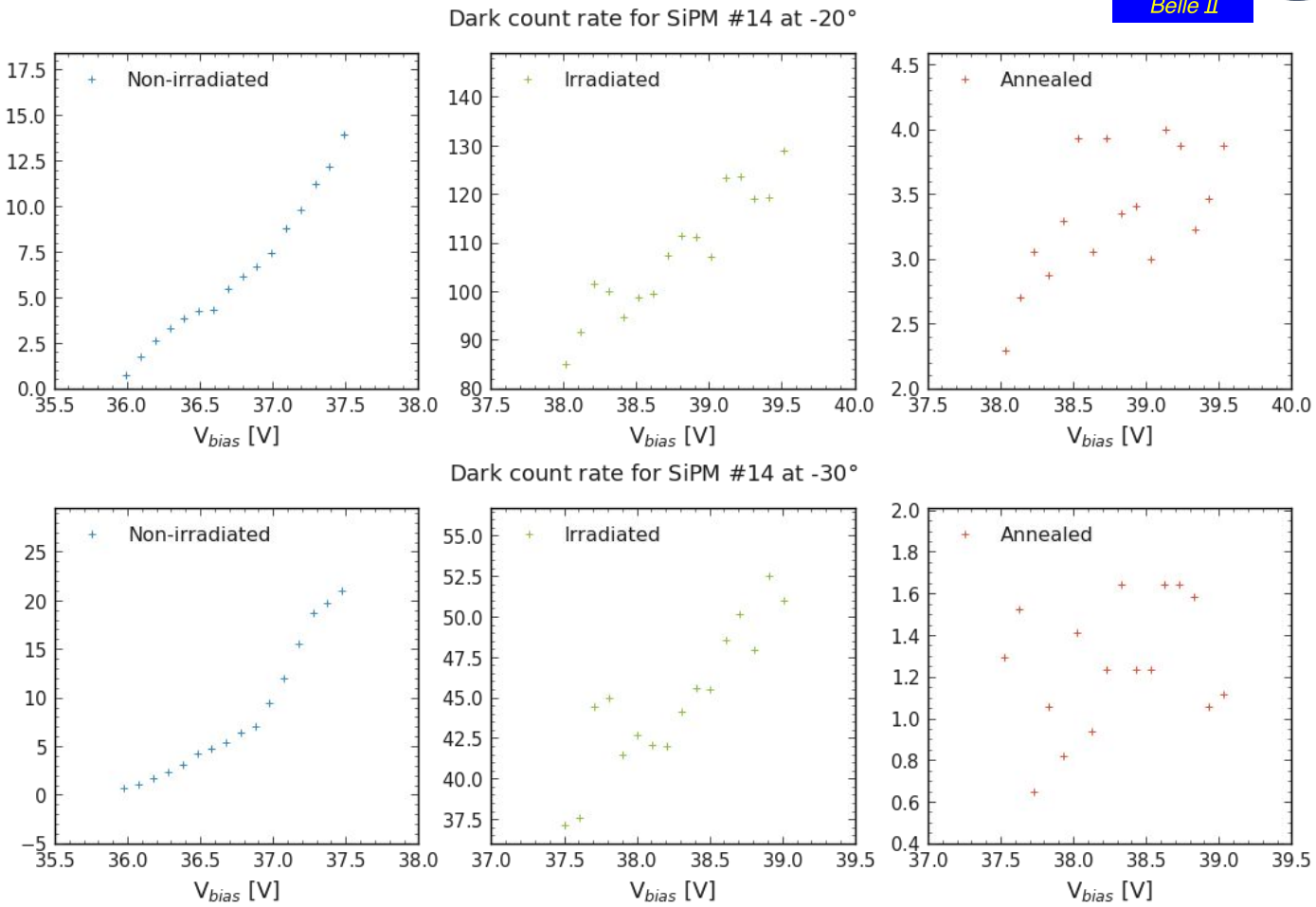
Dark count rate



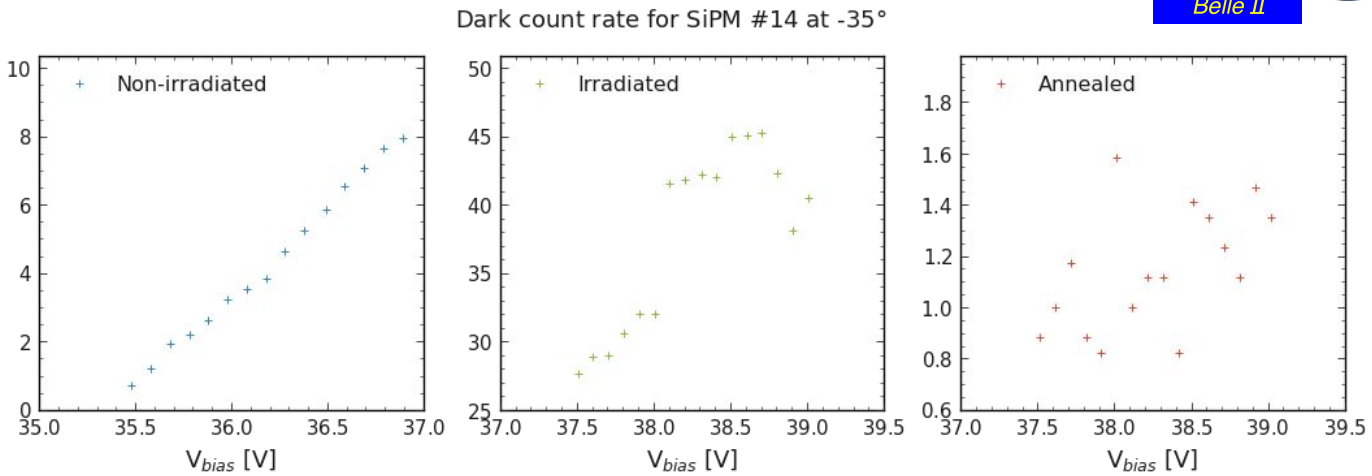
Dark count rate



Dark count rate



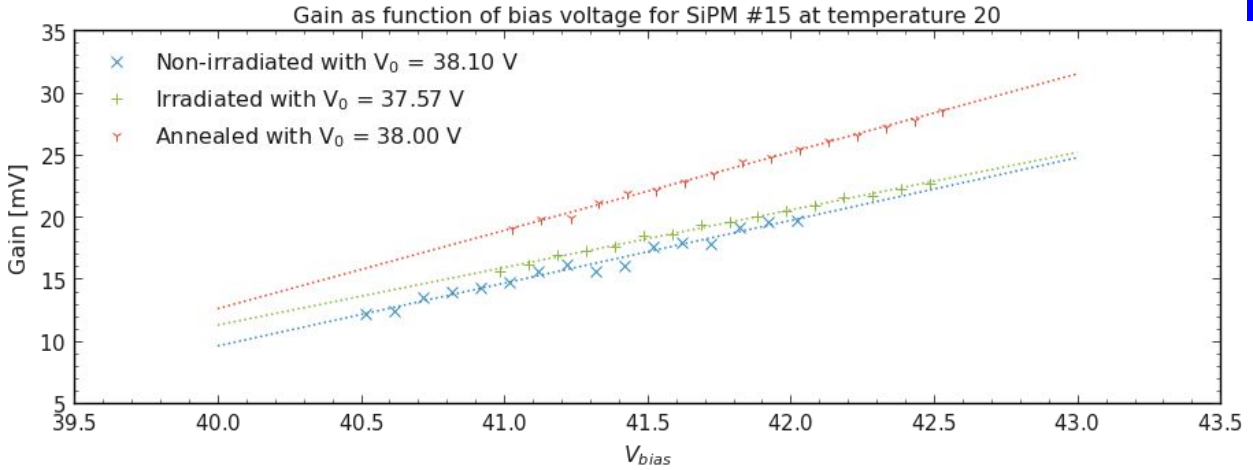
Dark count rate

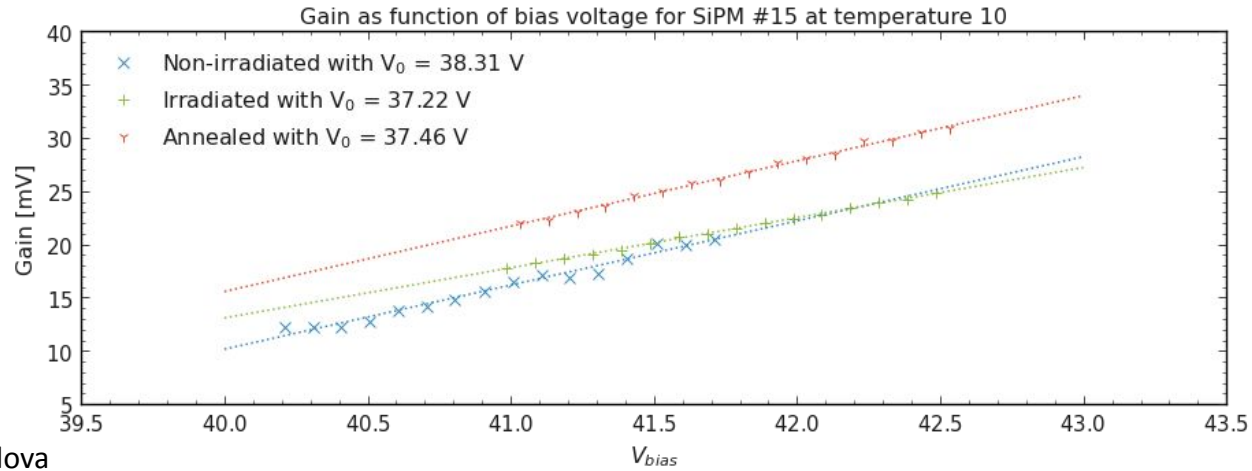


SiMP #15

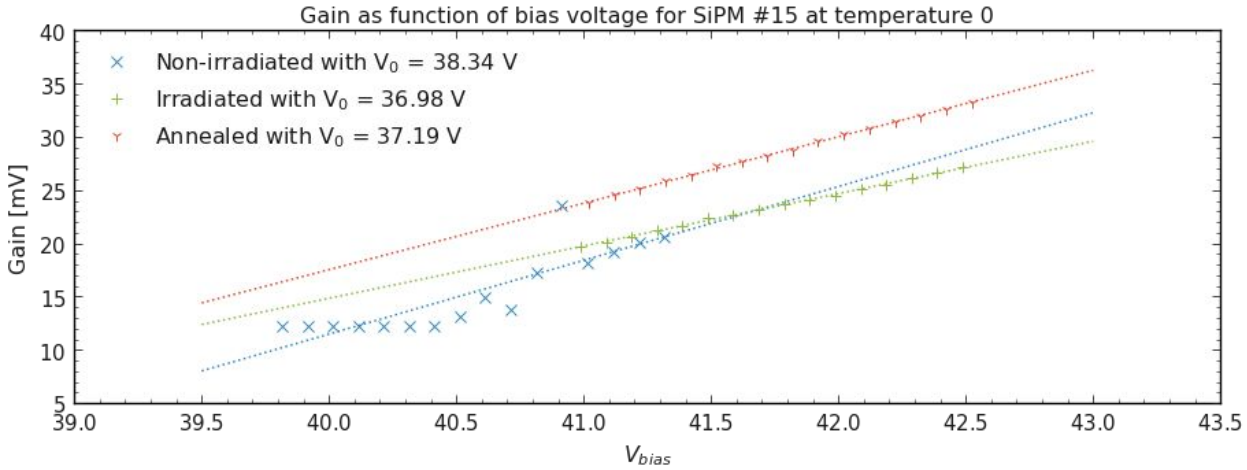
Gain as function of bias voltage for SiPM #15

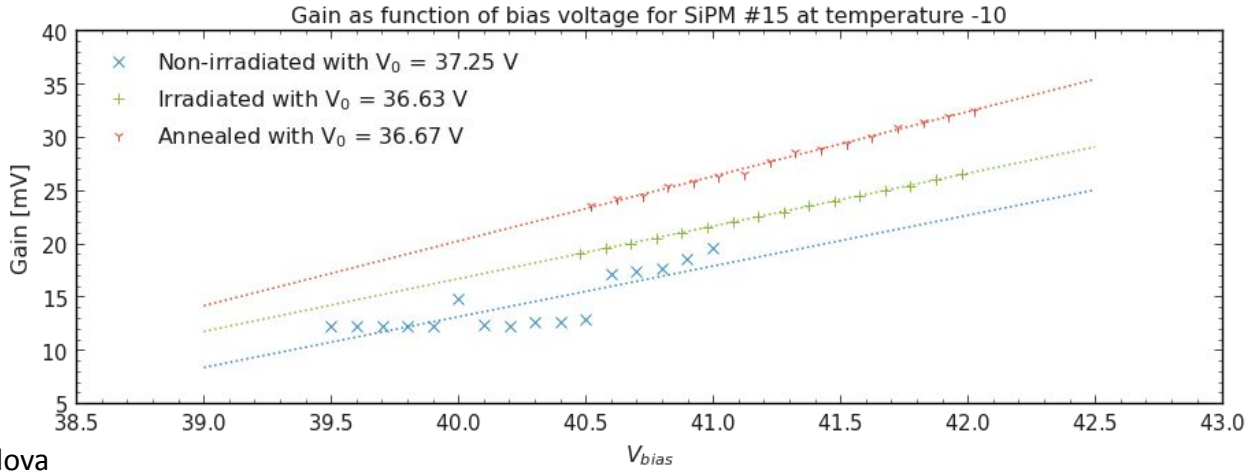
Gain as function of bias voltage



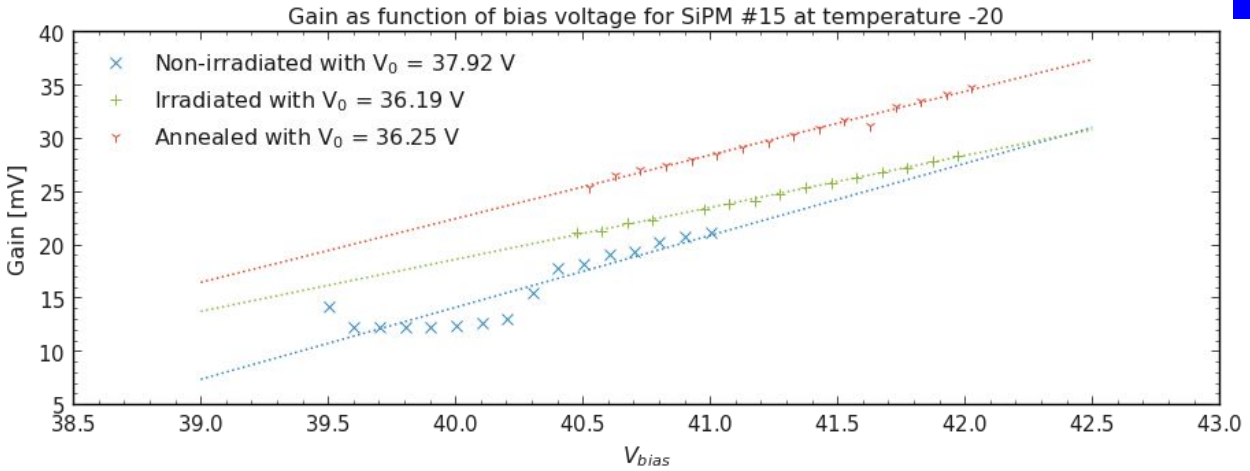


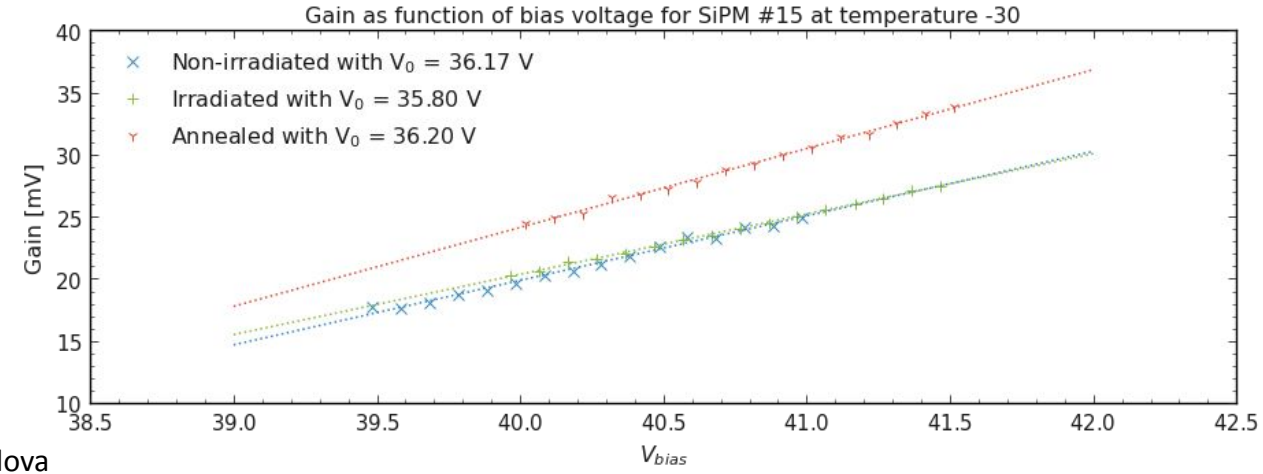
Gain as function of bias voltage



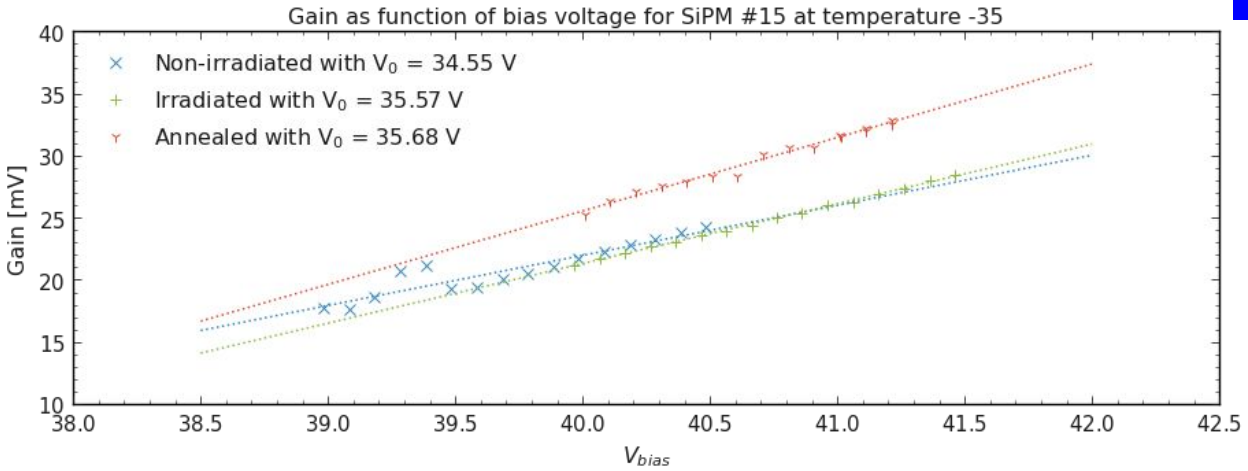


Gain as function of bias voltage



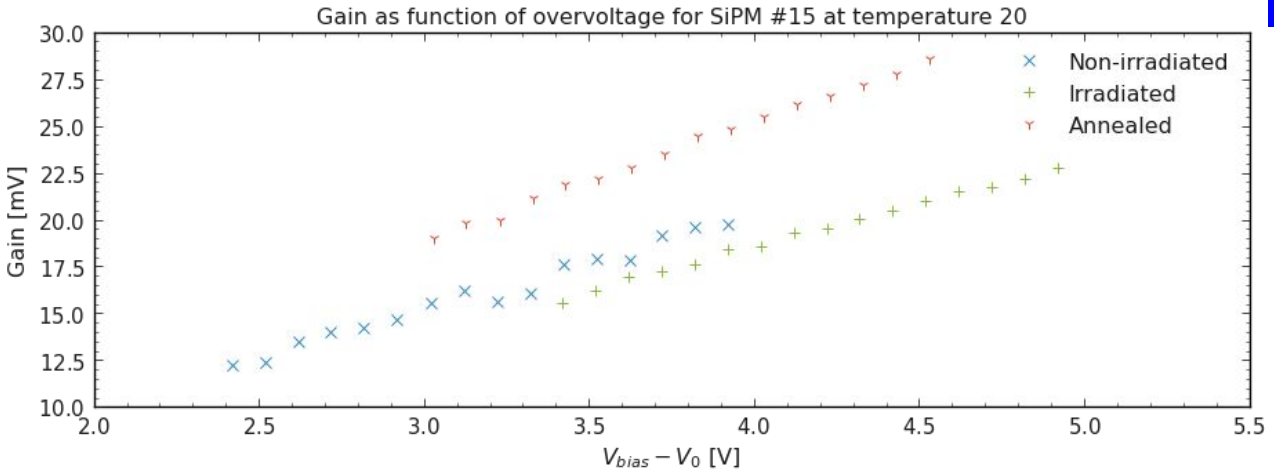


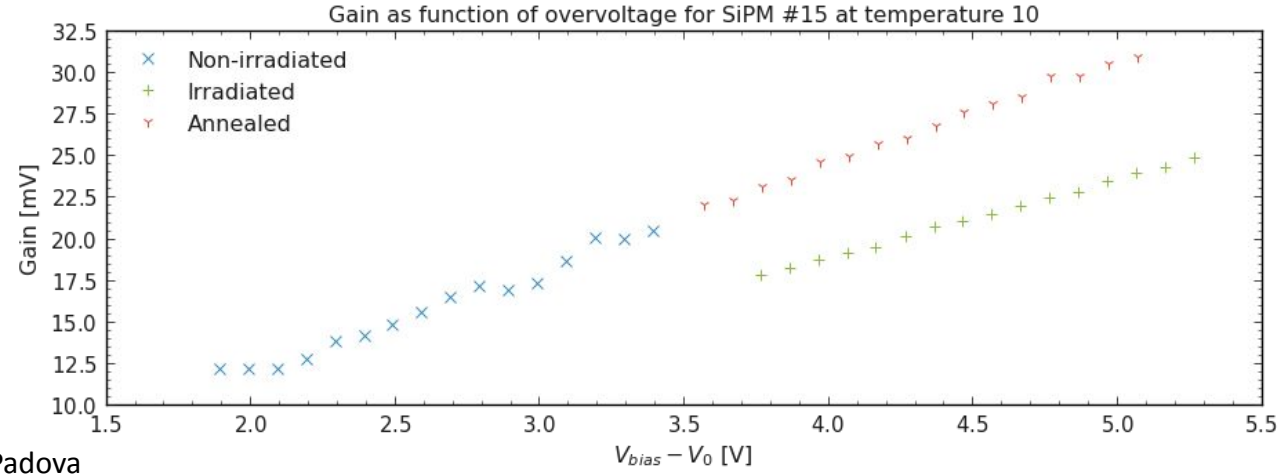
Gain as function of bias voltage



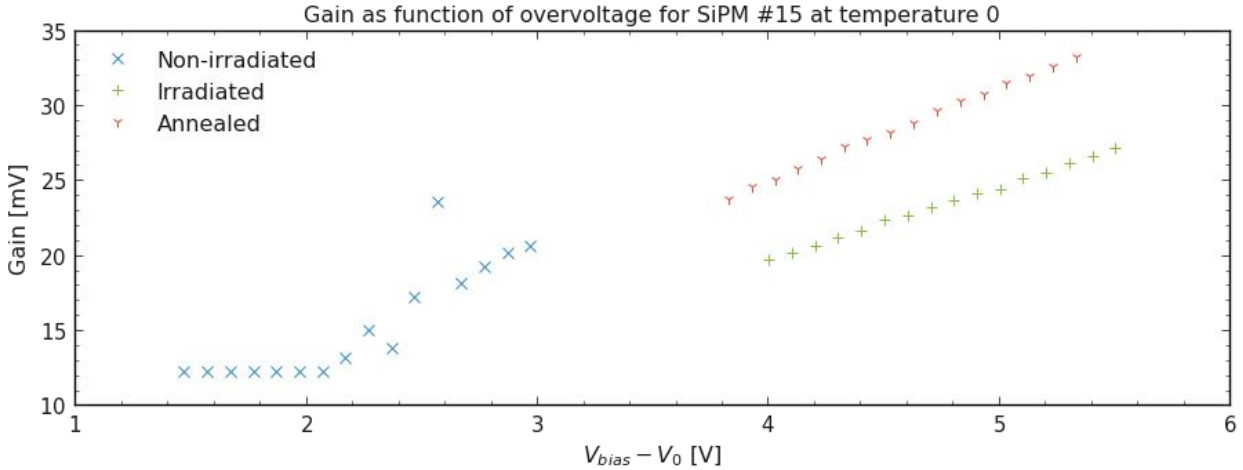
Gain as function of overvoltage for SiPM #15

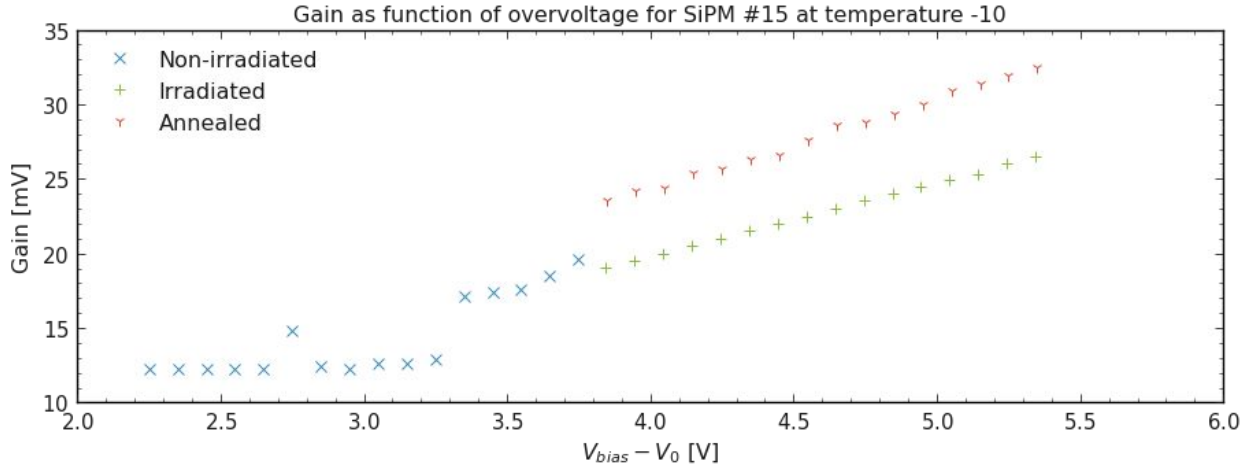
Gain as function of overvoltage



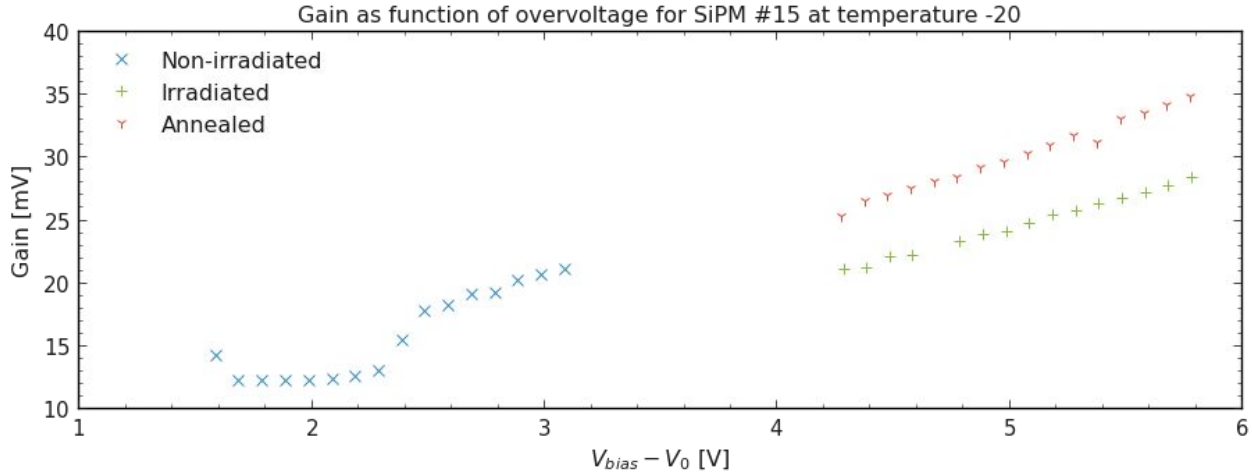


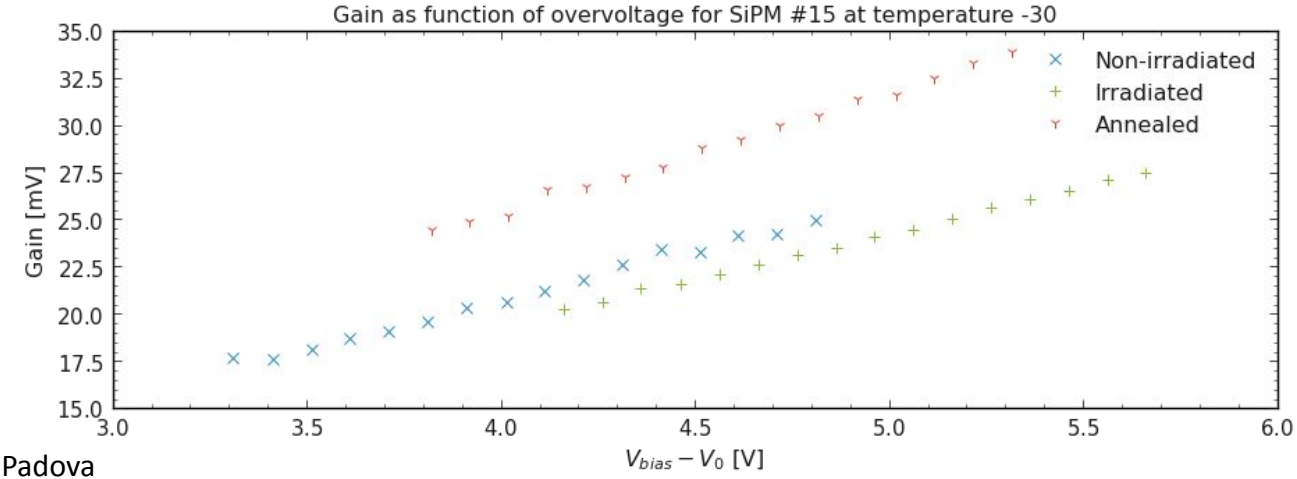
Gain as function of overvoltage



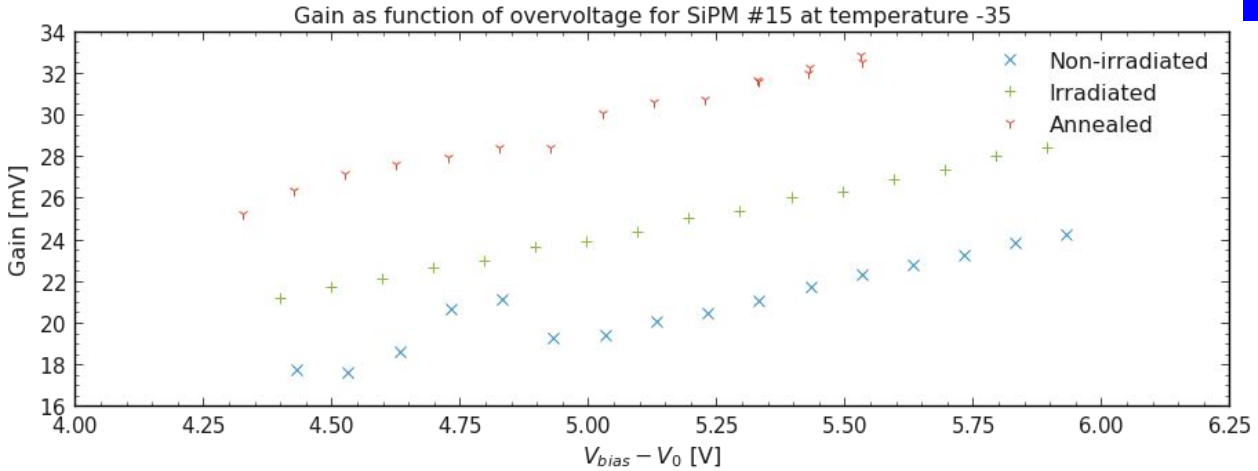


Gain as function of overvoltage



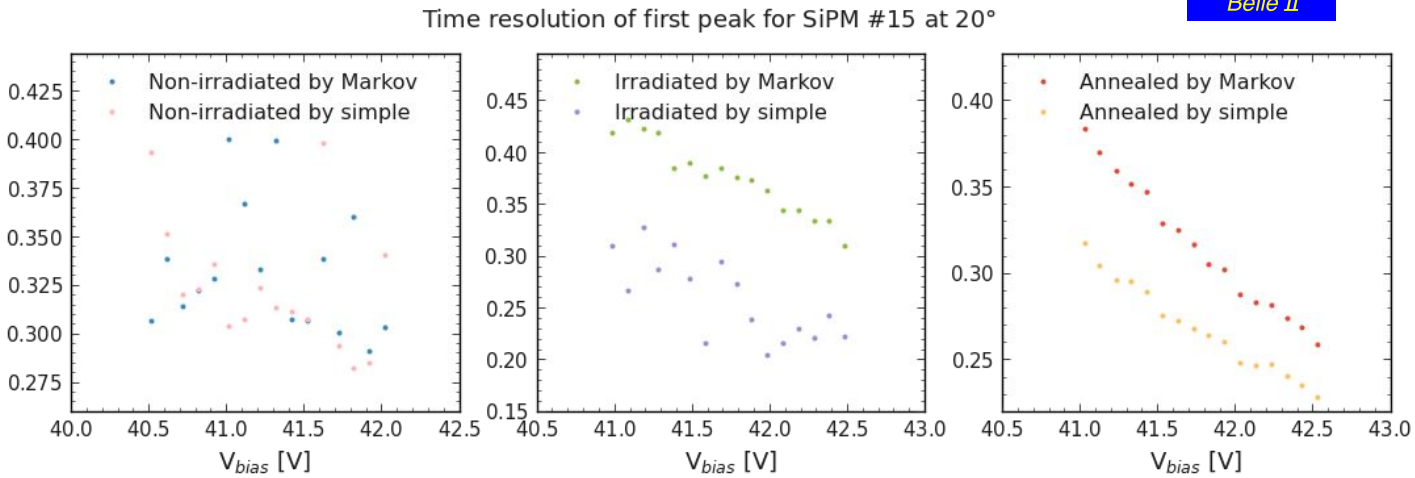


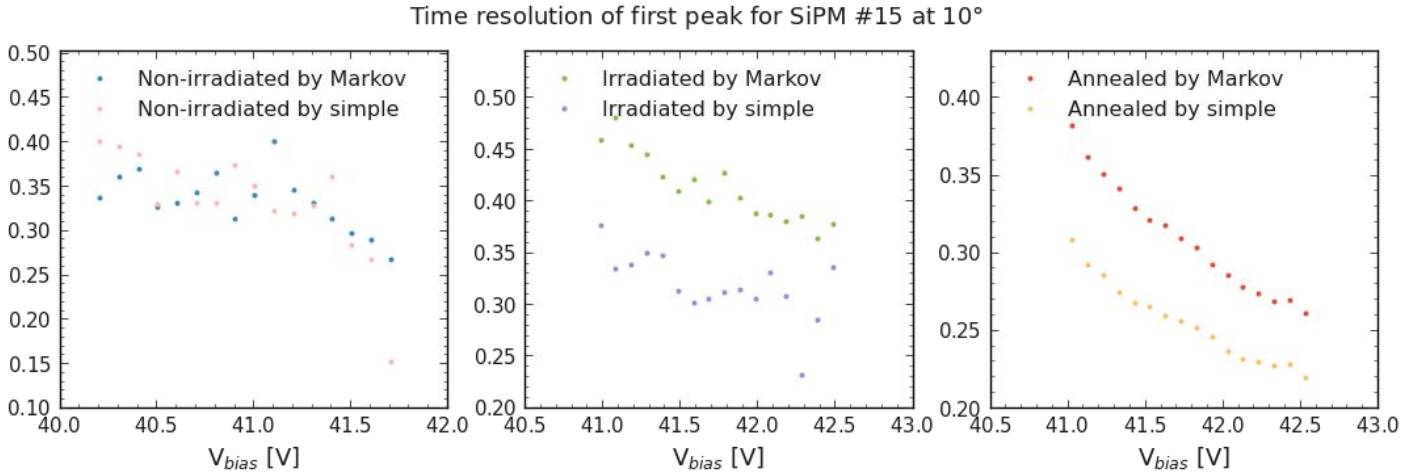
Gain as function of overvoltage



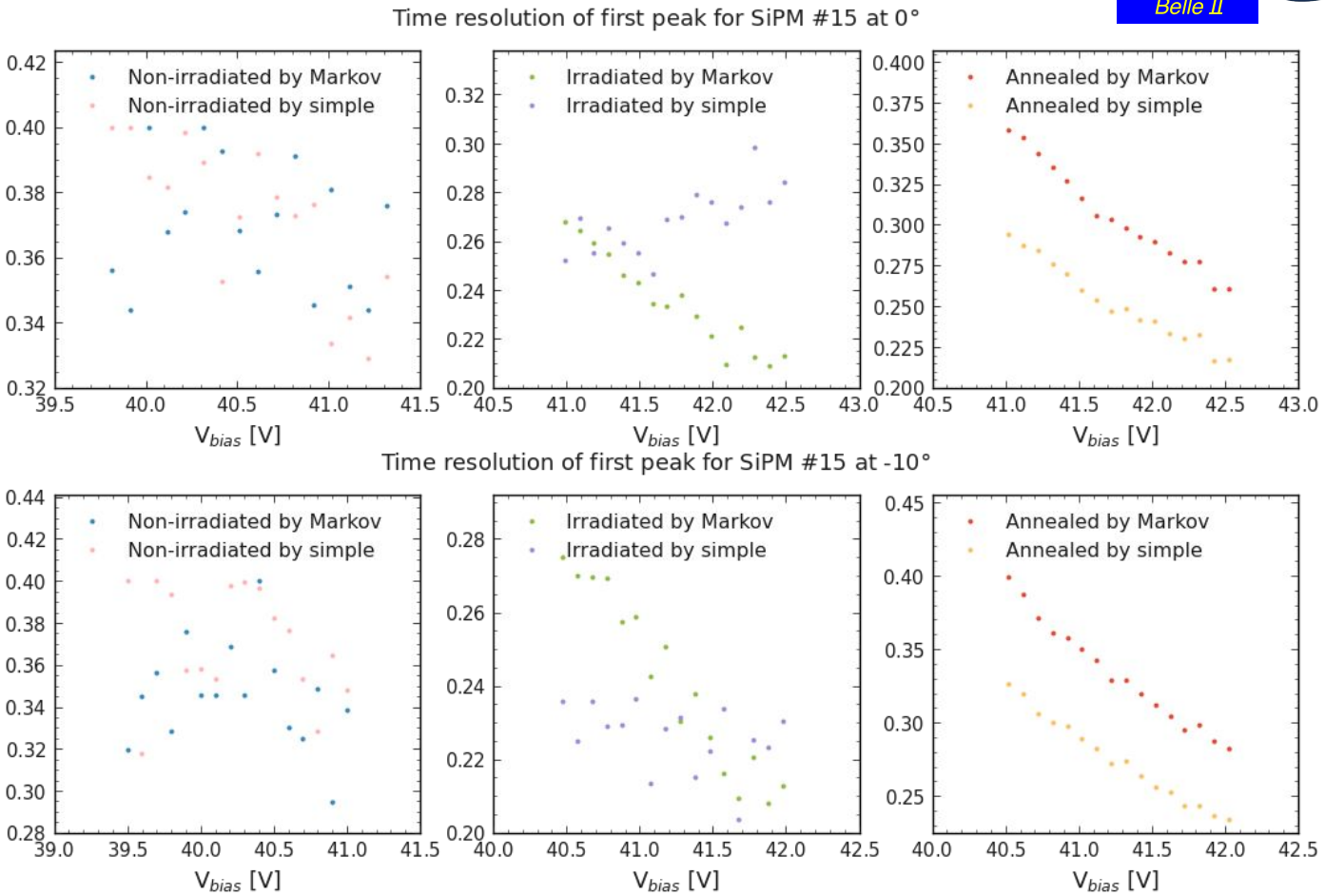
Time resolution for first photon peak for SiPM #15

Time resolution for first photon peak

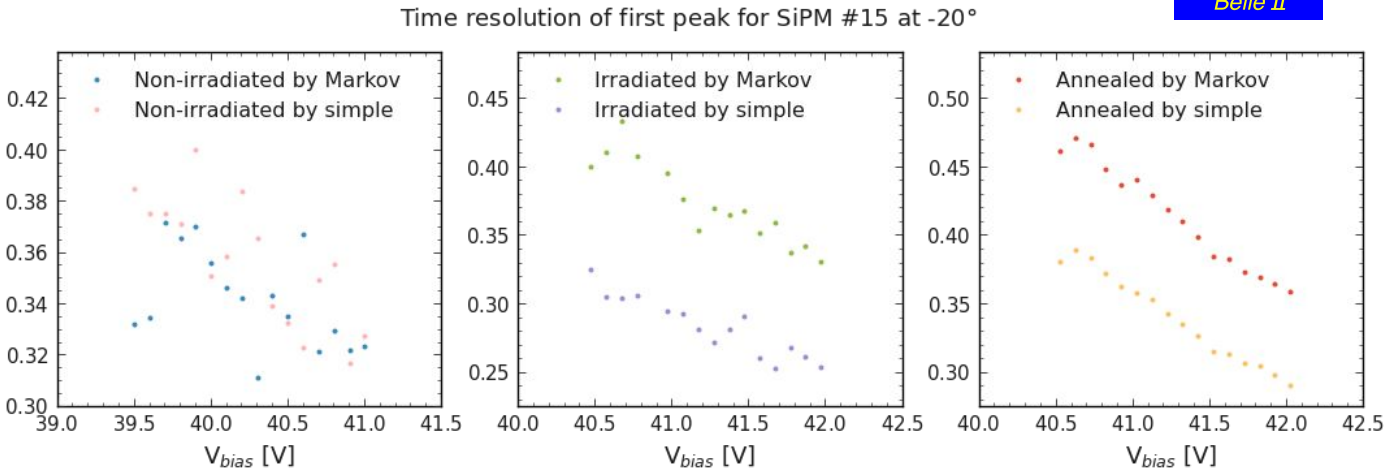


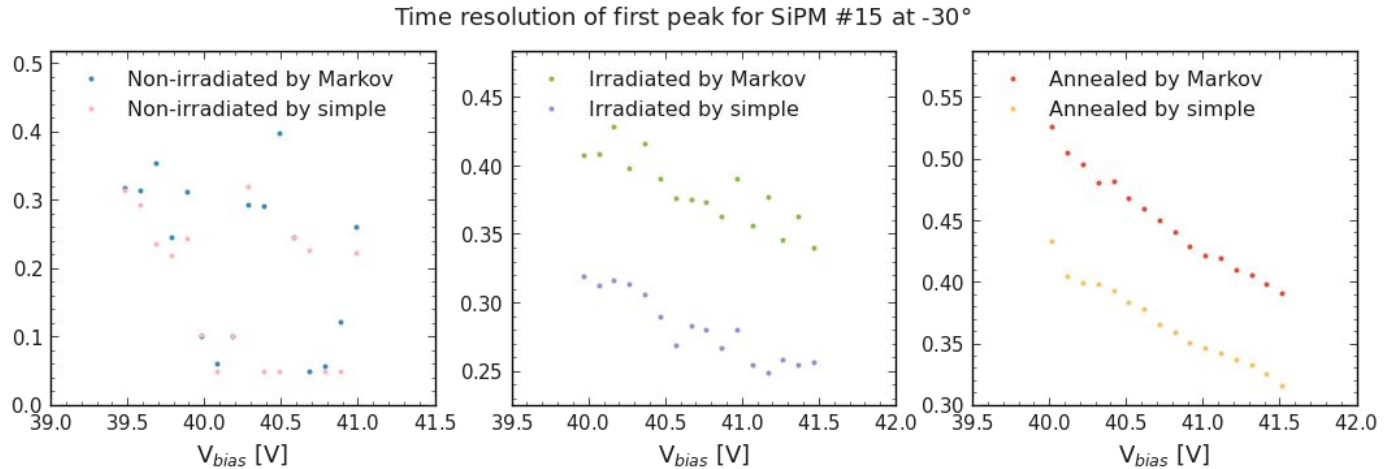


Time resolution for first photon peak

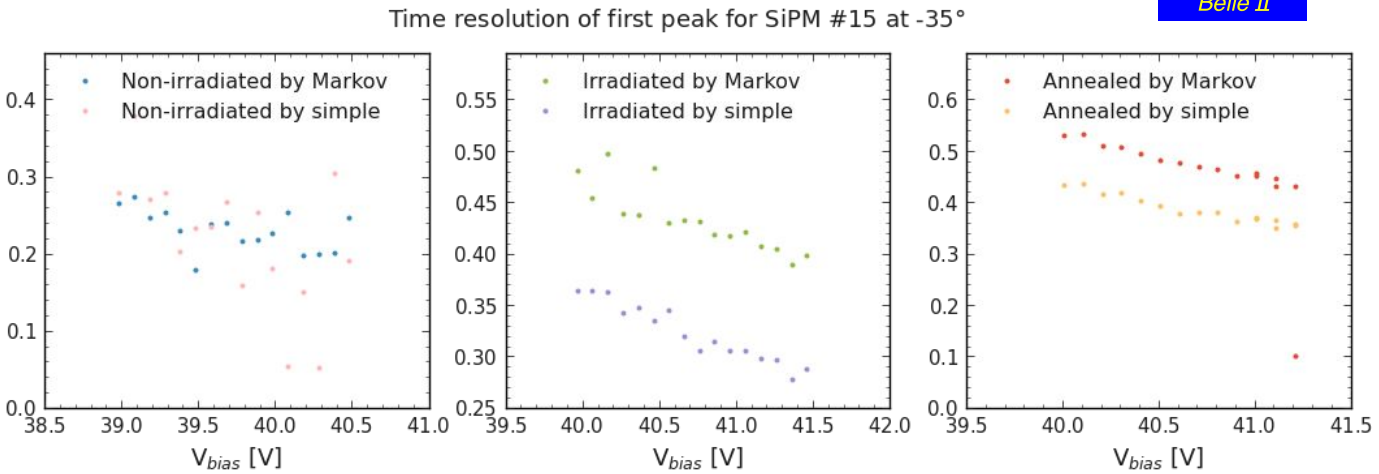


Time resolution for first photon peak



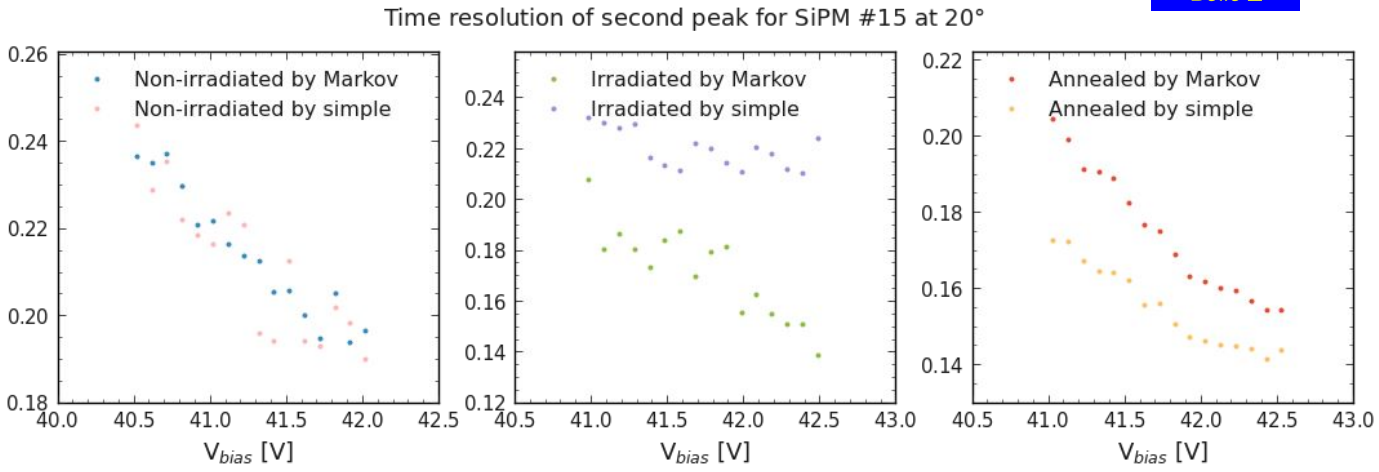


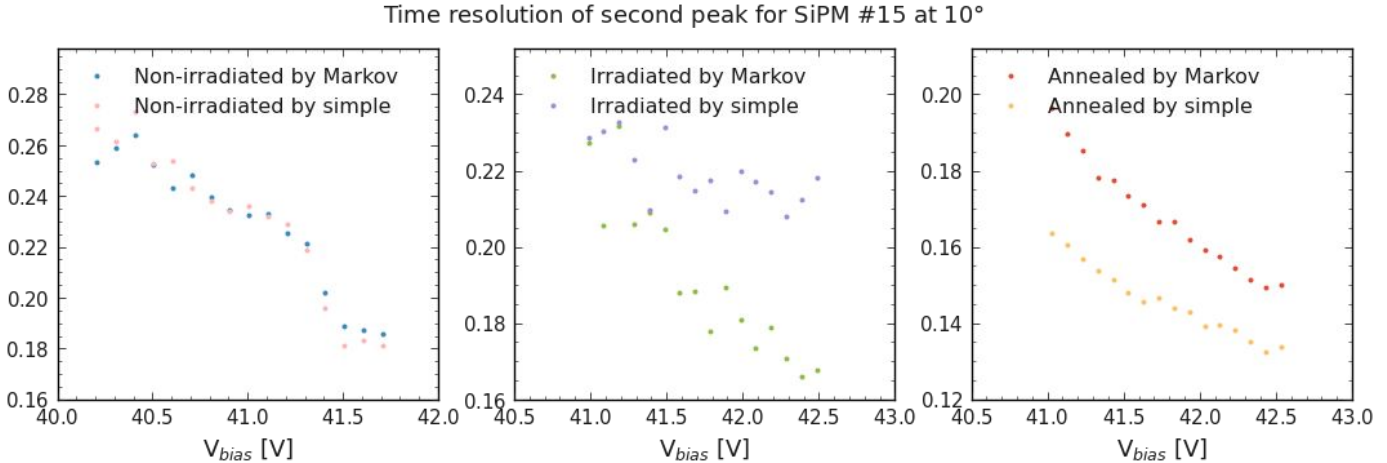
Time resolution for first photon peak



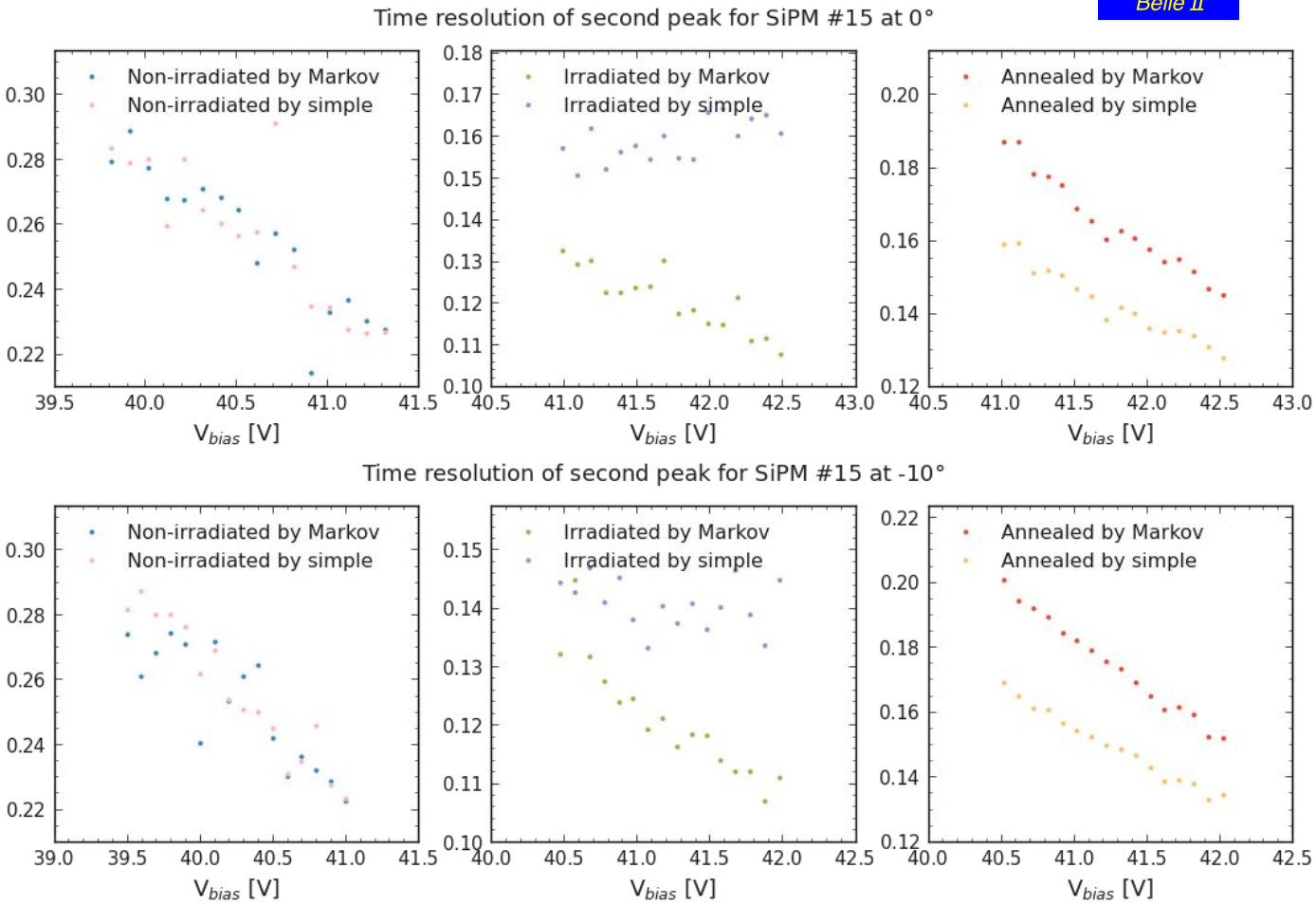
Time resolution for second photon peak for SiPM #15

Time resolution for second photon peak

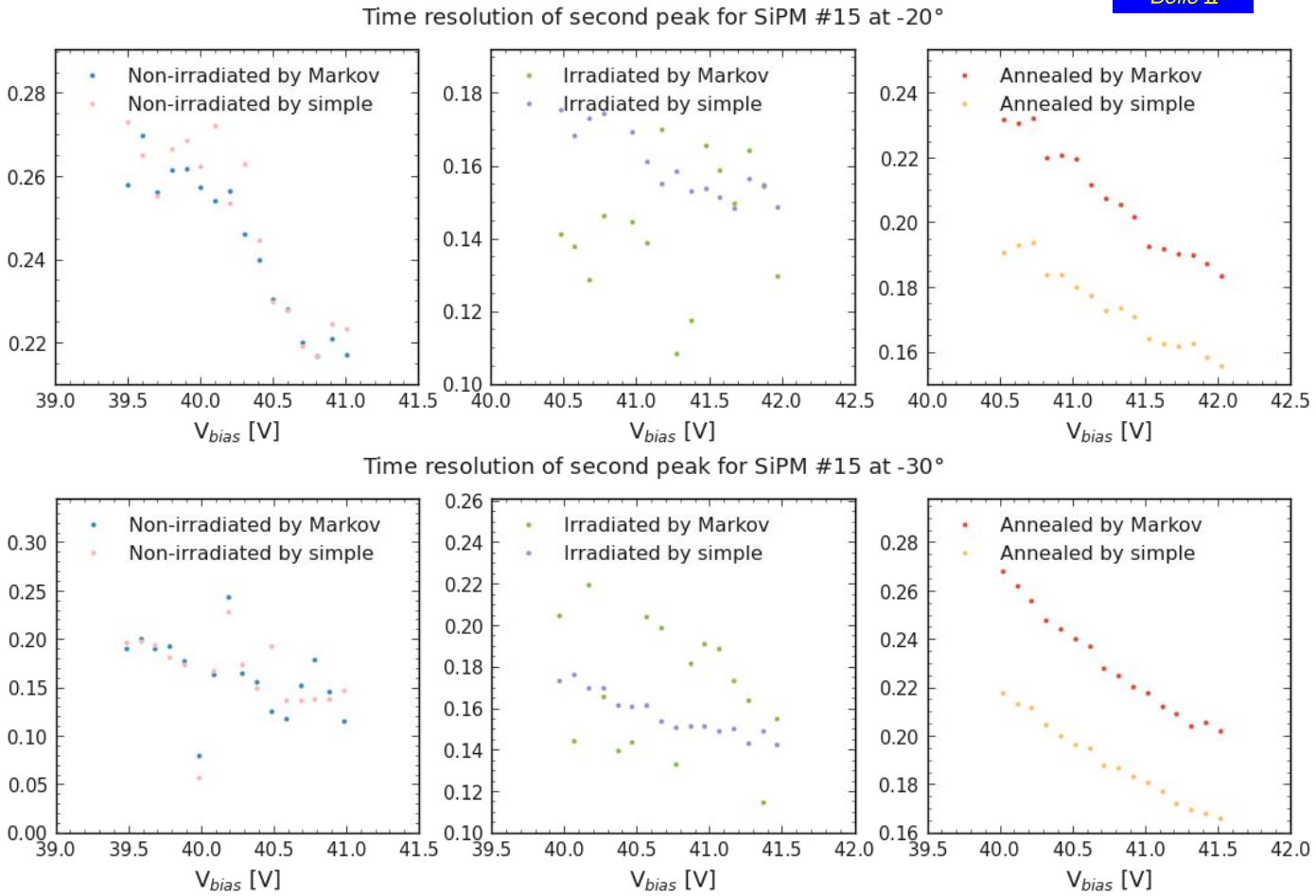




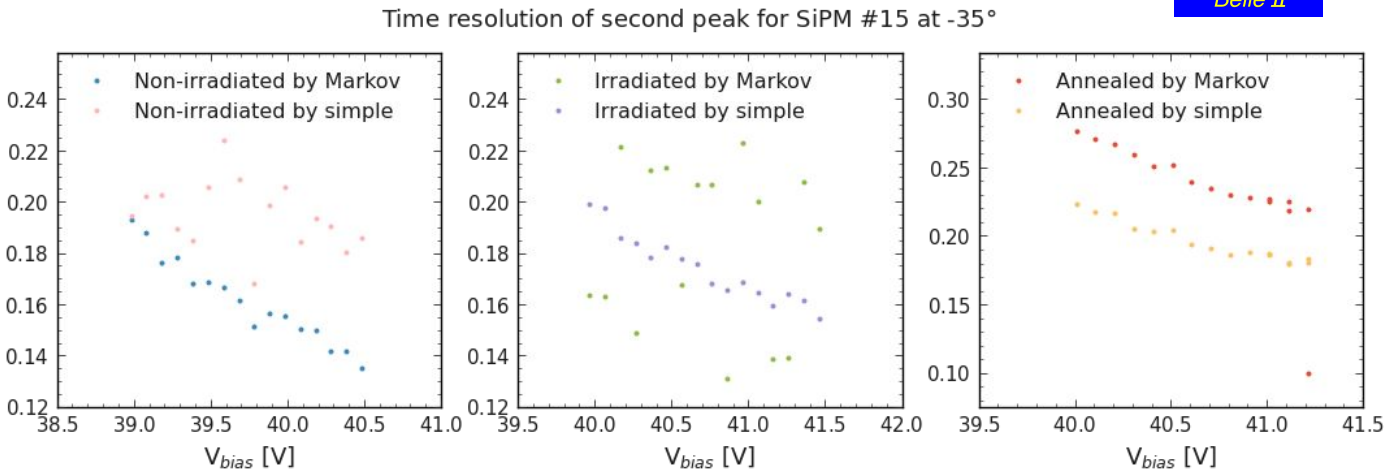
Time resolution for second photon peak



Time resolution for second photon peak

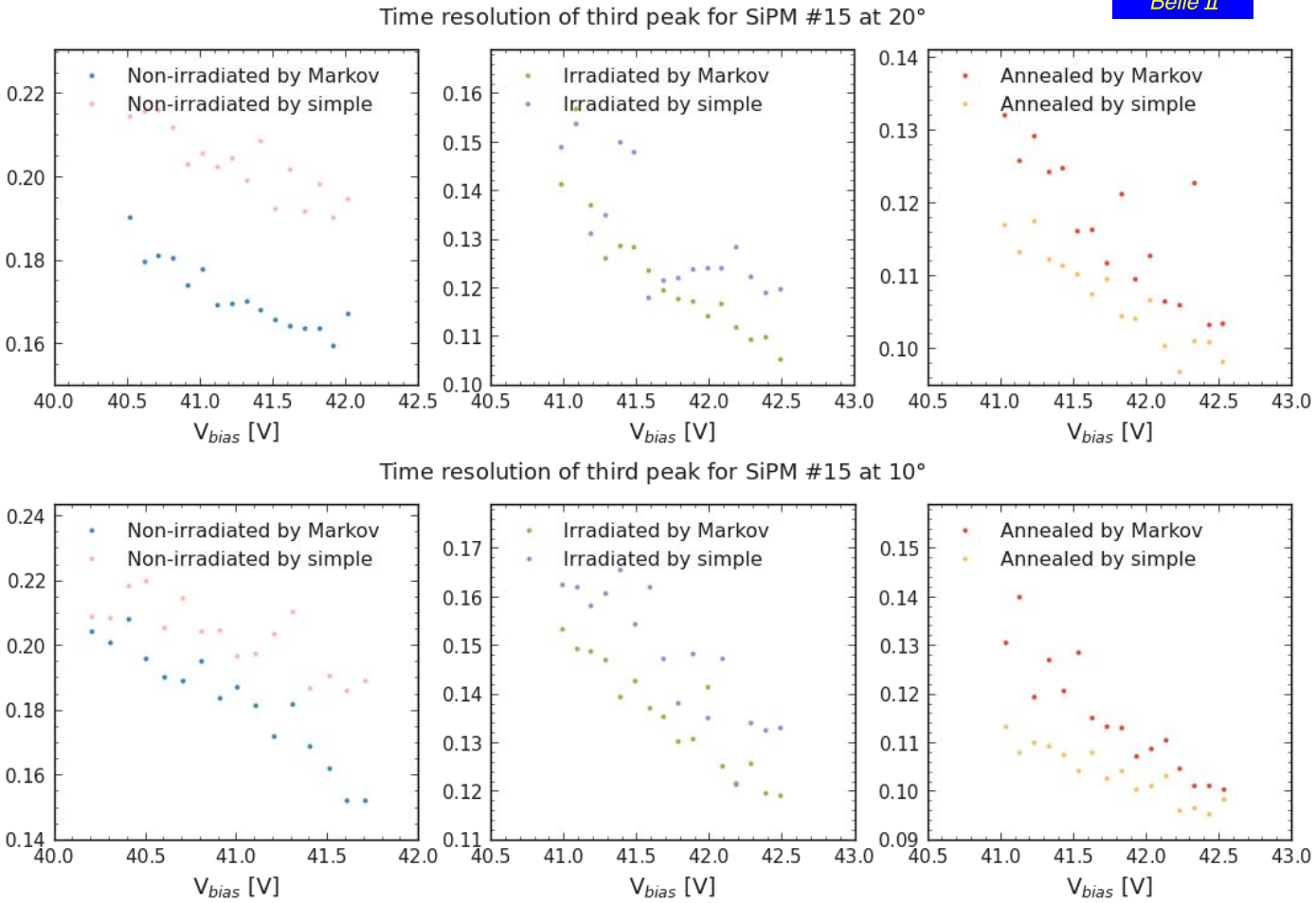


Time resolution for second photon peak

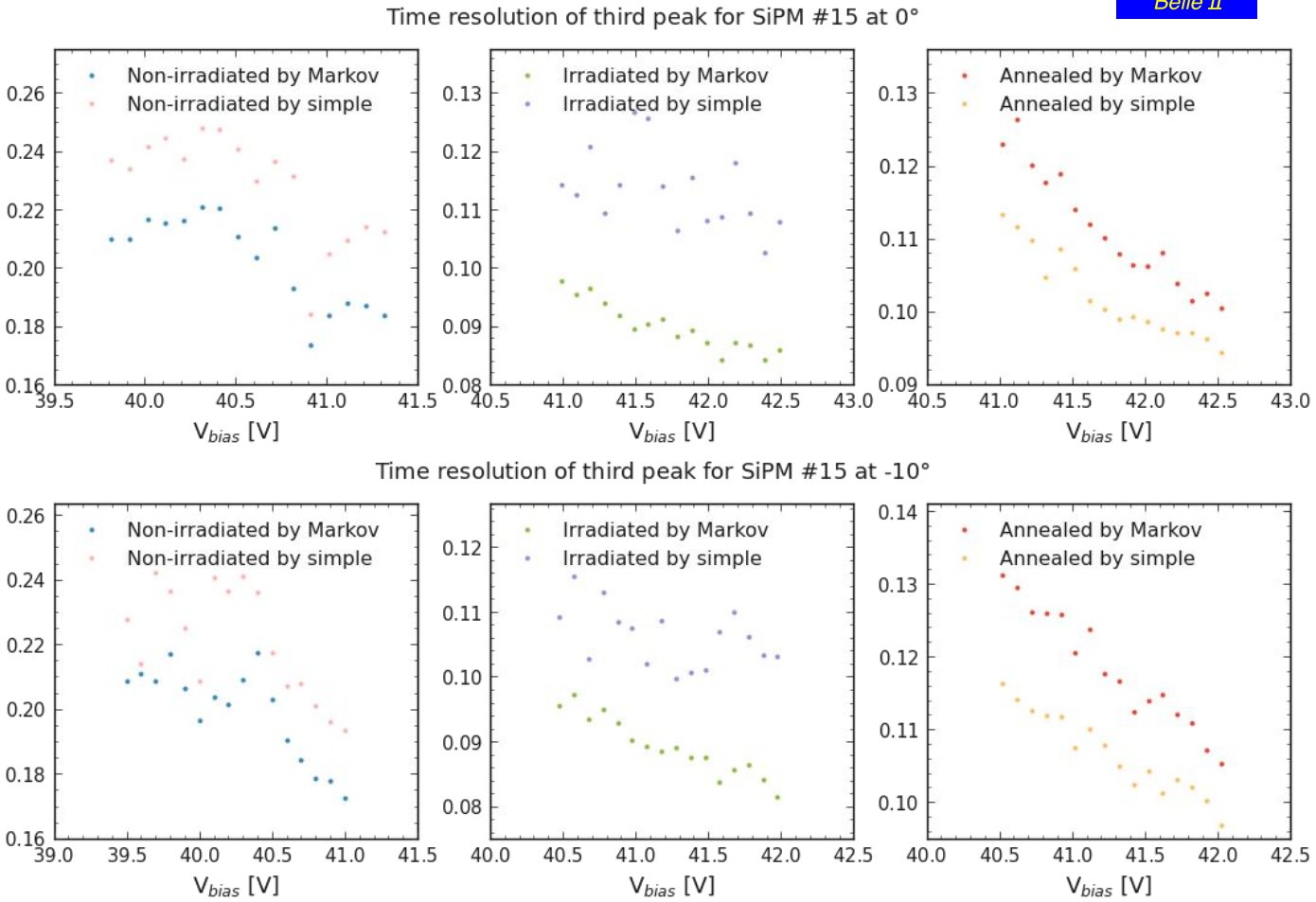


Time resolution for third photon peak for SiPM #15

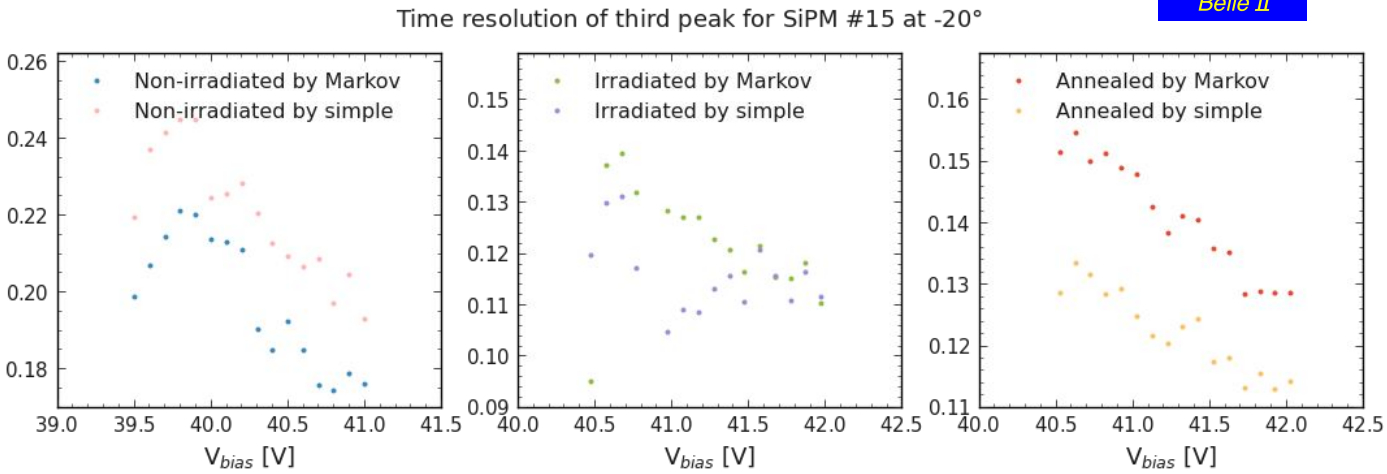
Time resolution for third photon peak

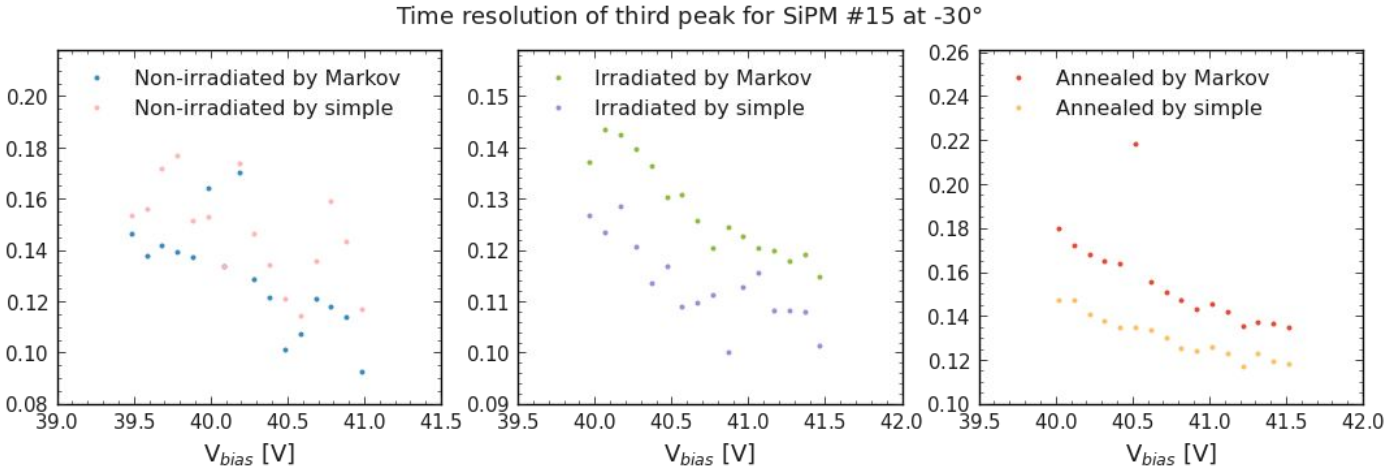


Time resolution for third photon peak

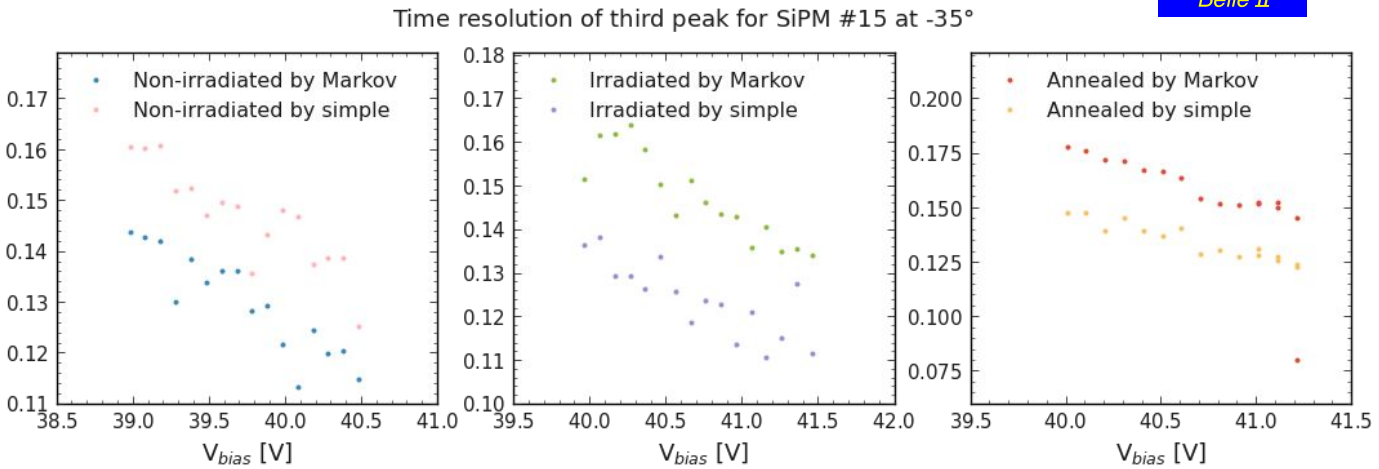


Time resolution for third photon peak



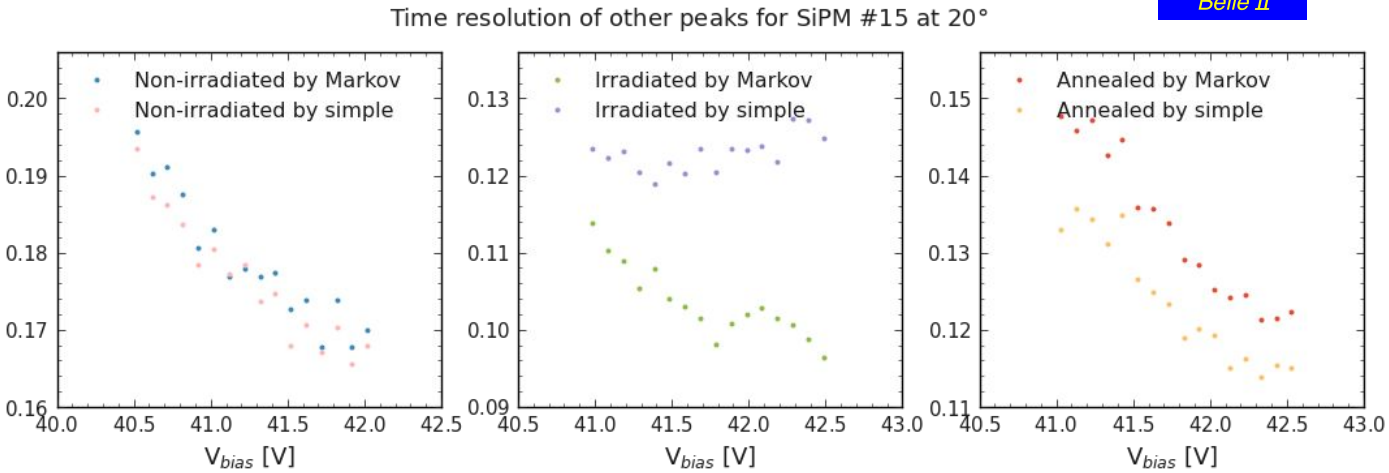


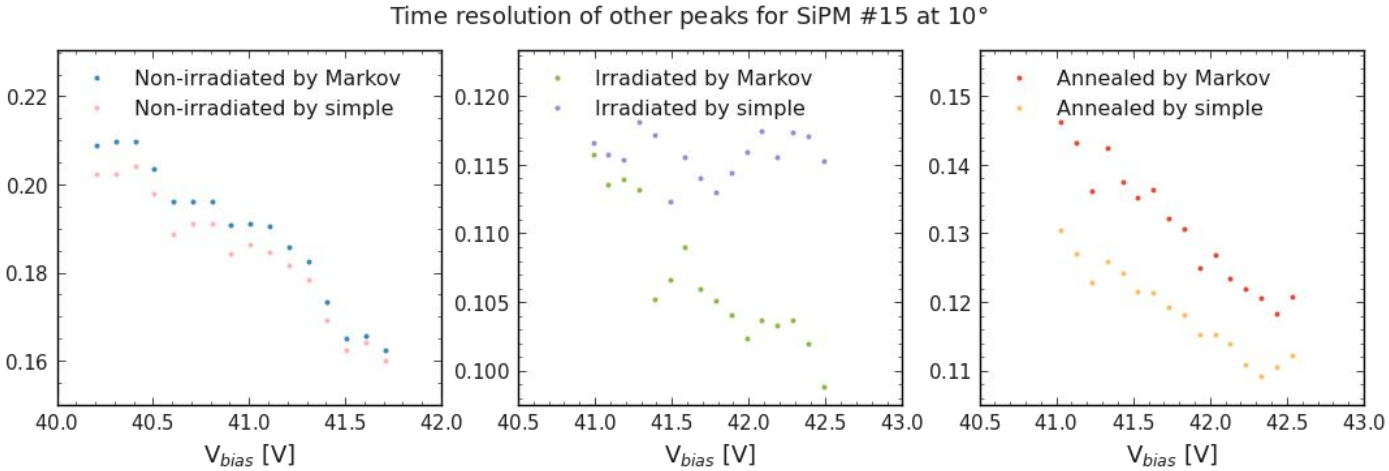
Time resolution for third photon peak



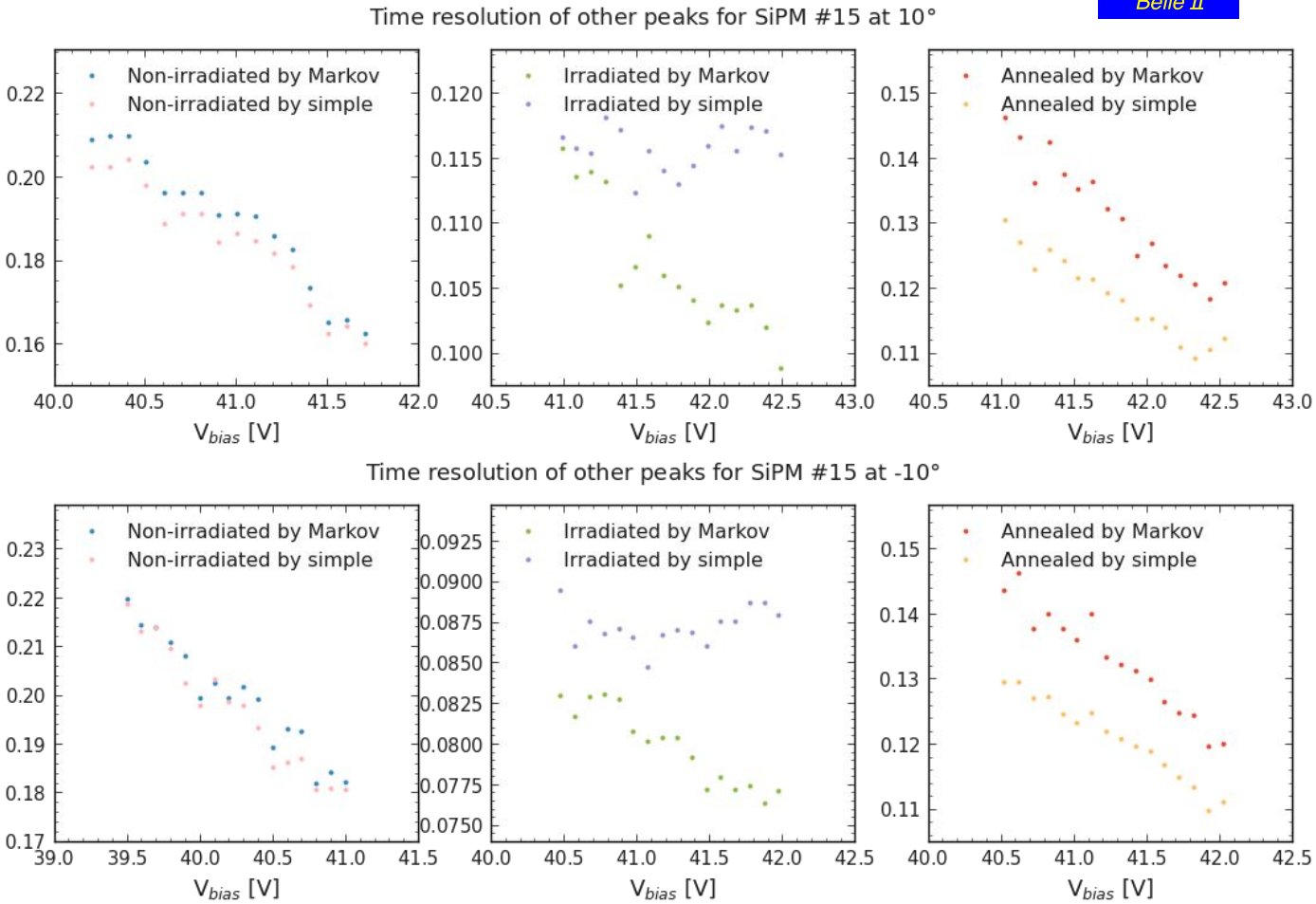
Time resolution for other photon peaks for SiPM #15

Time resolution for other photon peaks

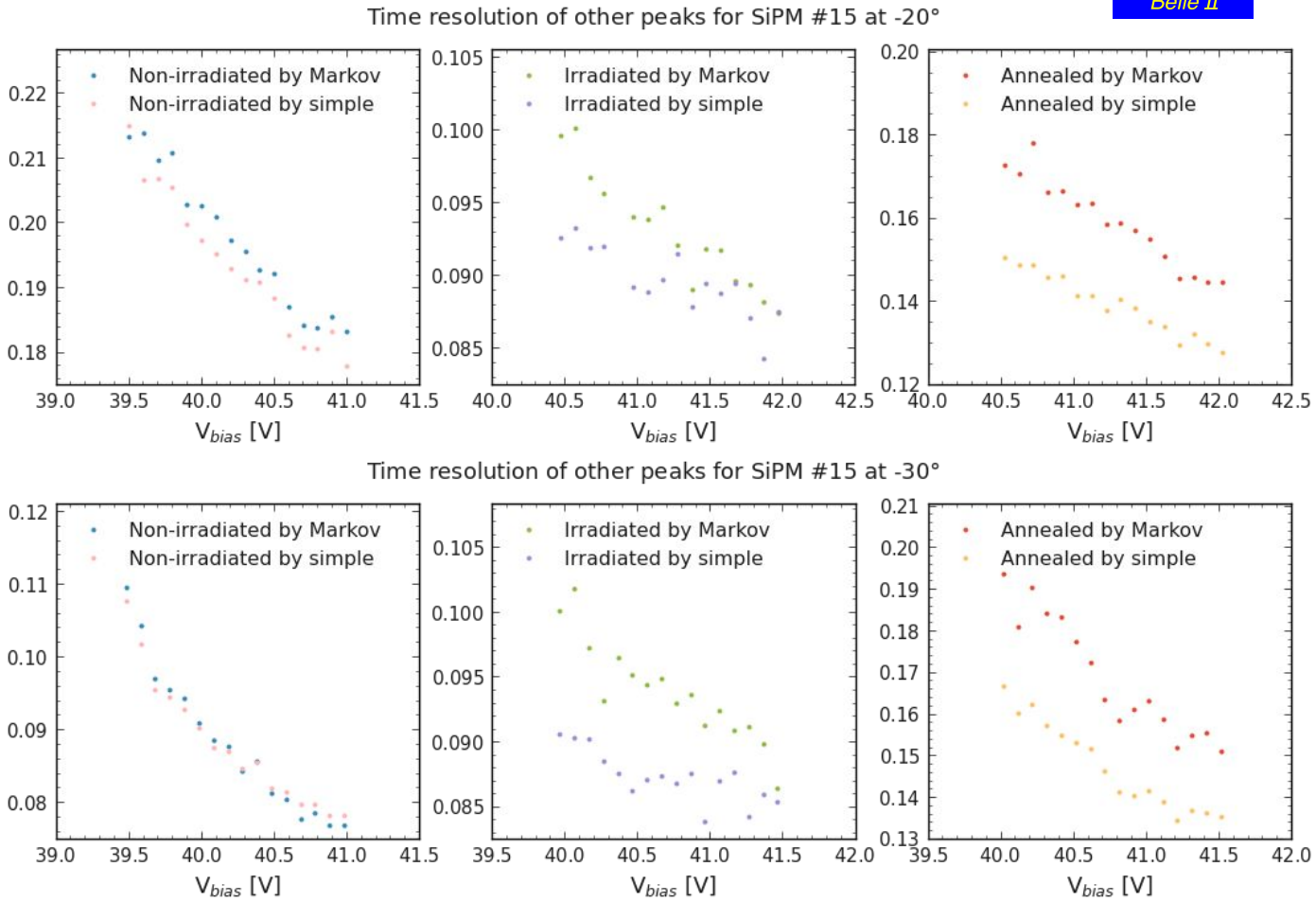




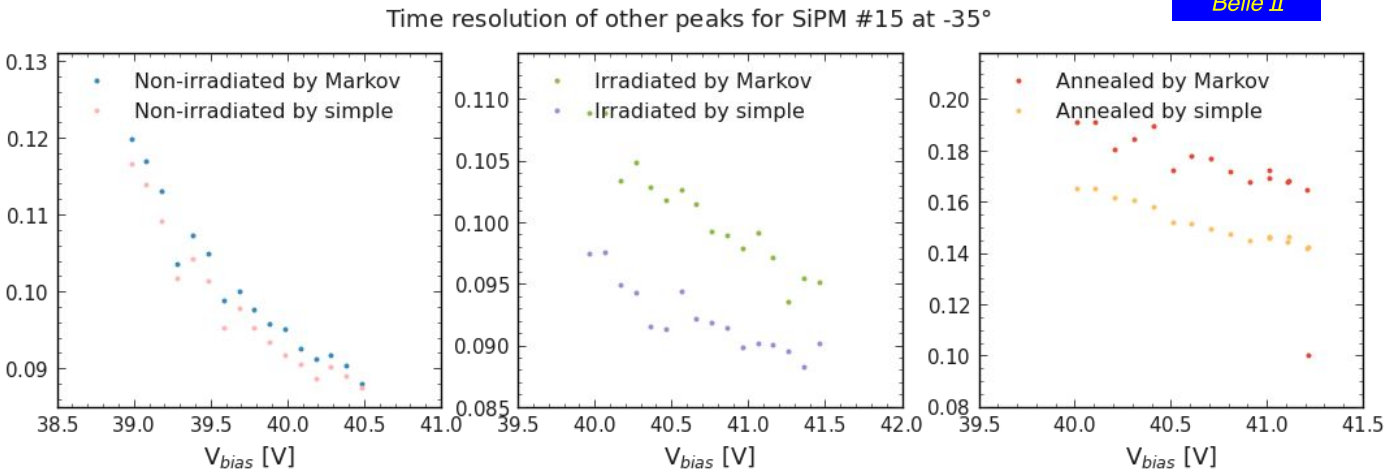
Time resolution for other photon peaks



Time resolution for other photon peaks

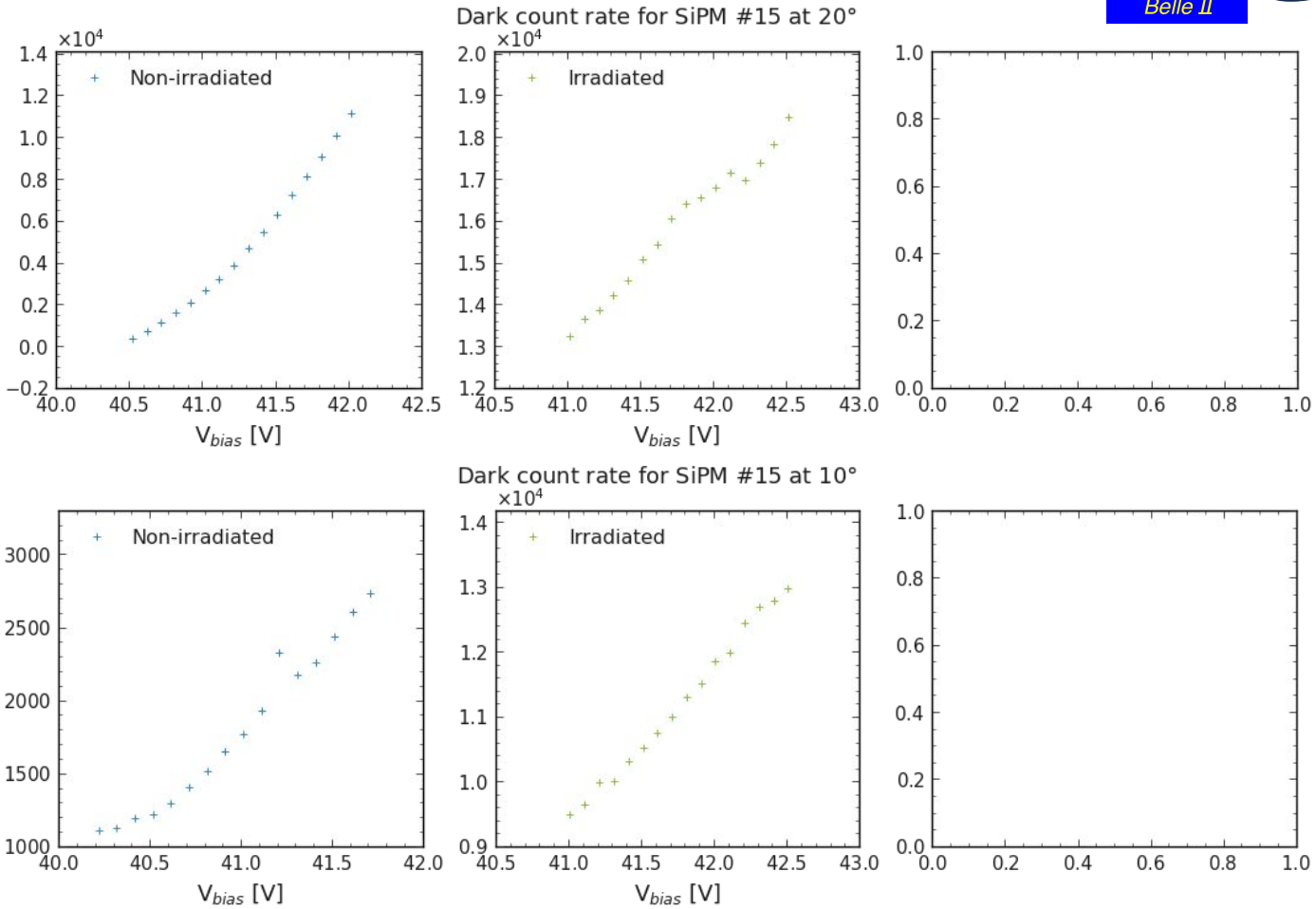


Time resolution for other photon peaks

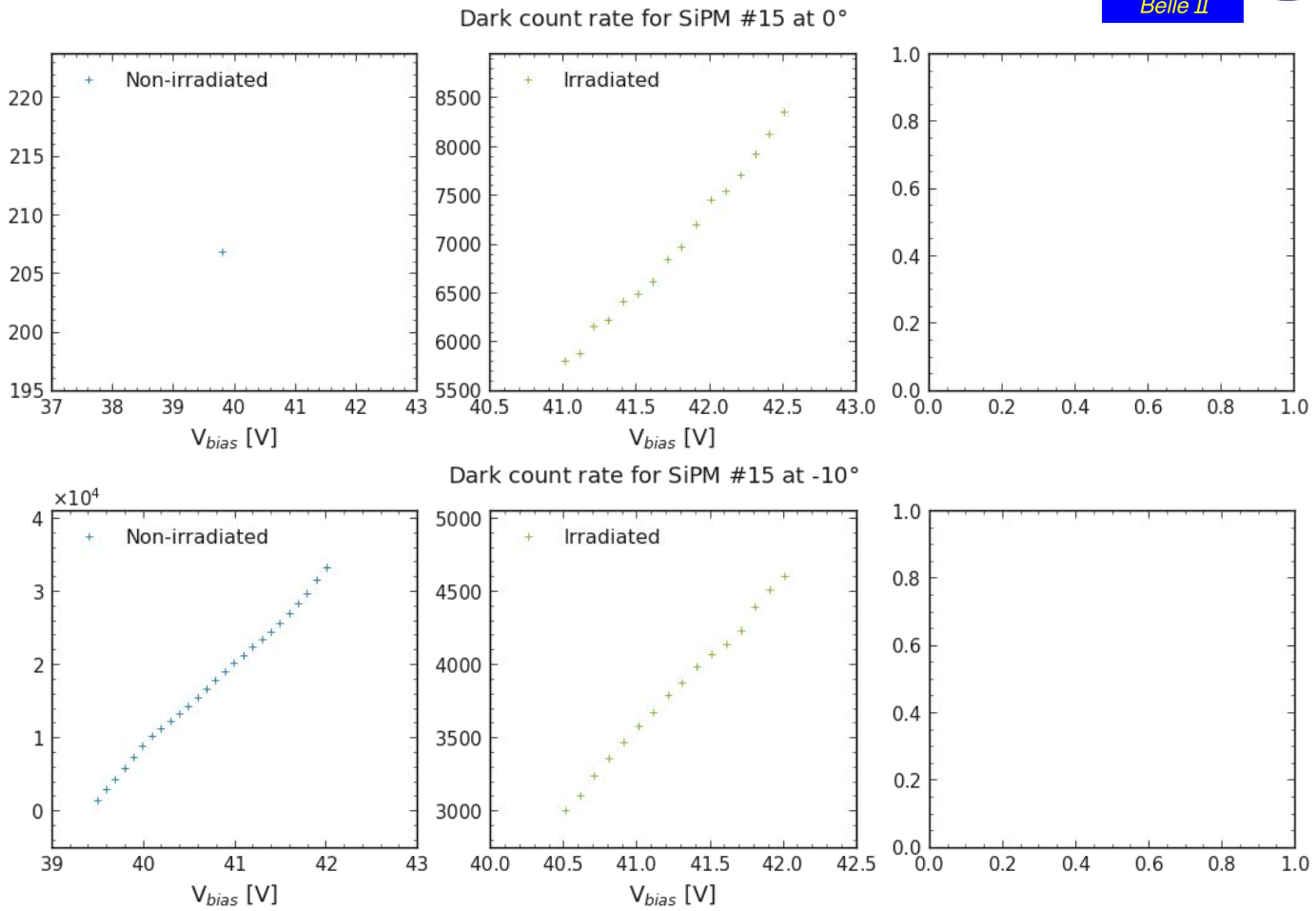


Dark count rate for SiPM #15

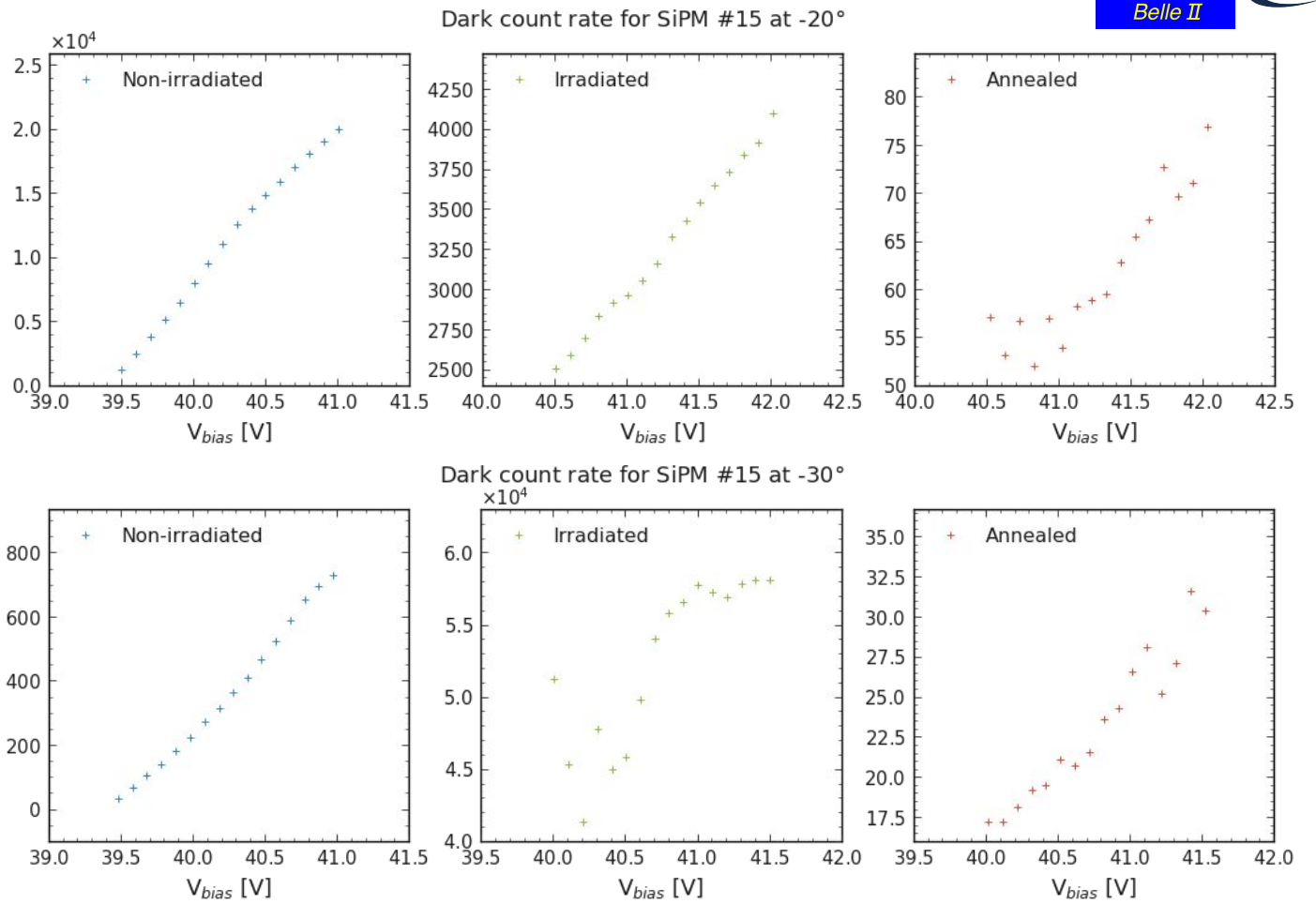
Dark count rate



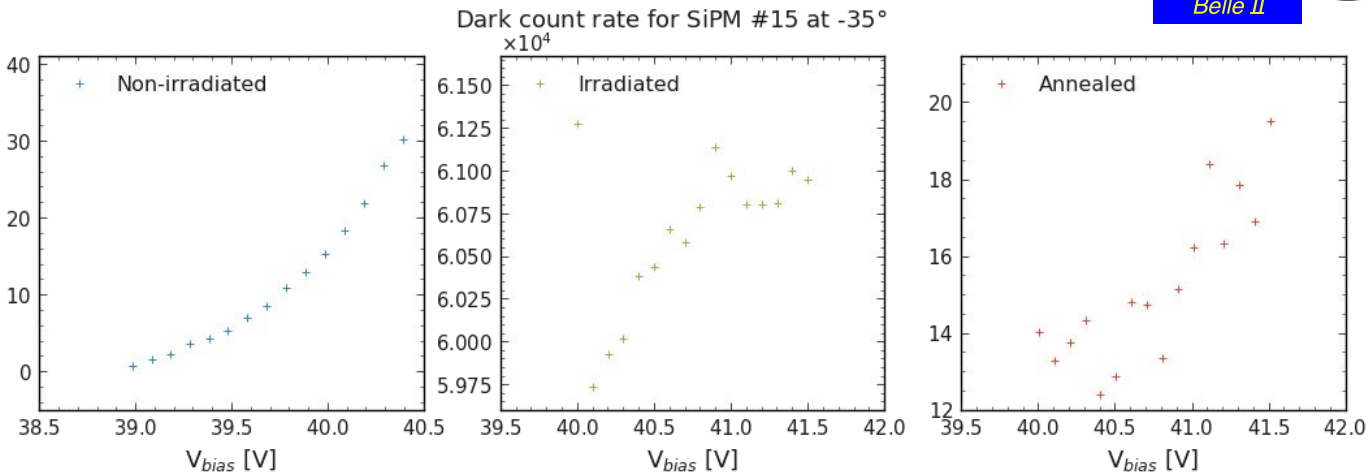
Dark count rate



Dark count rate



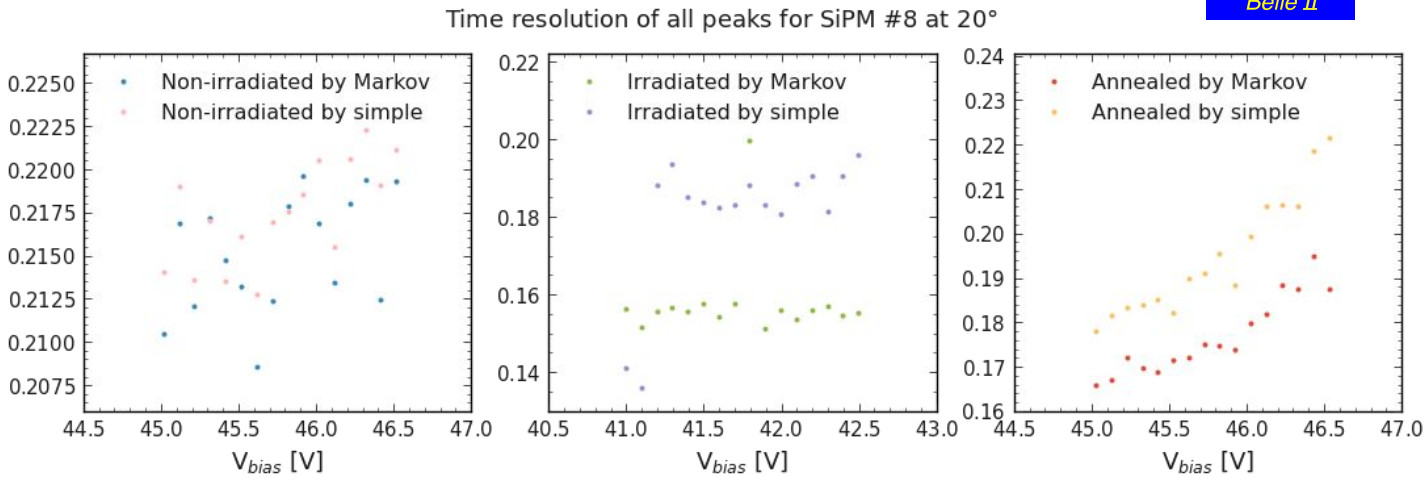
Dark count rate

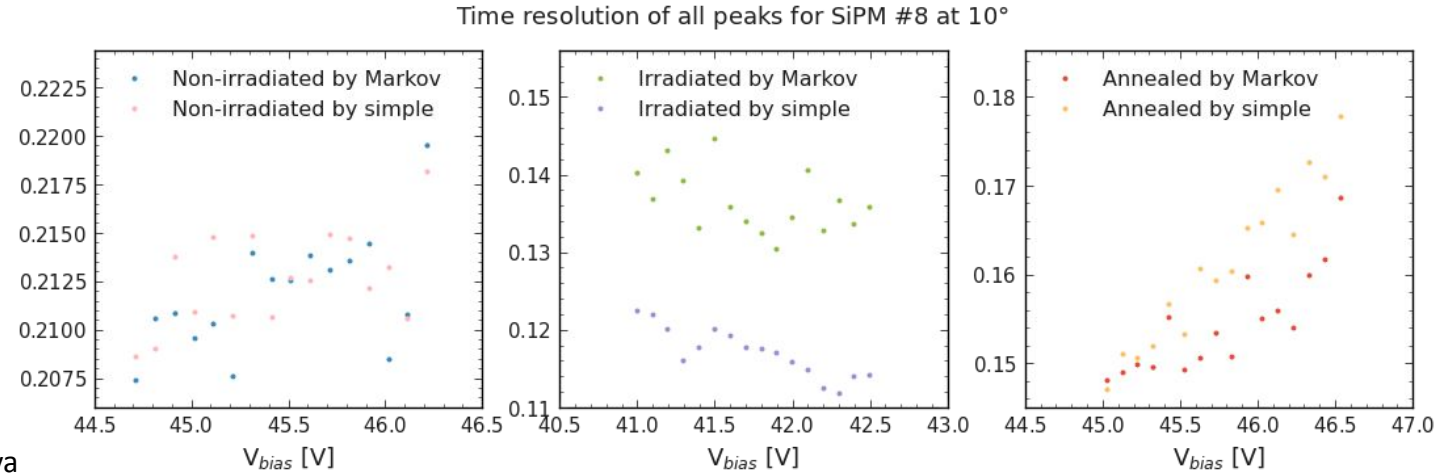


SiMP #8

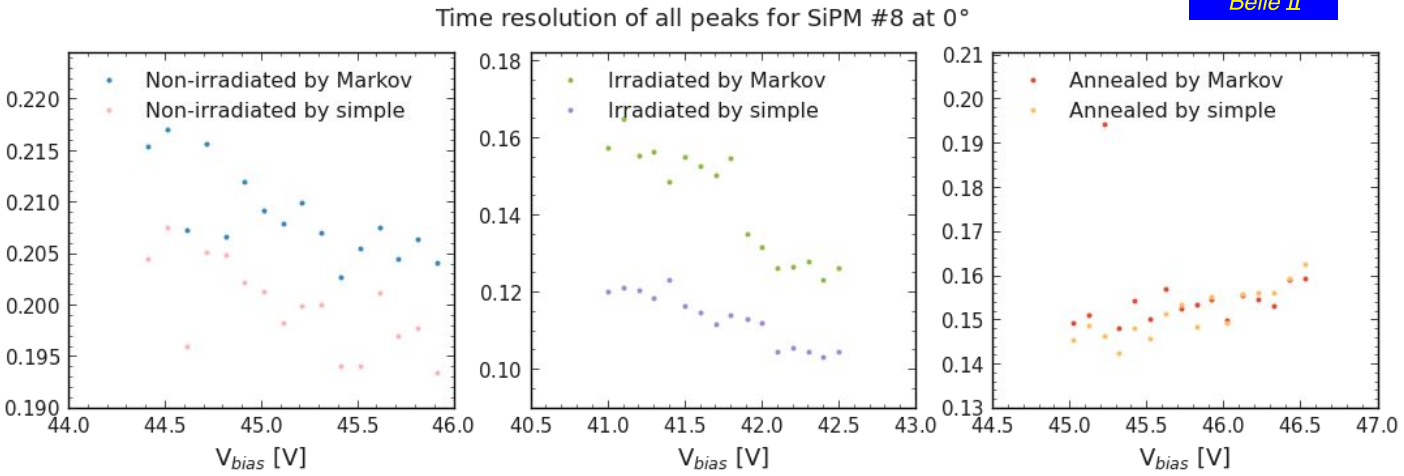
Time resolution for all photon peaks for SiPM #8

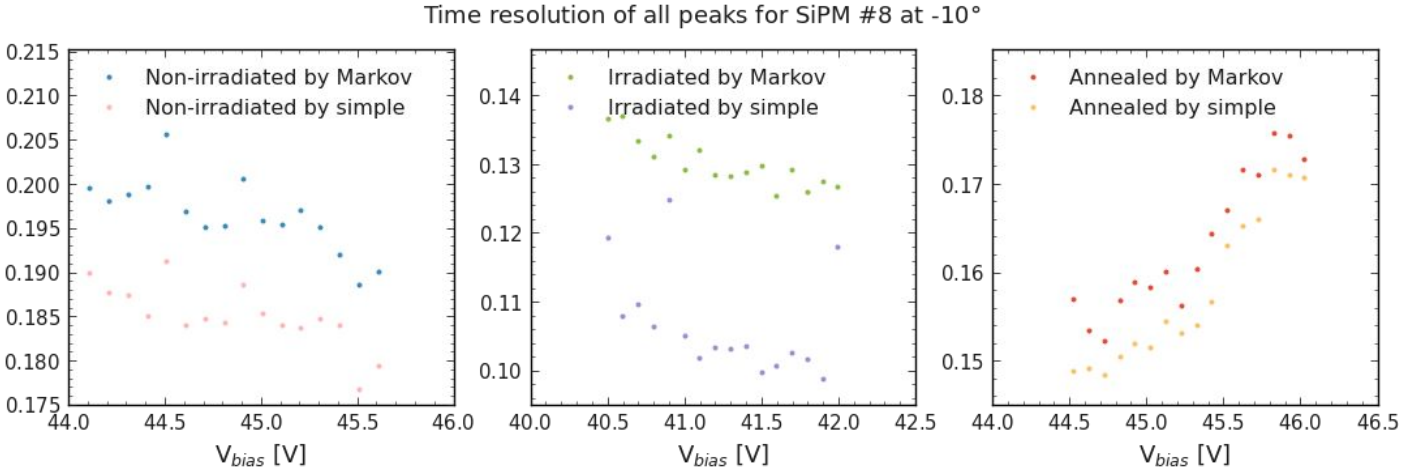
Time resolution for first photon peak



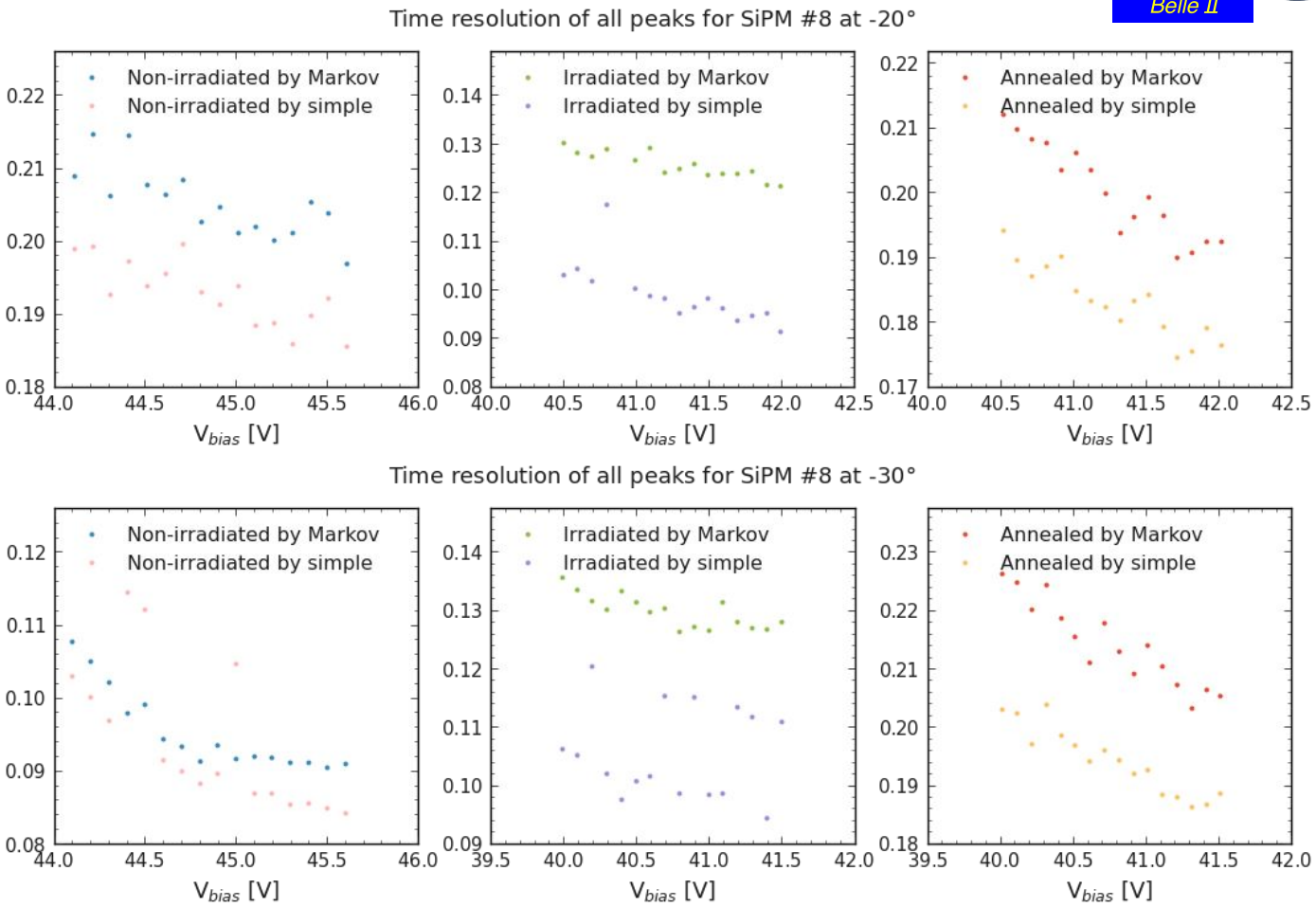


Time resolution for first photon peak

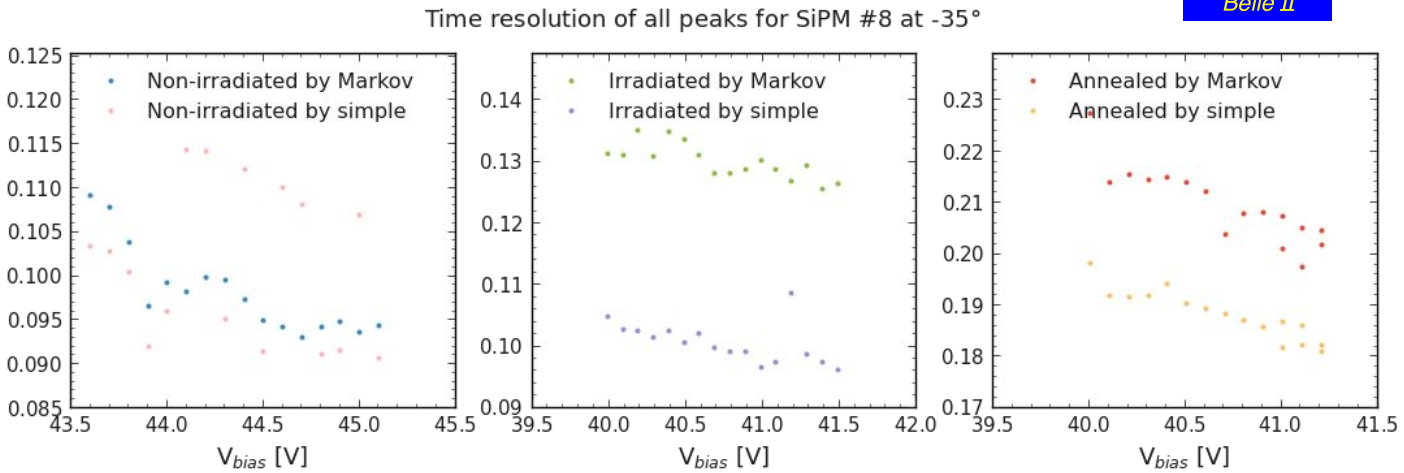




Time resolution for first photon peak

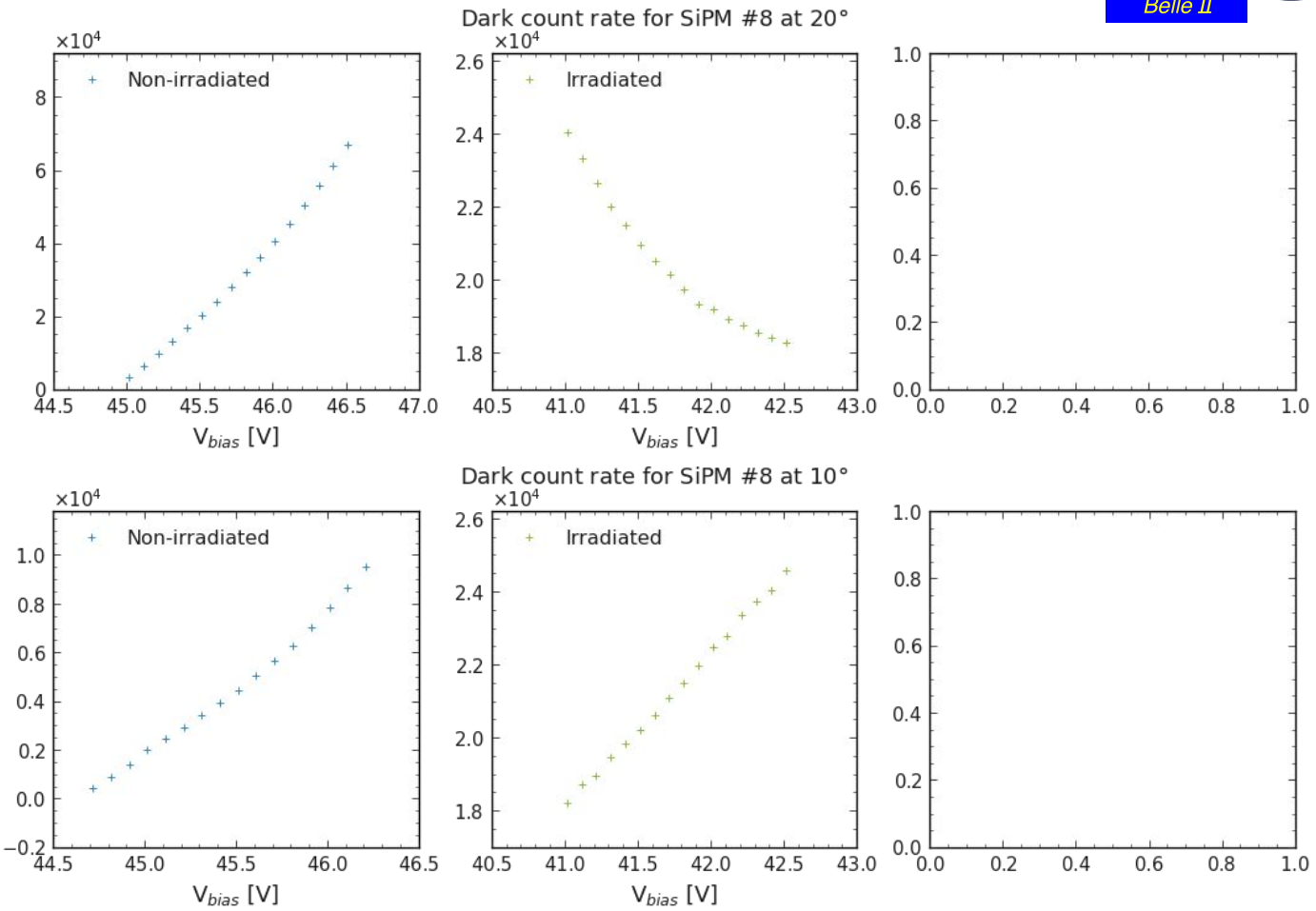


Time resolution for first photon peak

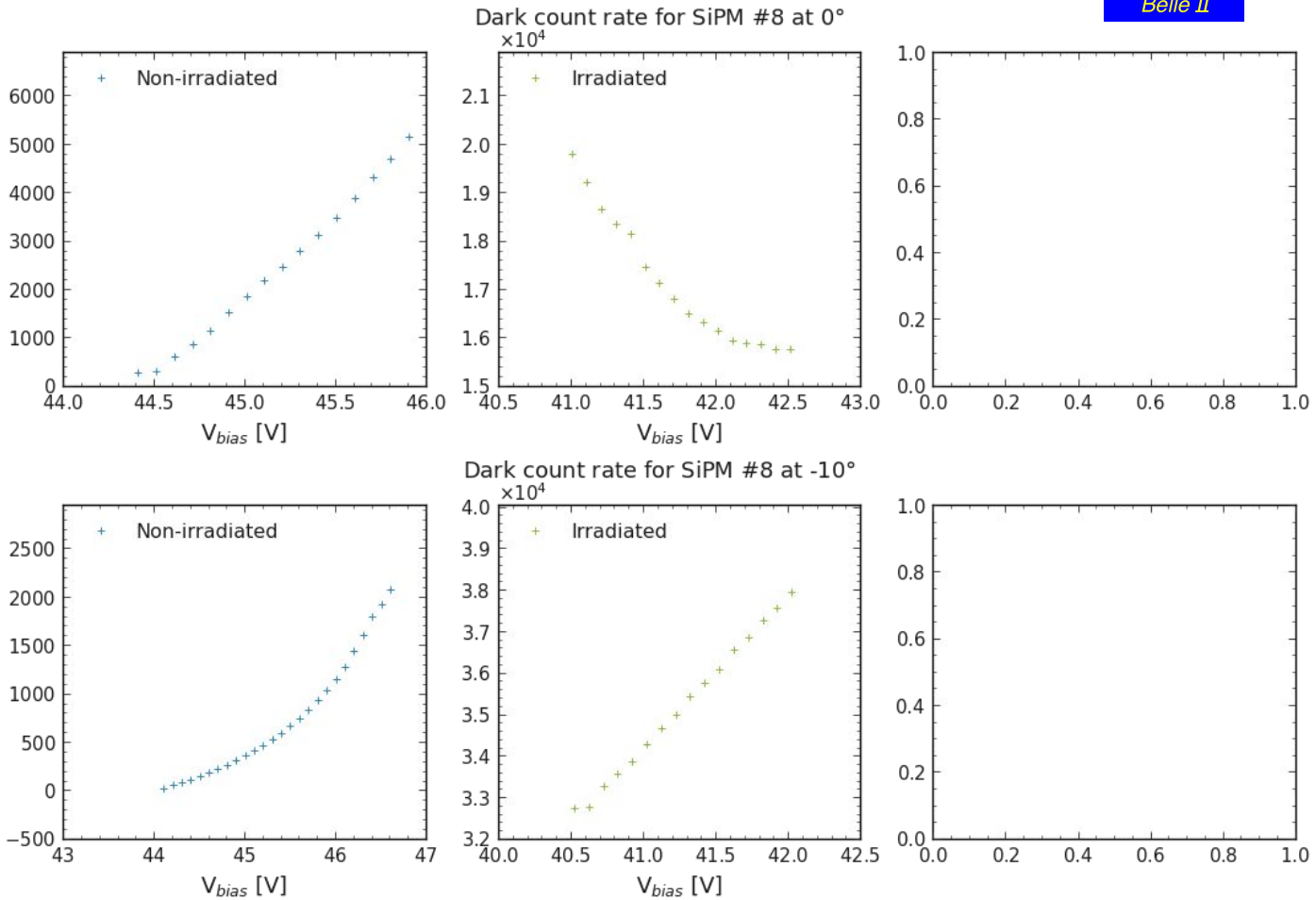


Dark count rate for SiPM #8

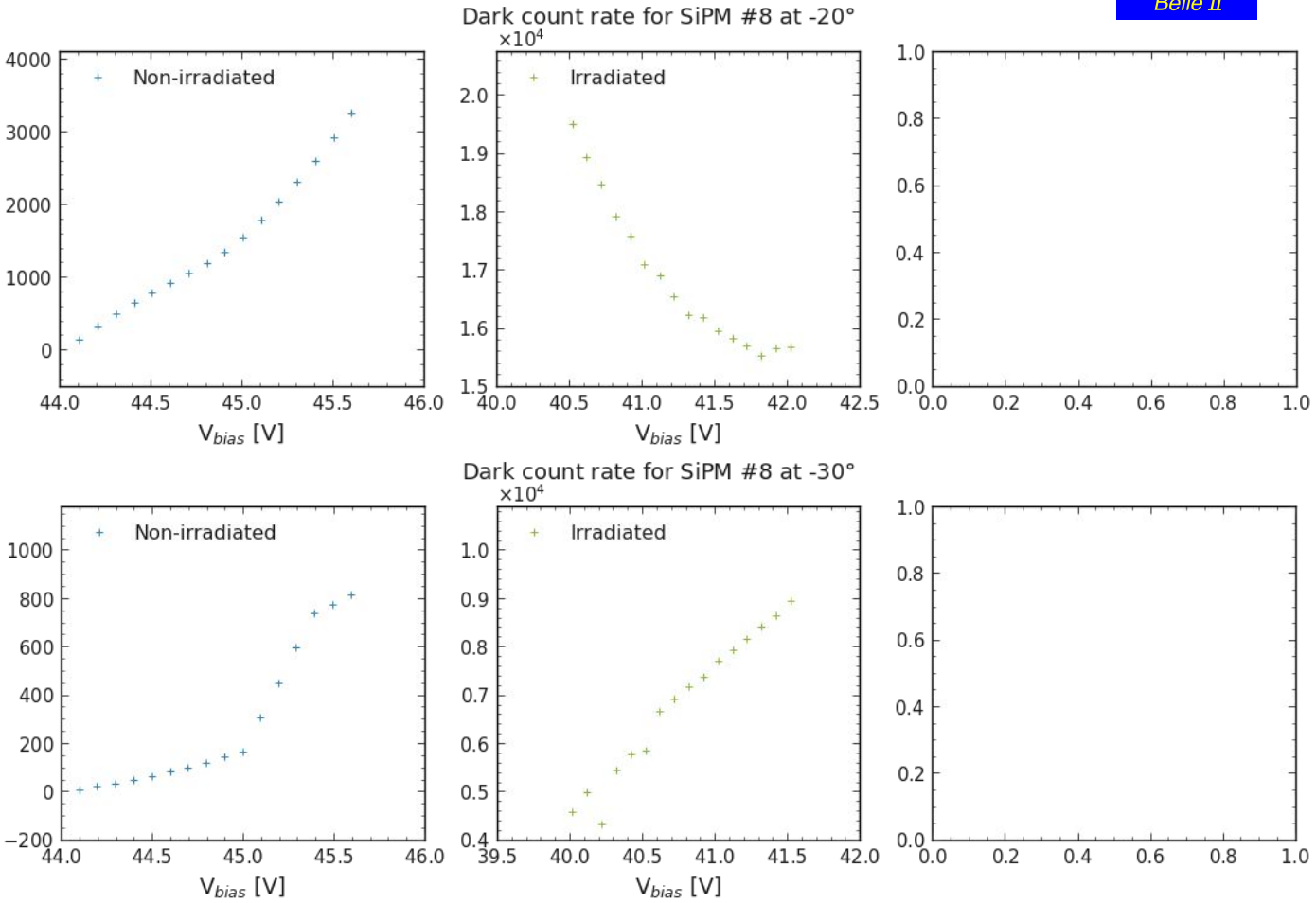
Dark count rate



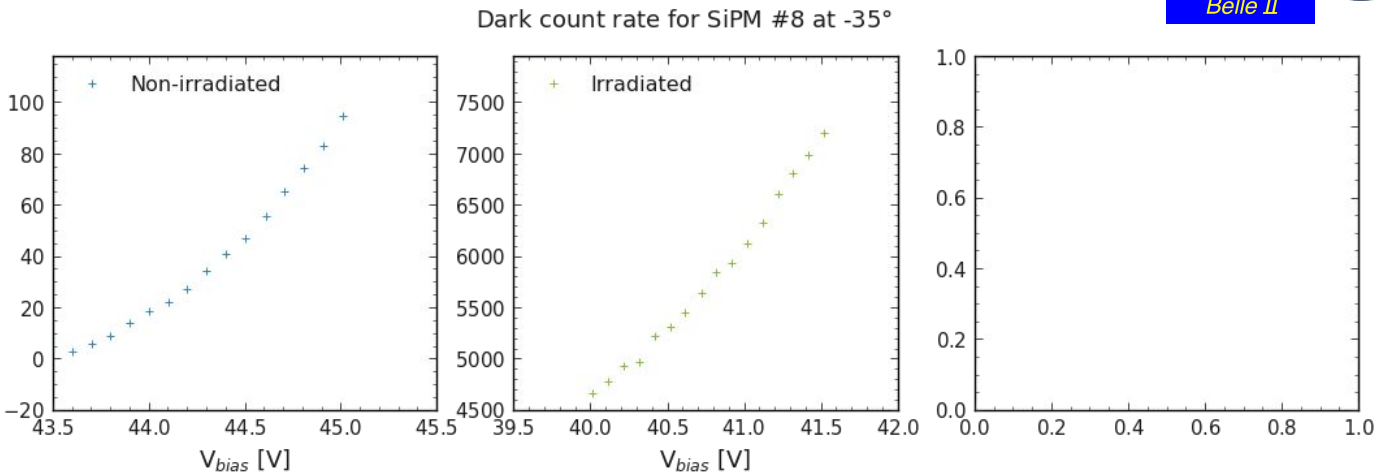
Dark count rate



Dark count rate



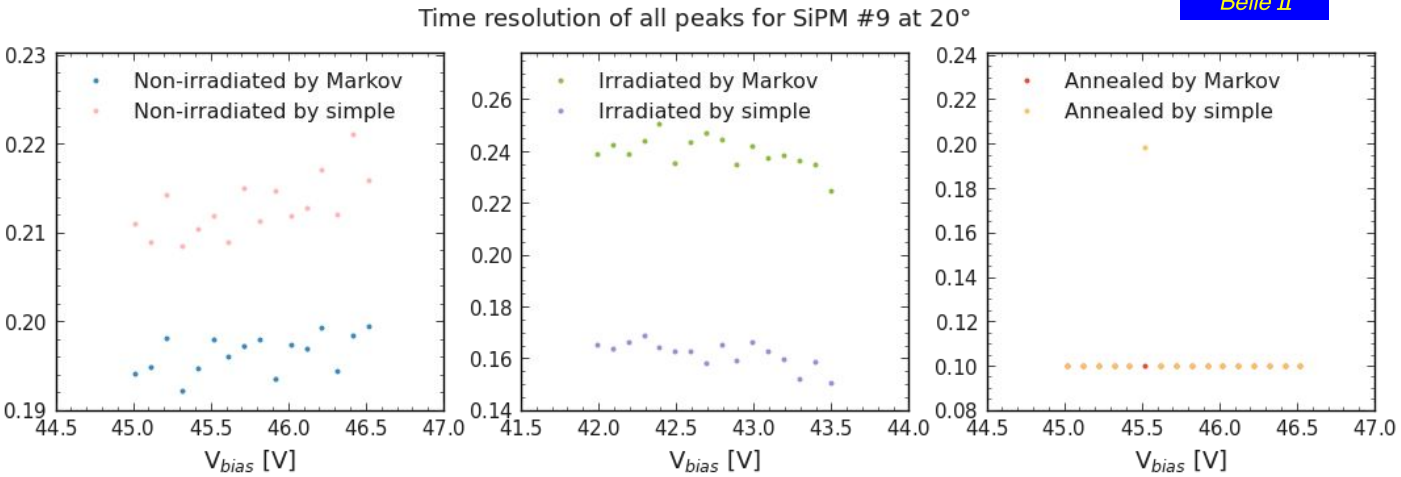
Dark count rate

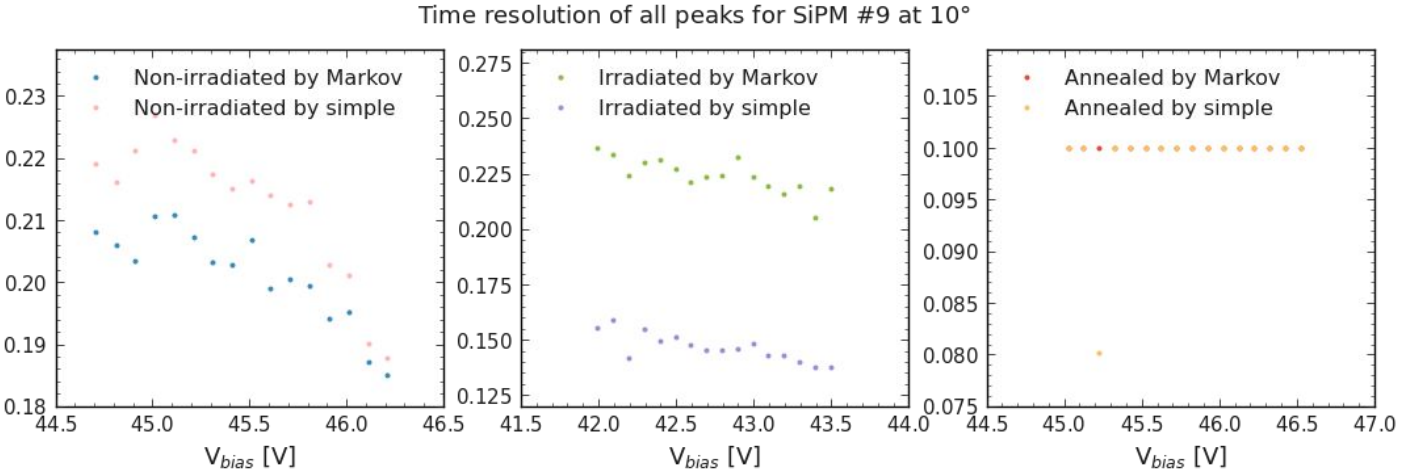


SiMP #9

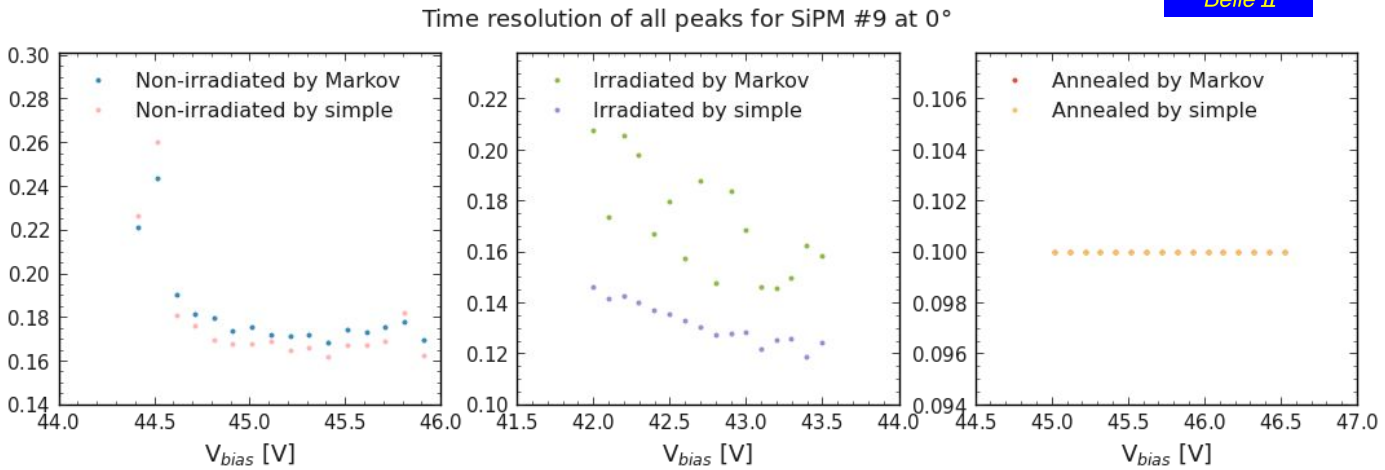
Time resolution for all photon peaks for SiPM #9

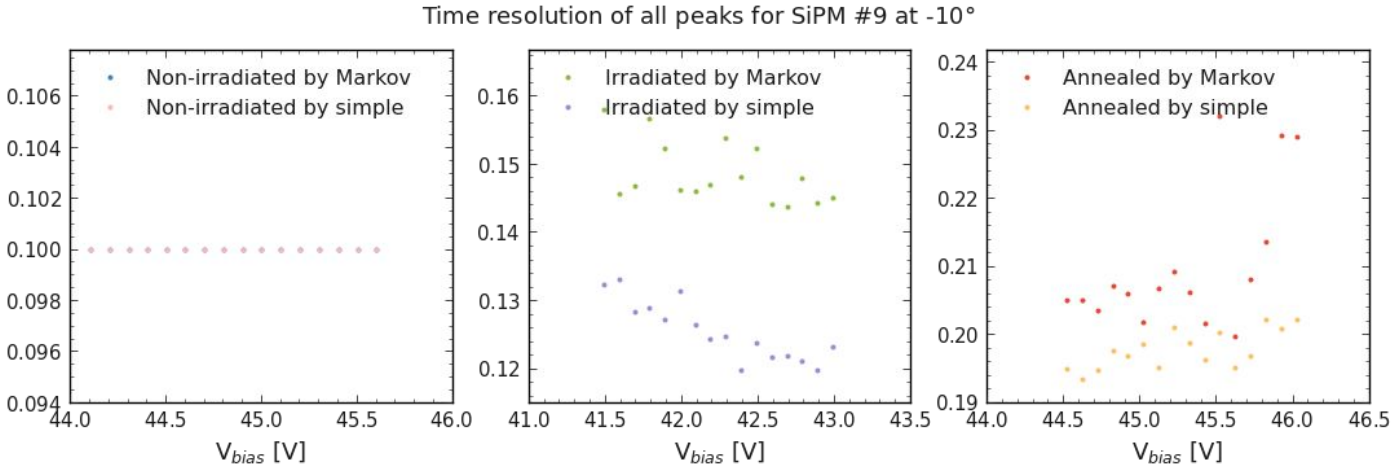
Time resolution for first photon peak



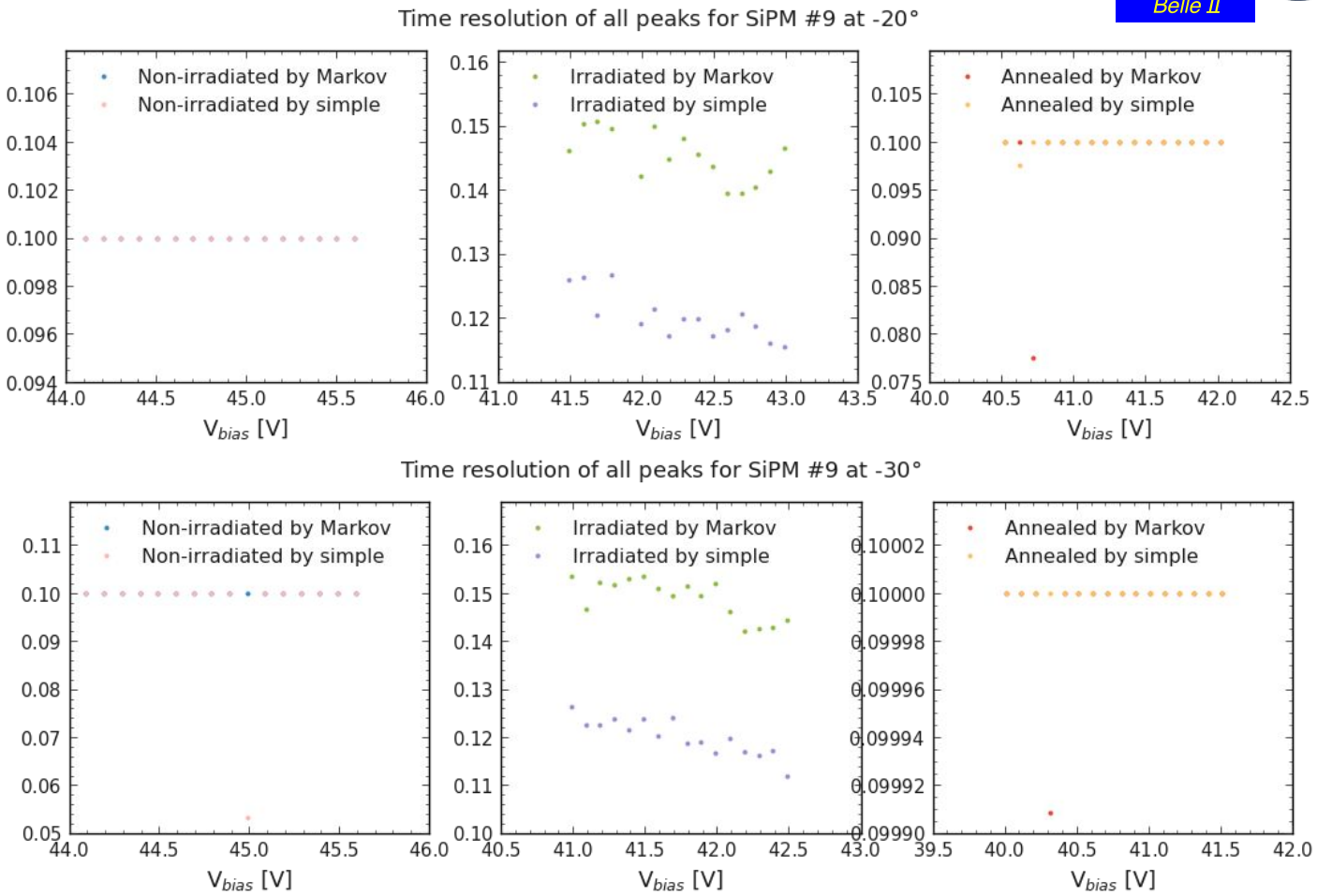


Time resolution for first photon peak

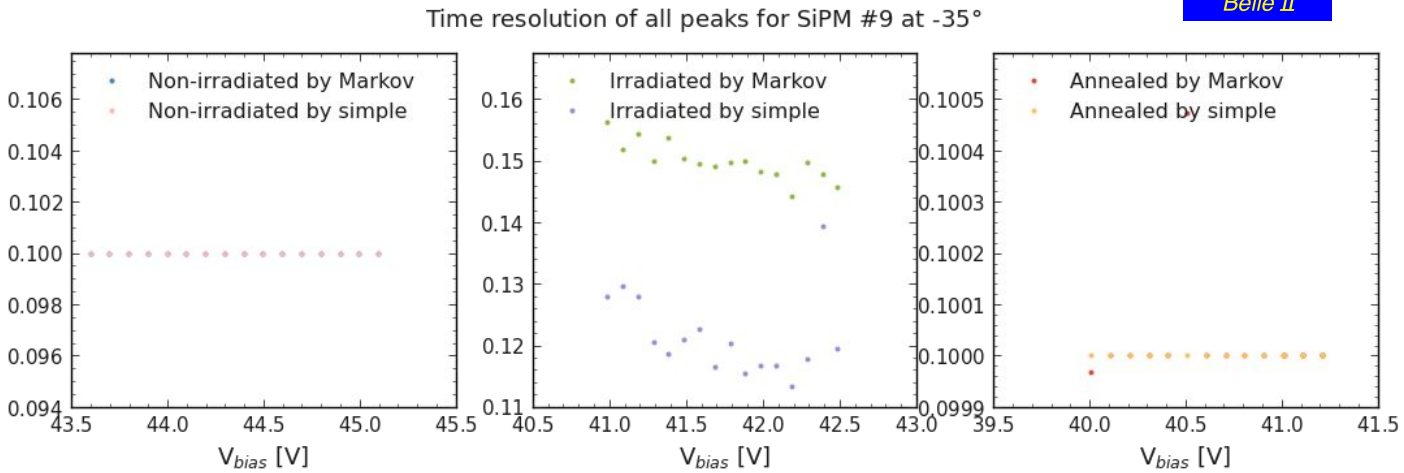




Time resolution for first photon peak

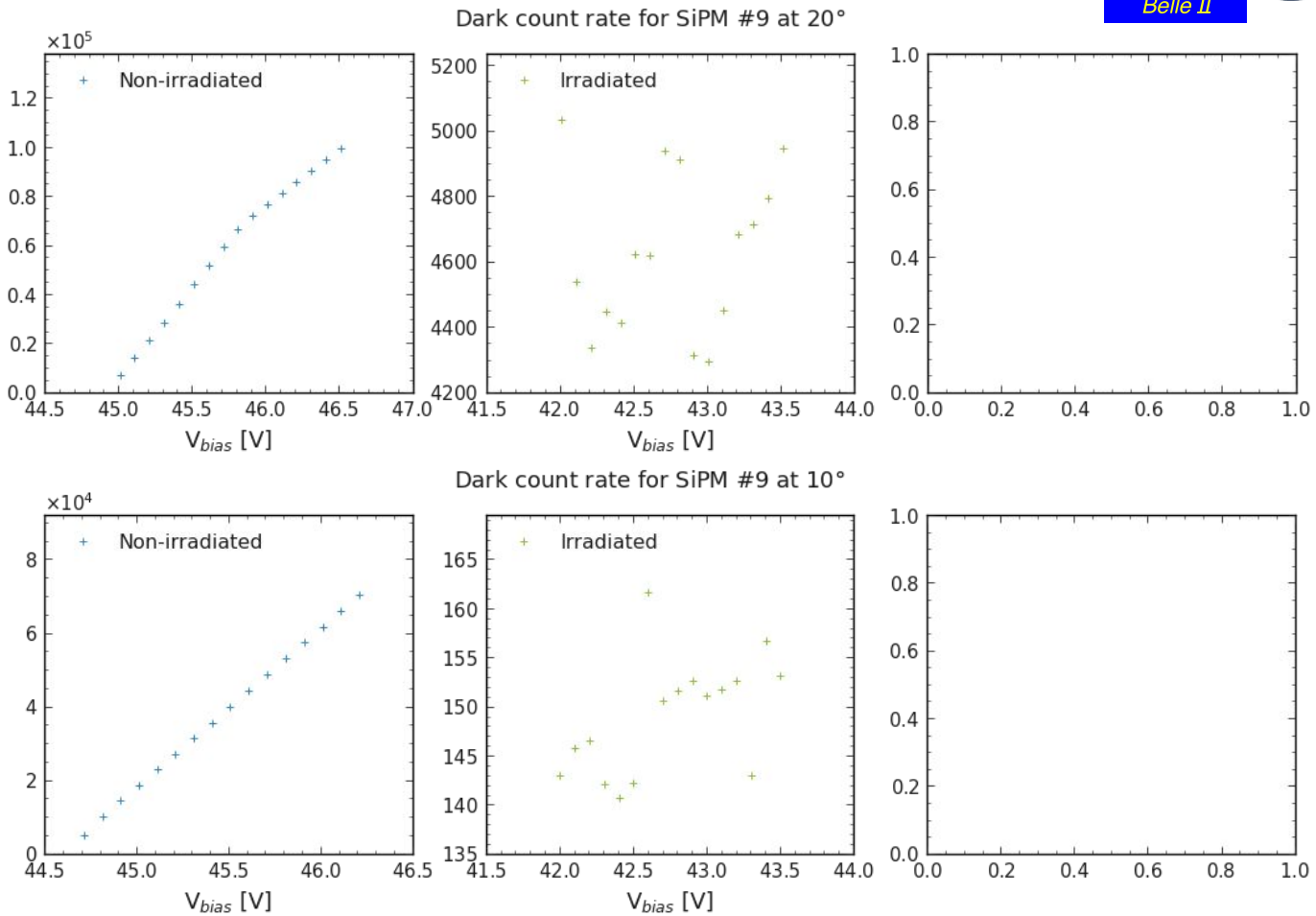


Time resolution for first photon peak

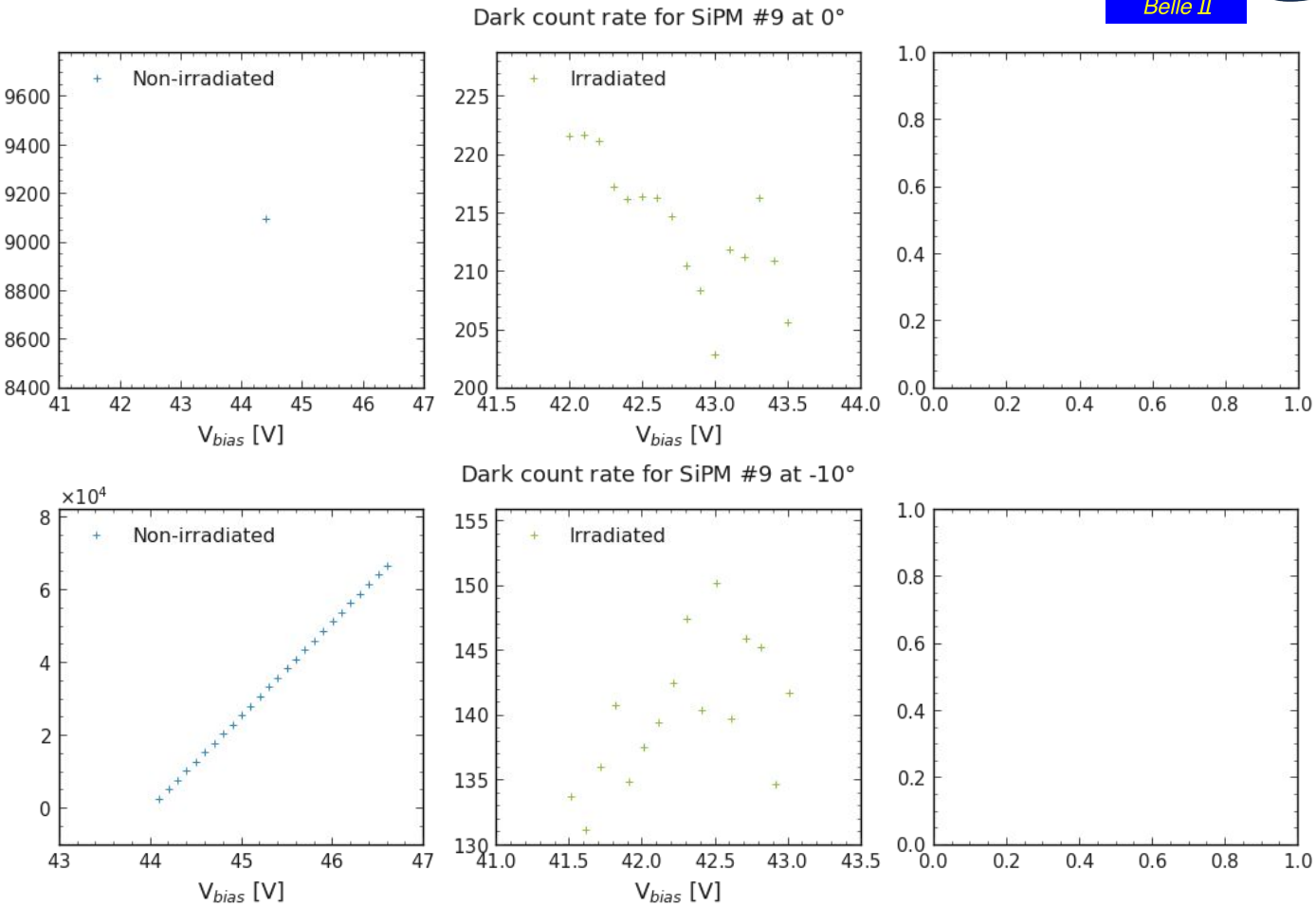


Dark count rate for SiPM #9

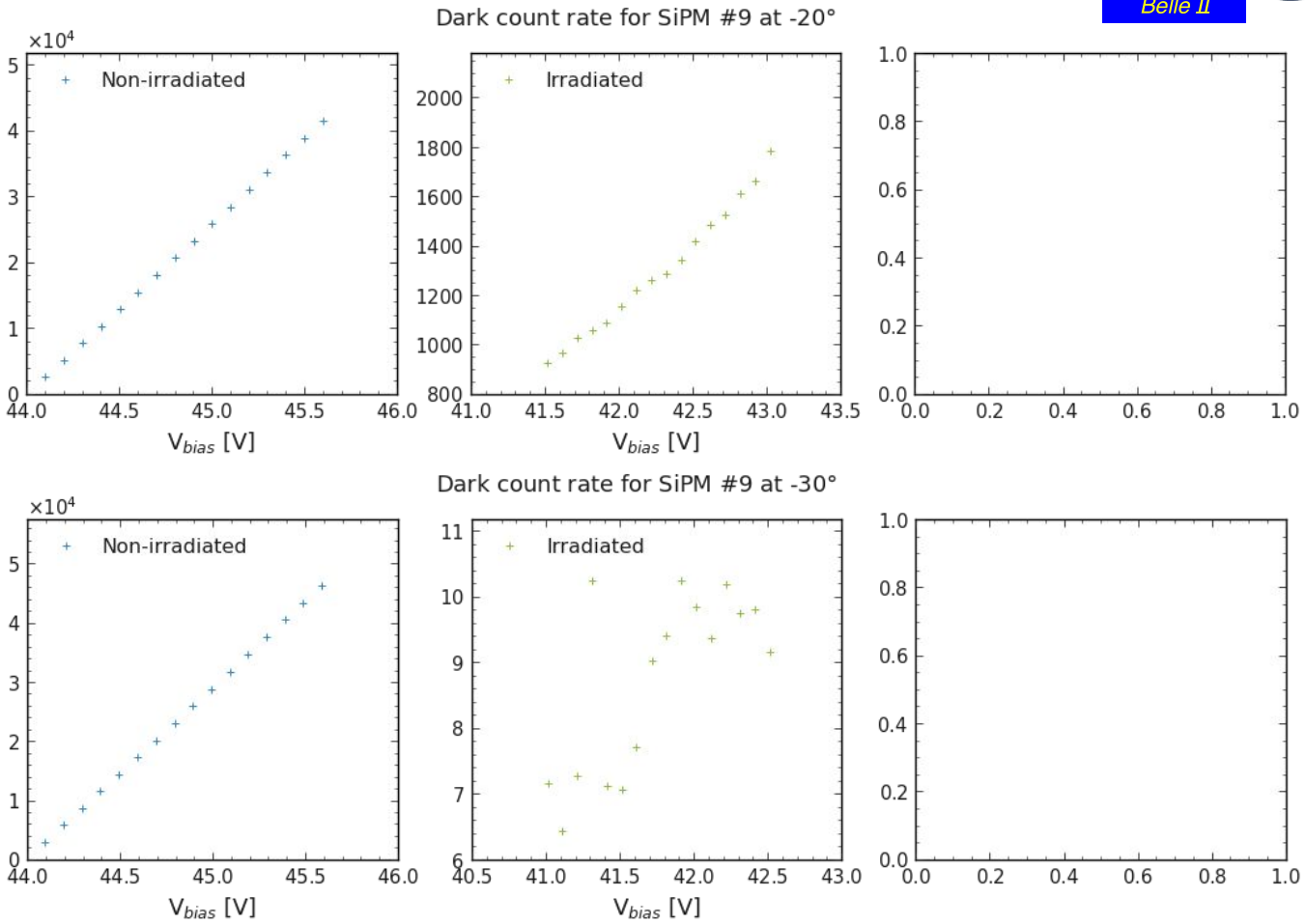
Dark count rate



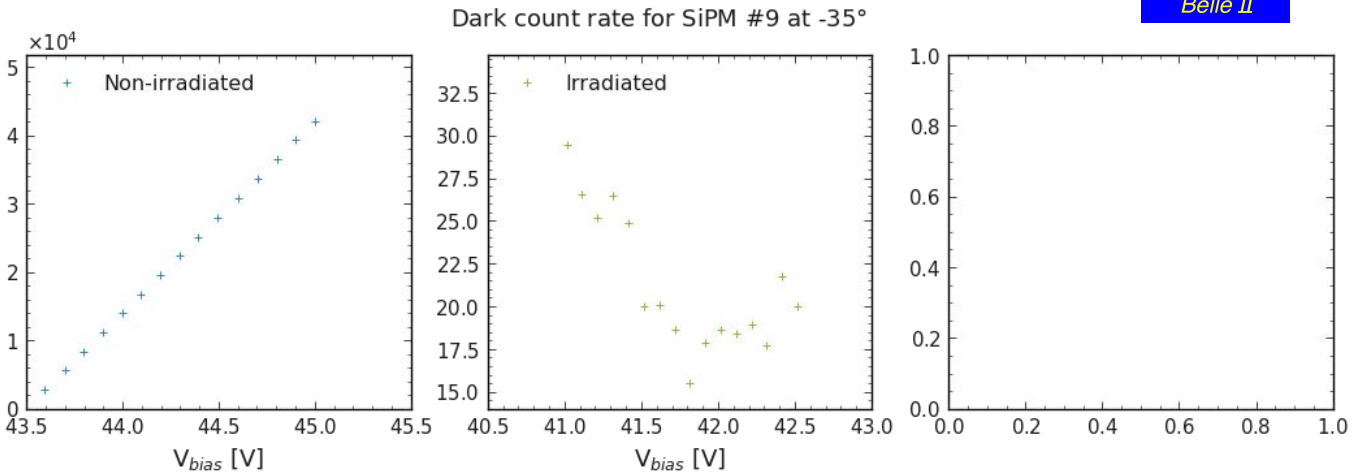
Dark count rate



Dark count rate



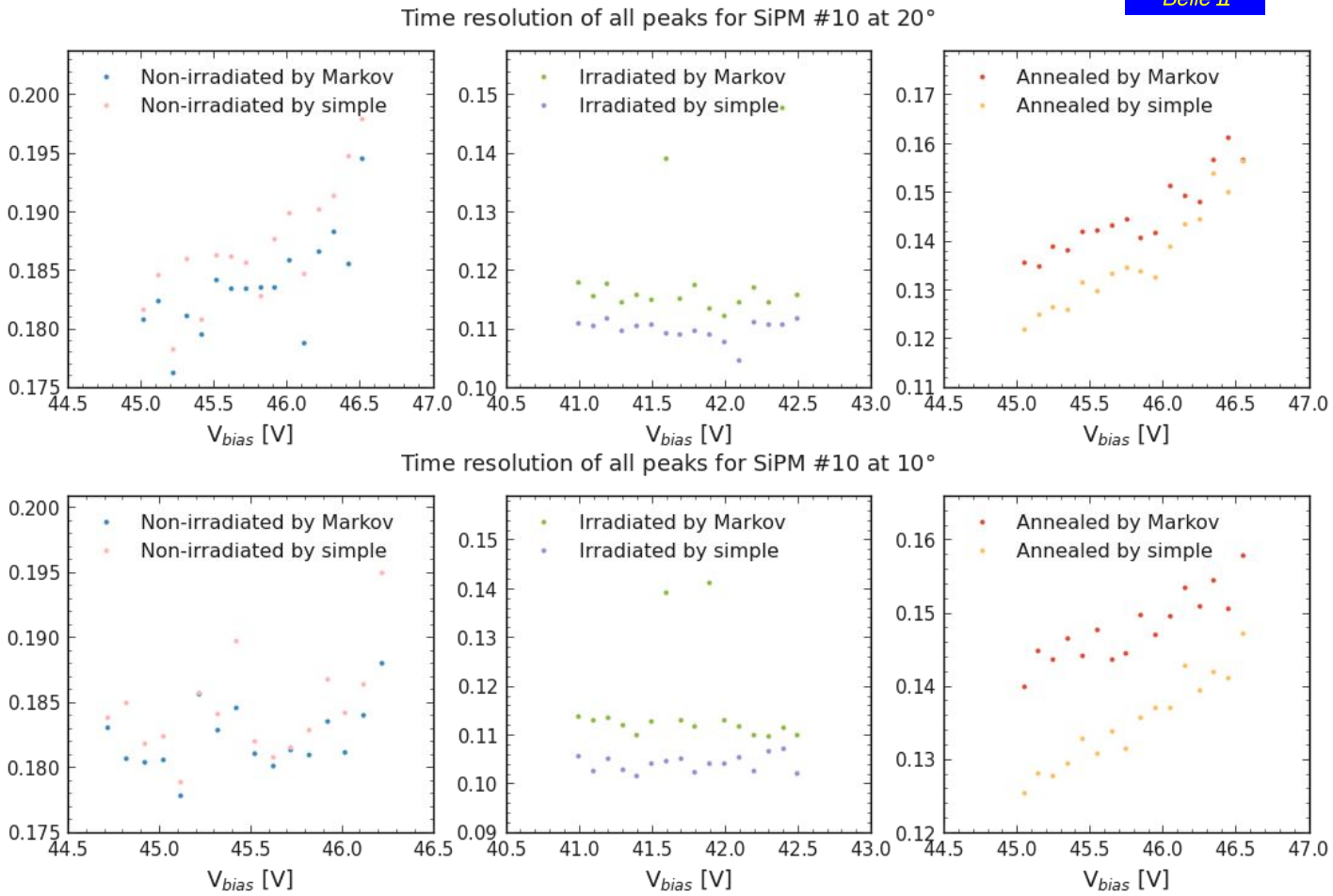
Dark count rate



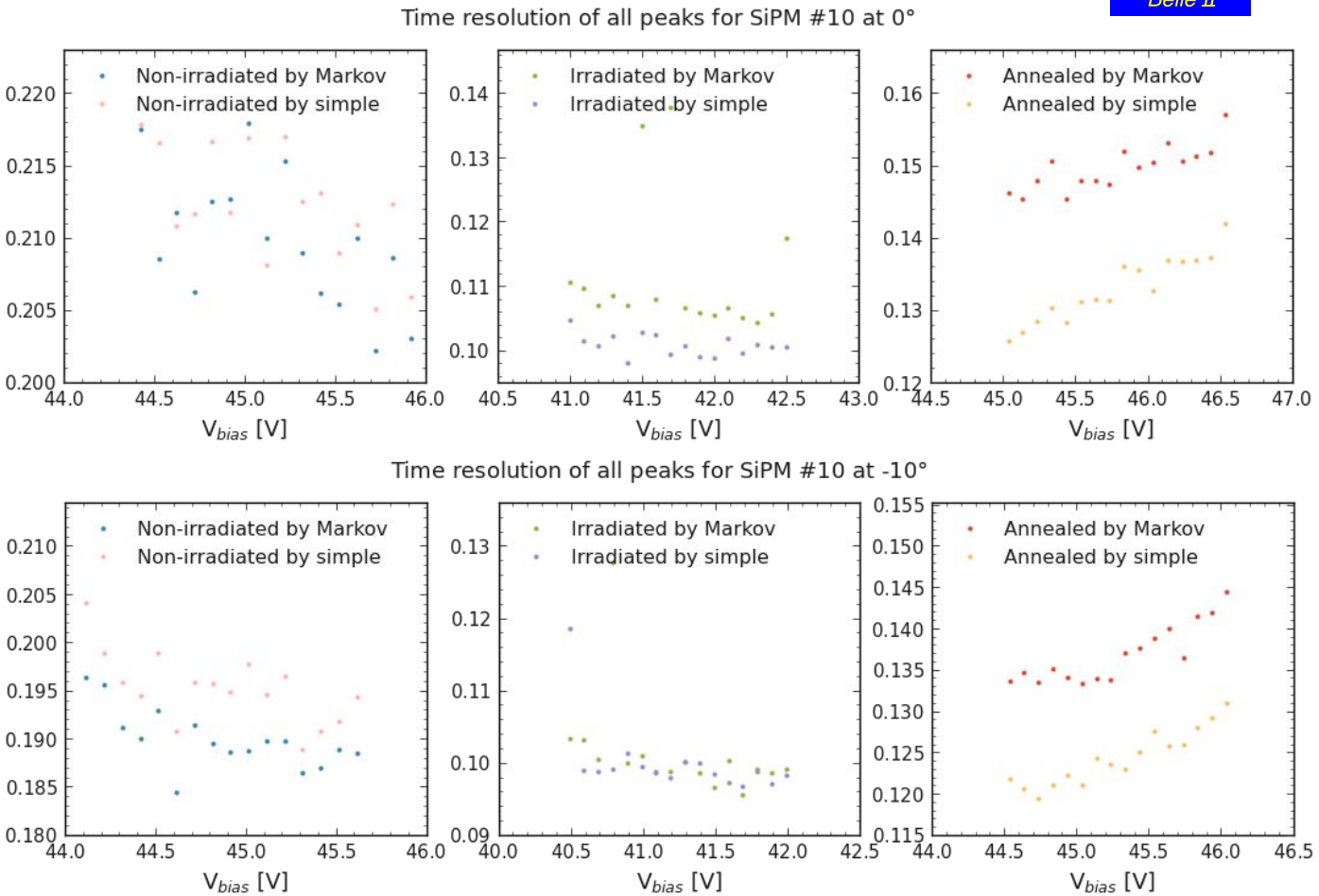
SiMP #10

Time resolution for all photon peaks for SiPM #10

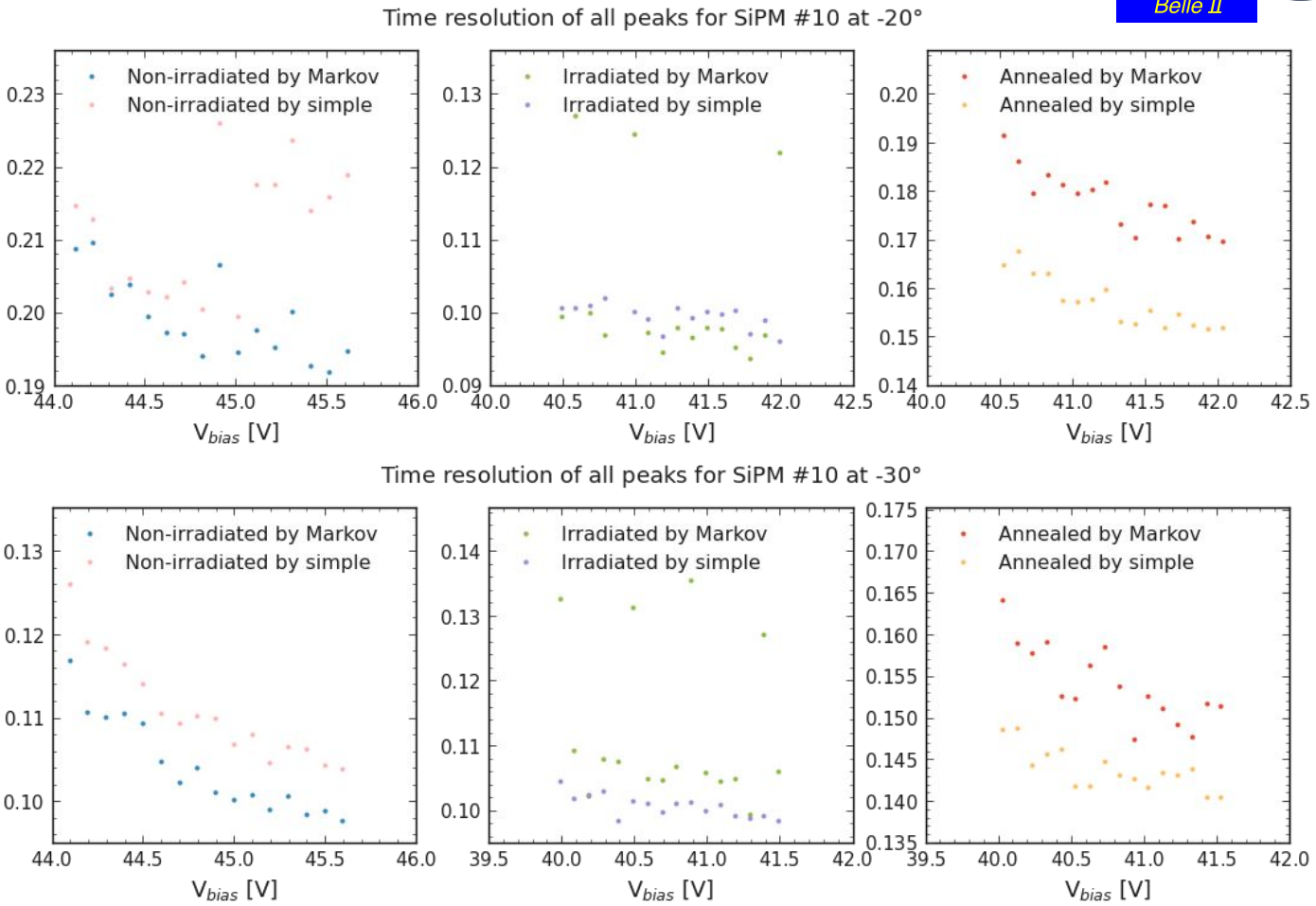
Time resolution for first photon peak



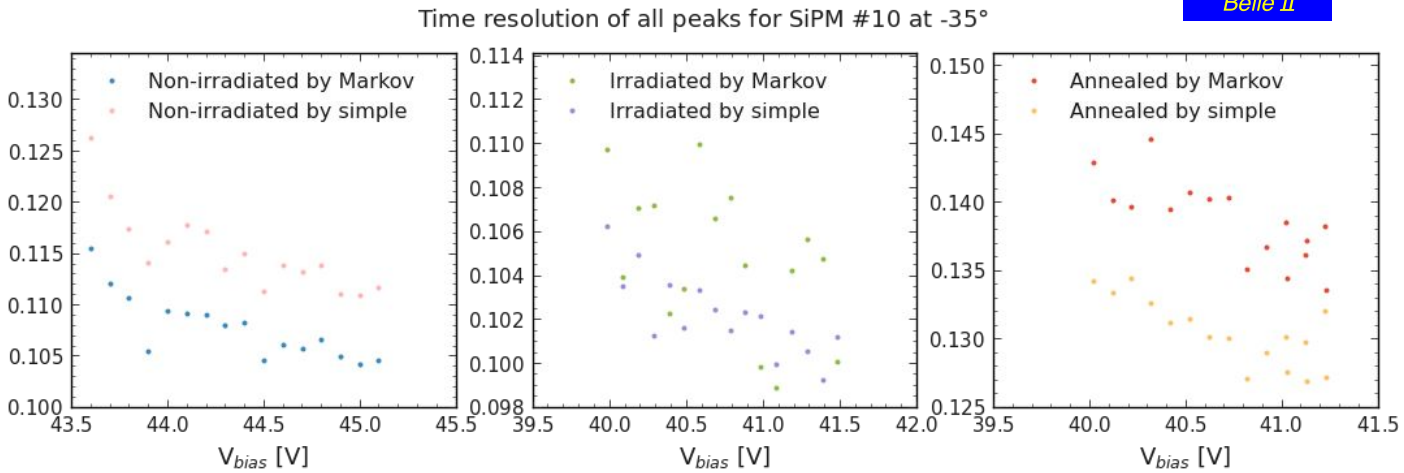
Time resolution for first photon peak



Time resolution for first photon peak

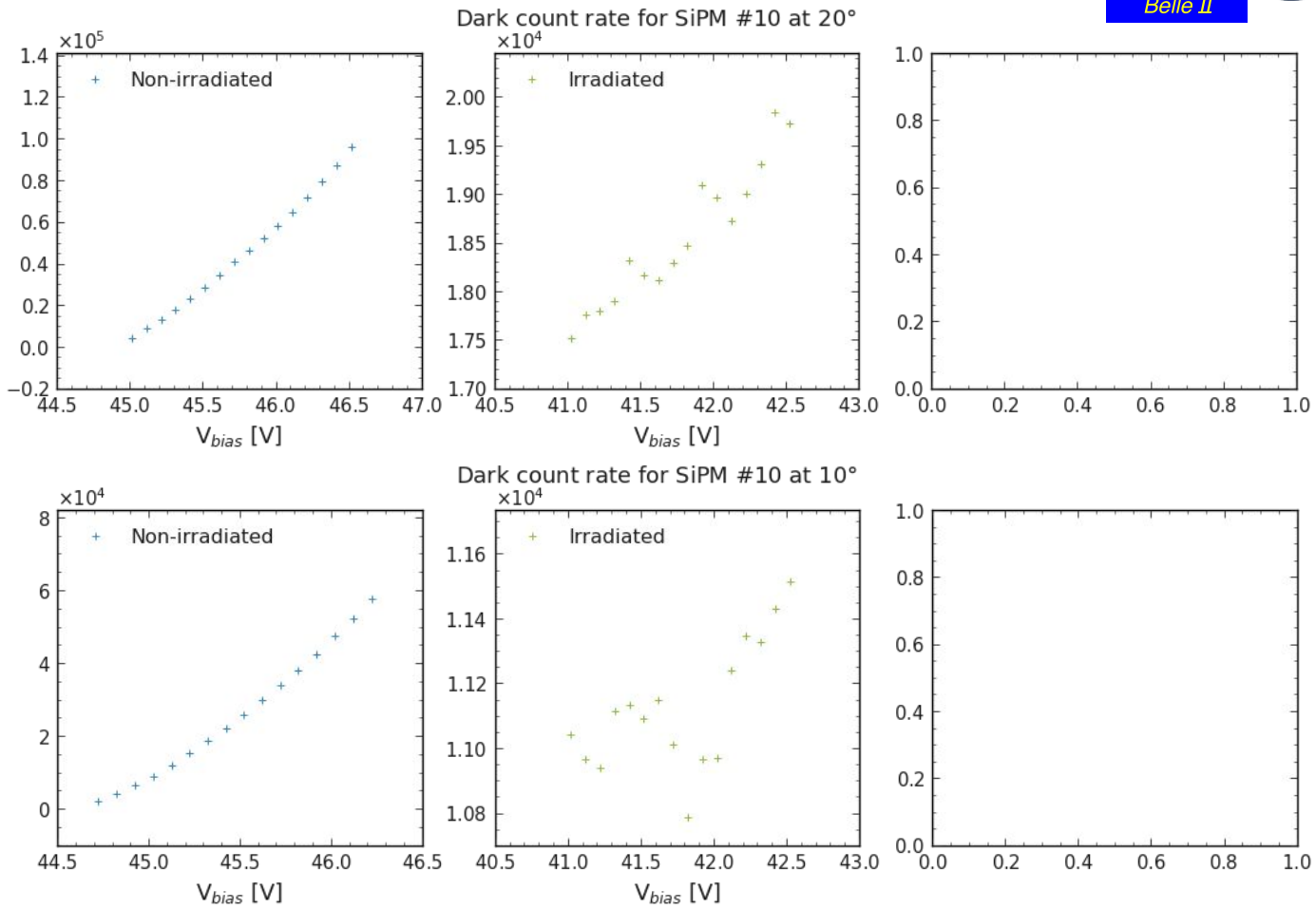


Time resolution for first photon peak

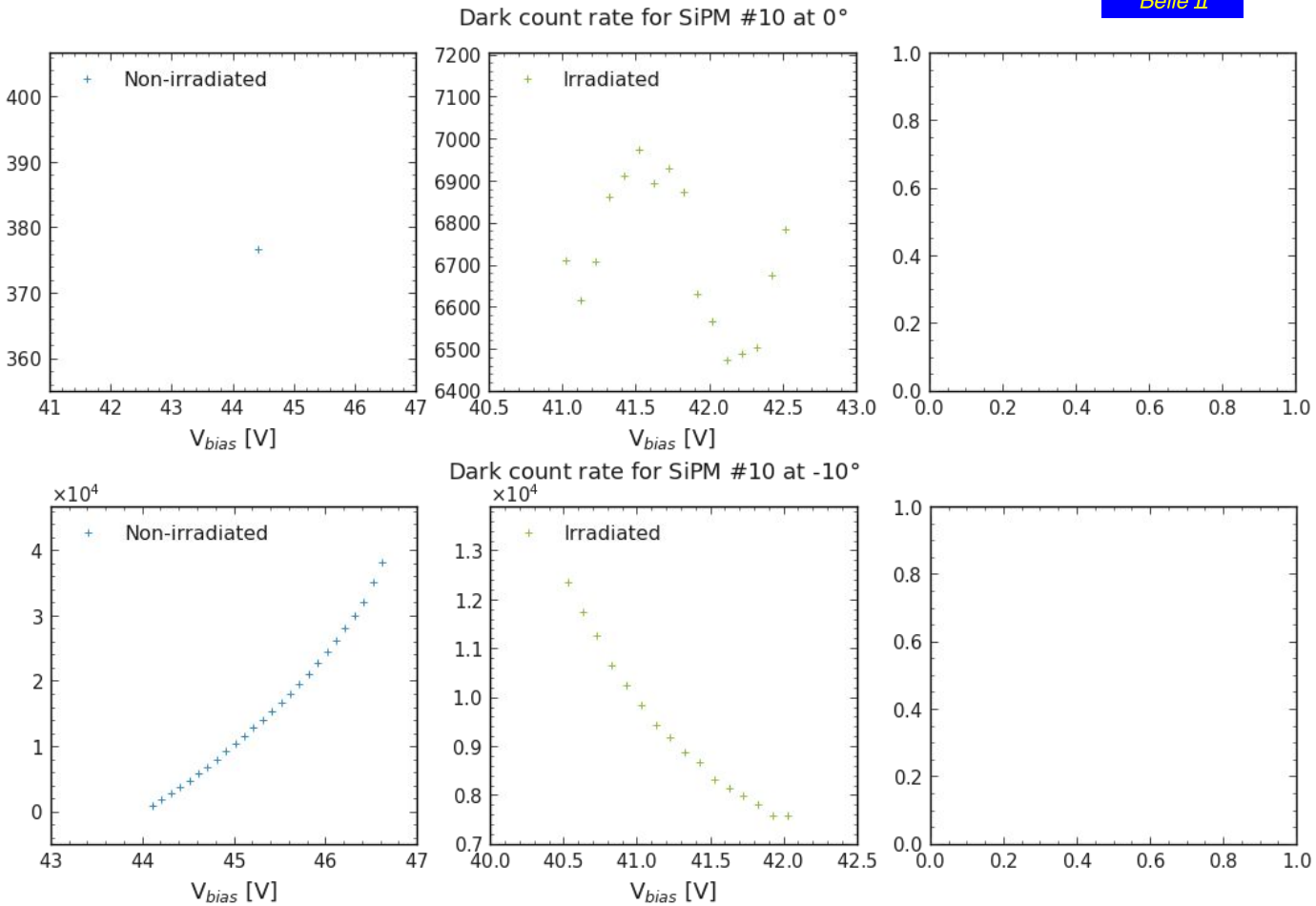


Dark count rate for SiPM #10

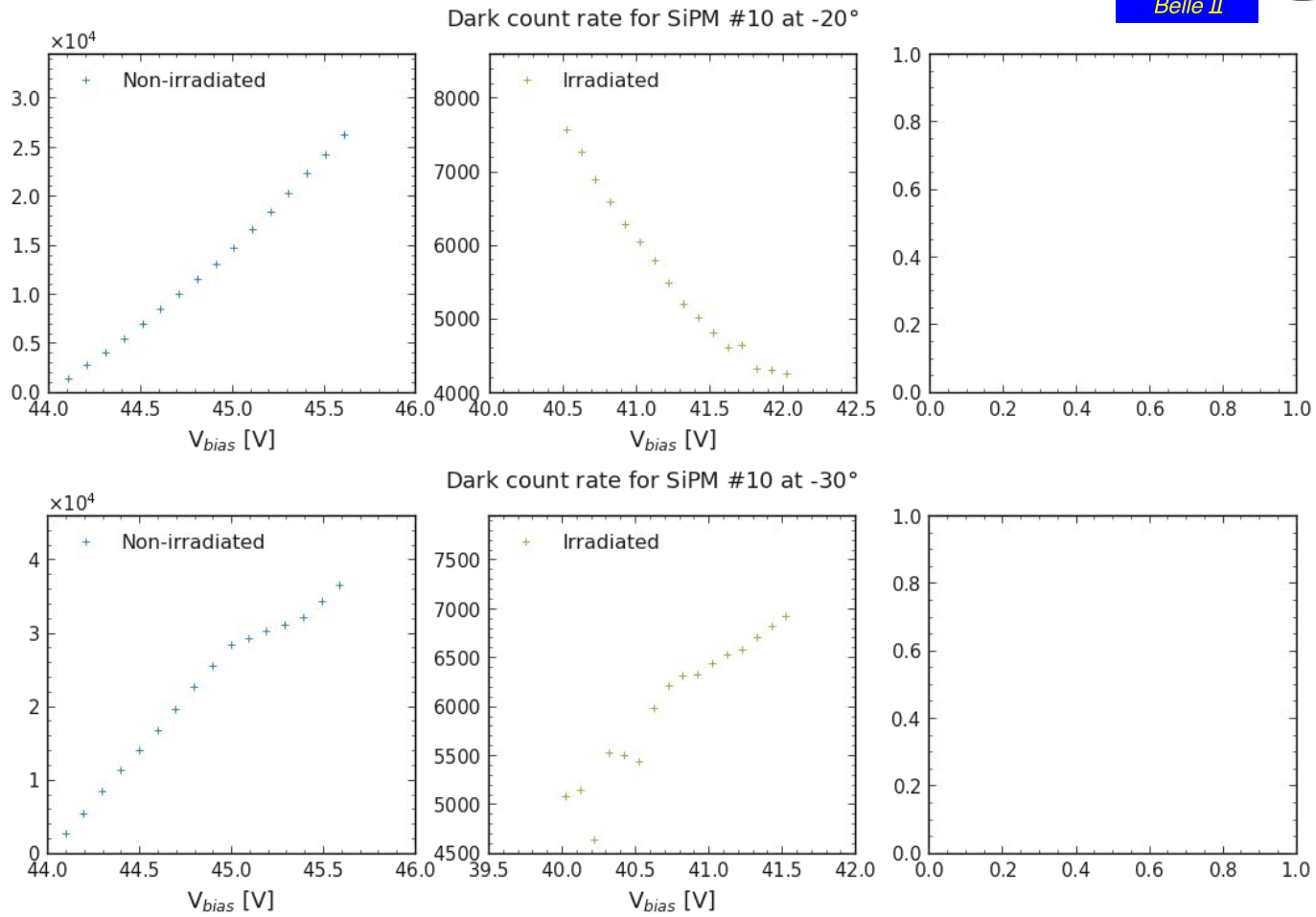
Dark count rate



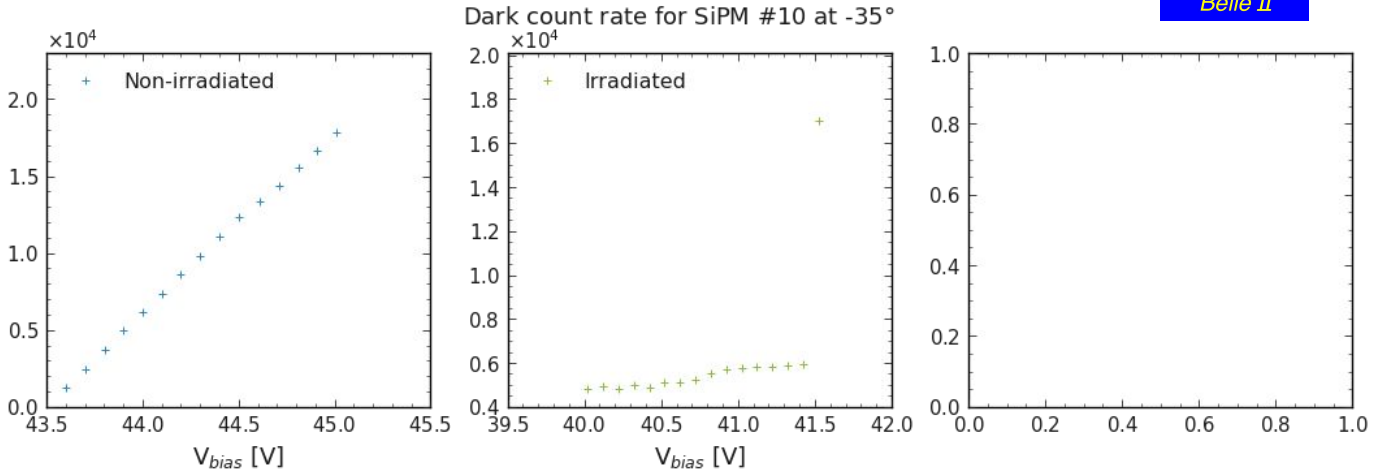
Dark count rate



Dark count rate



Dark count rate



Backup

Markov parameters tuning using SiPM #14

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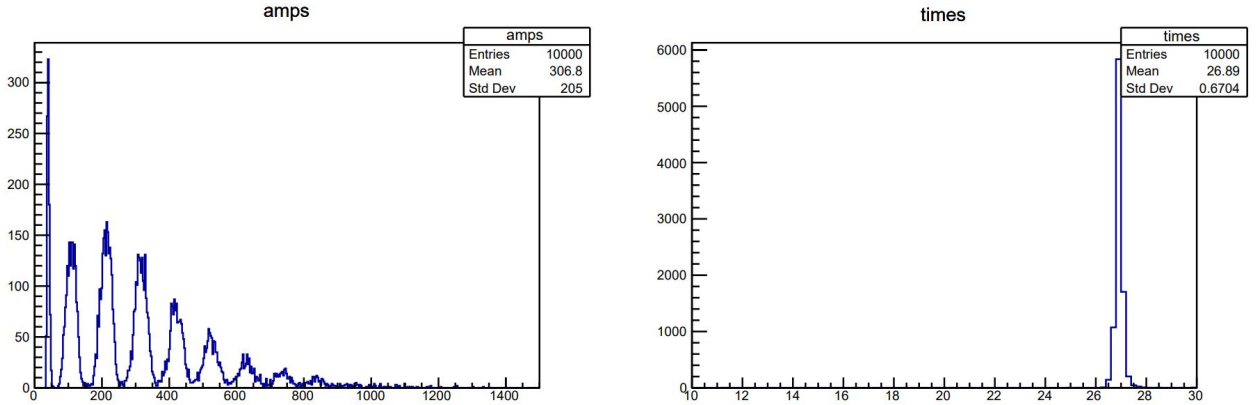
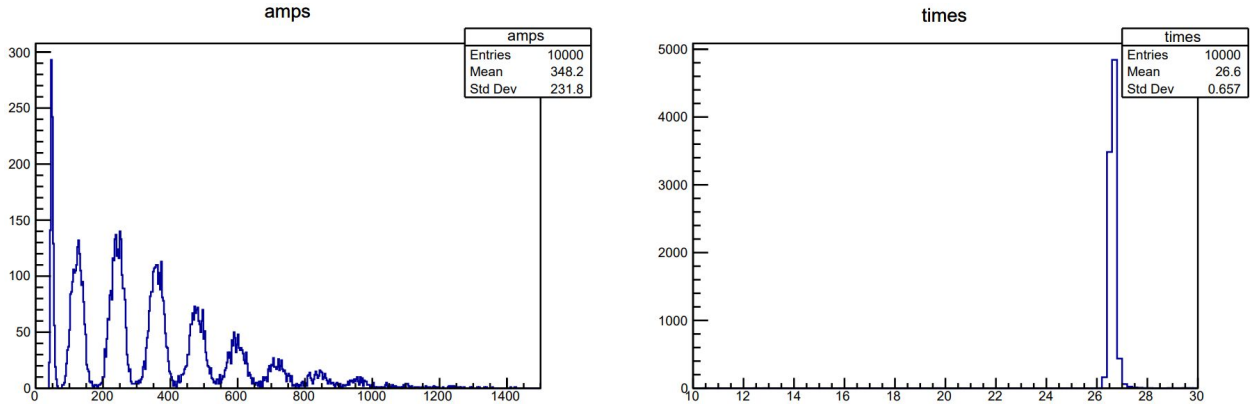
Background iterated 10 times

Difference between background and original waveform



Signal waveform extracted using Markov algorithm



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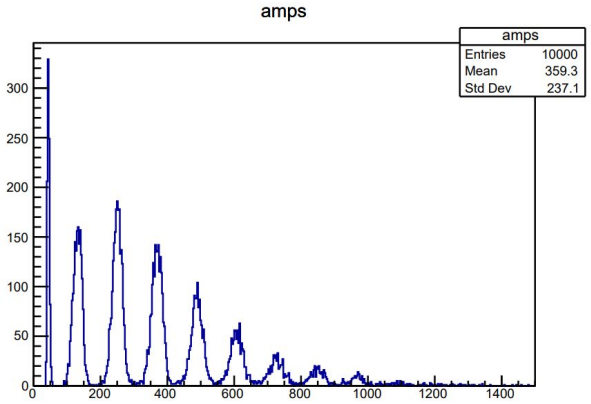
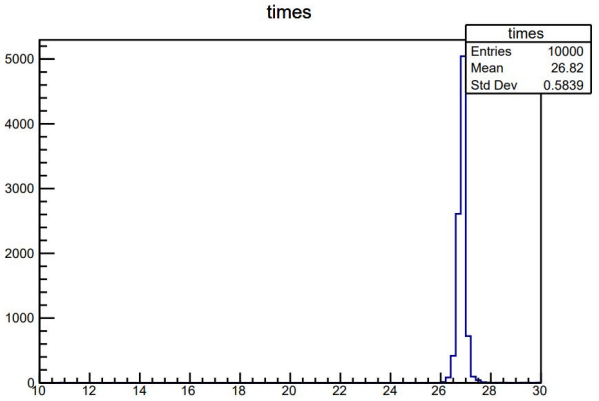
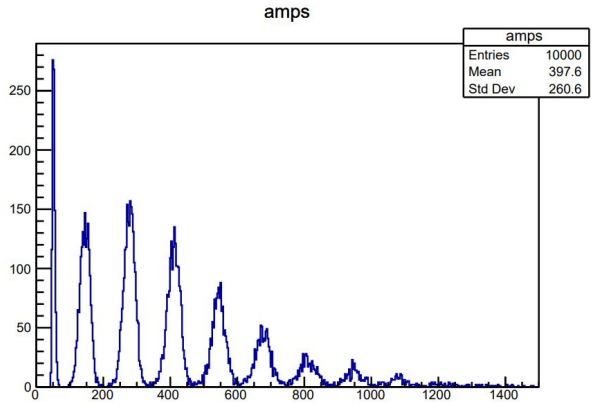
Background iterated 20 times

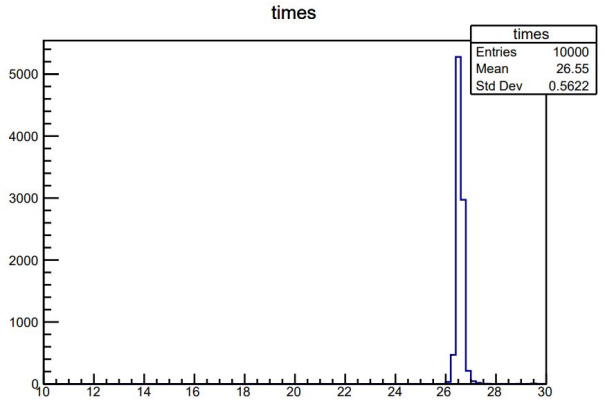
Difference between background and original waveform





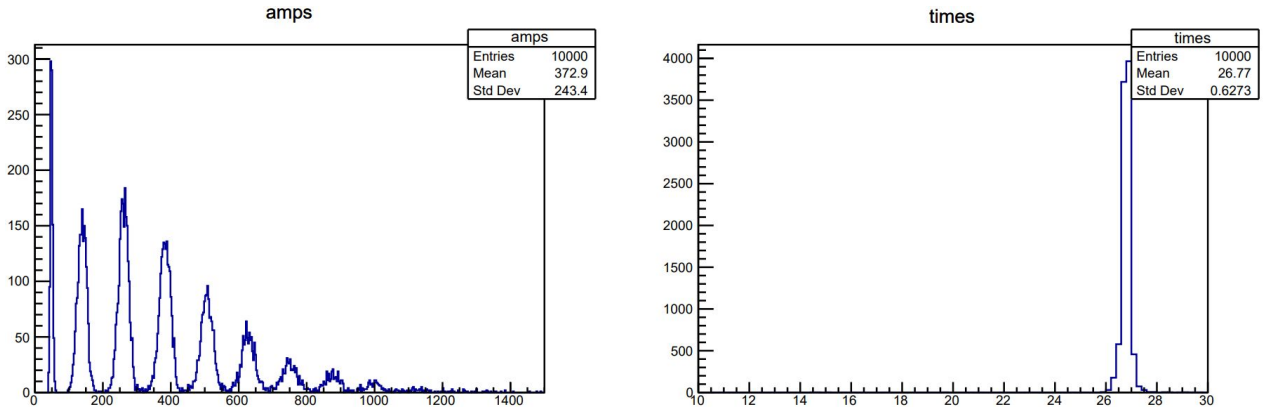
Signal waveform extracted using Markov algorithm



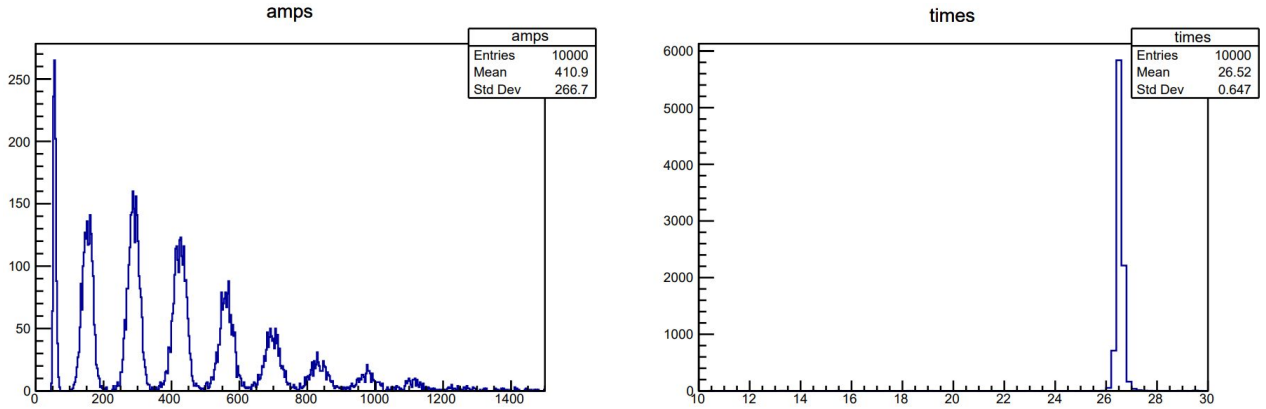


Background iterated 30 times

Difference between background and original waveform

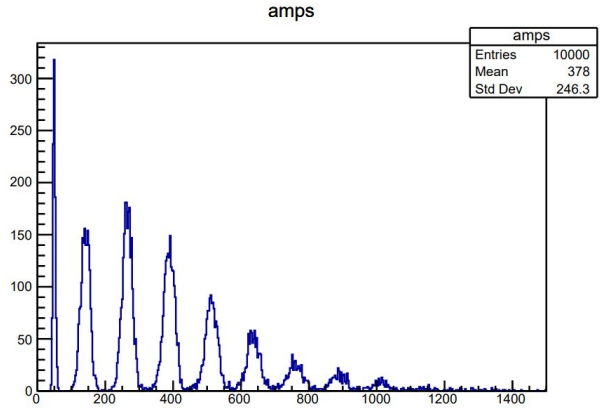


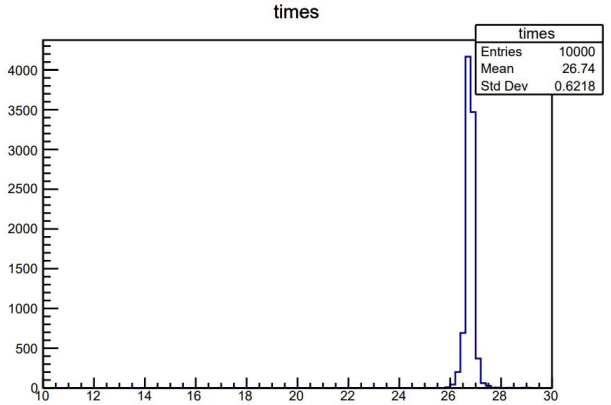
Signal waveform extracted using Markov algorithm



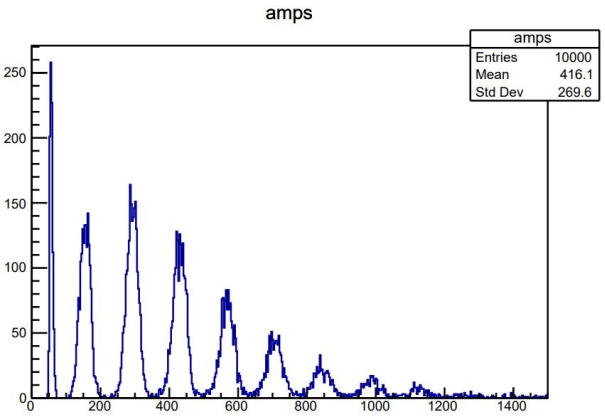
Background iterated 40 times

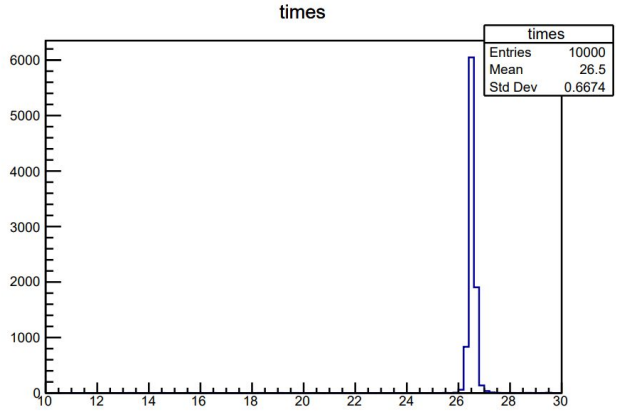
Difference between background and original waveform





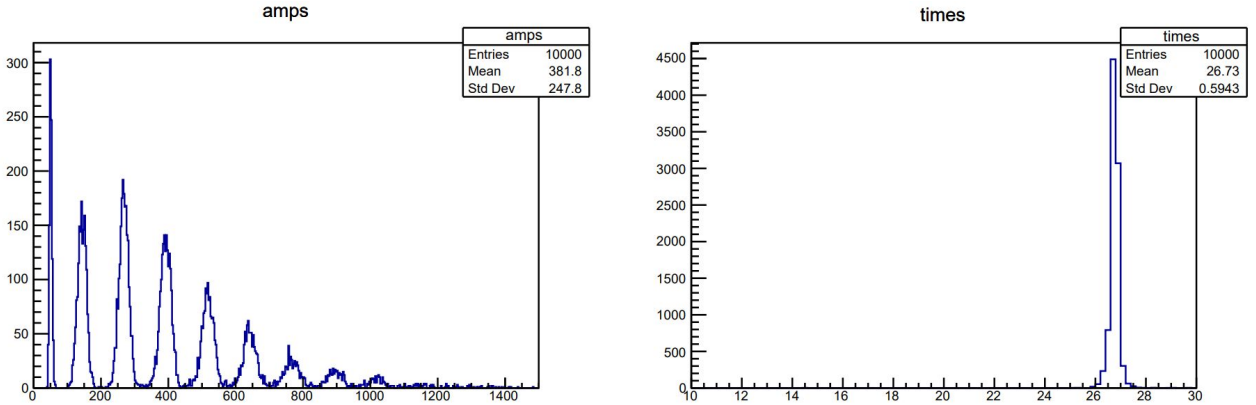
Signal waveform extracted using Markov algorithm



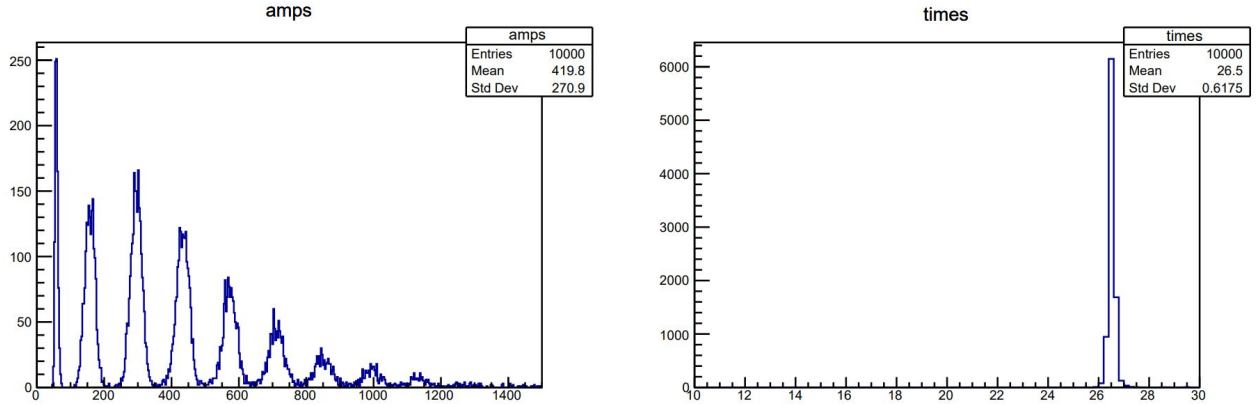


Background iterated 50 times

Difference between background and original waveform



Signal waveform extracted using Markov algorithm



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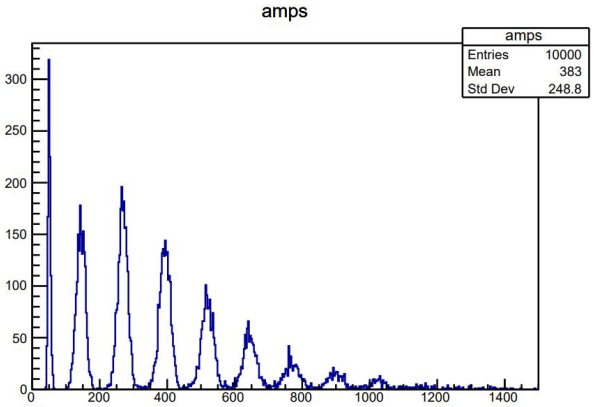
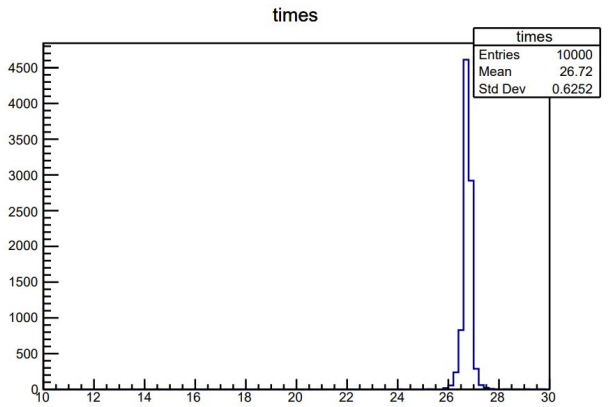
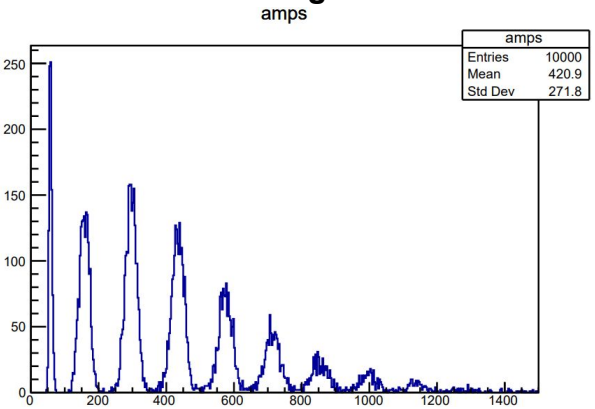
Background iterated 60 times

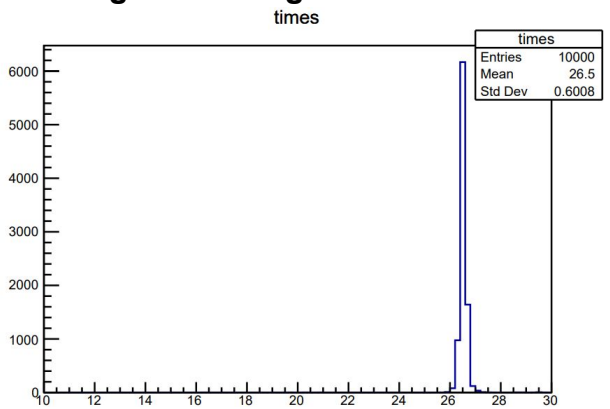
Difference between background and original waveform





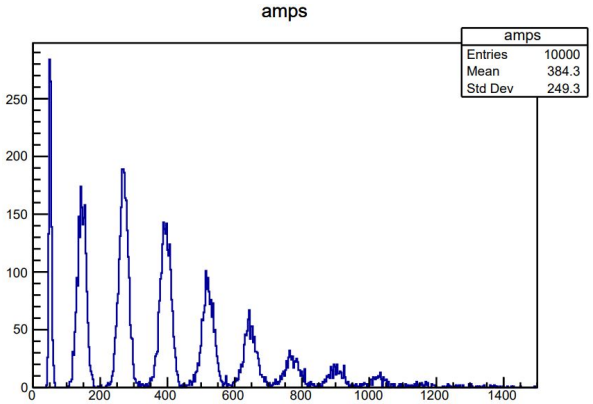
Signal waveform extracted using Markov algorithm

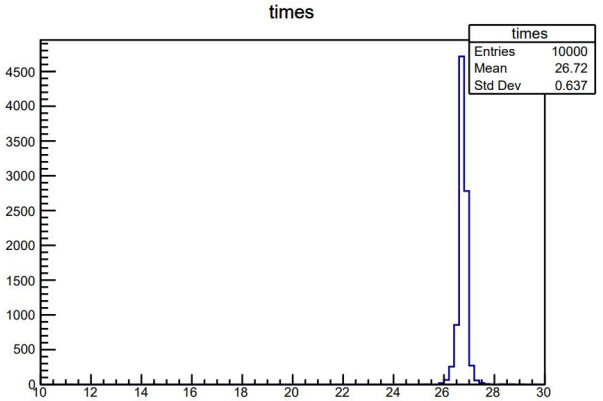




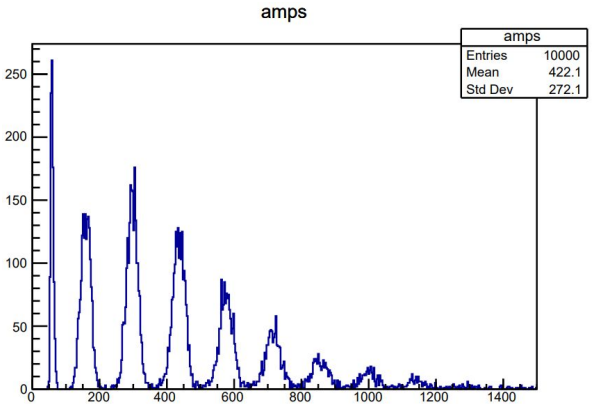
Background iterated 70 times

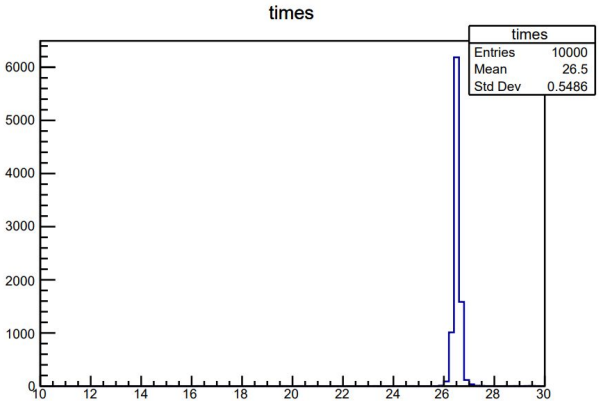
Difference between background and original waveform





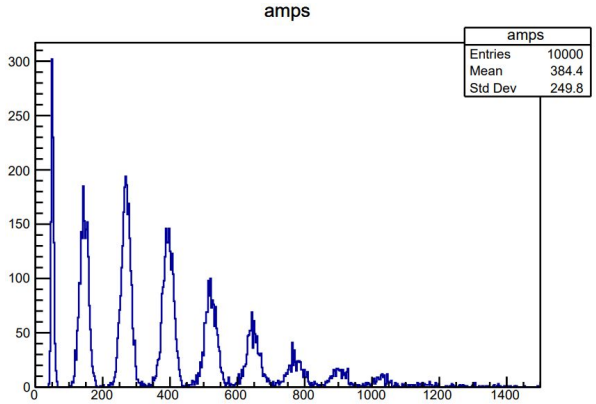
Signal waveform extracted using Markov algorithm

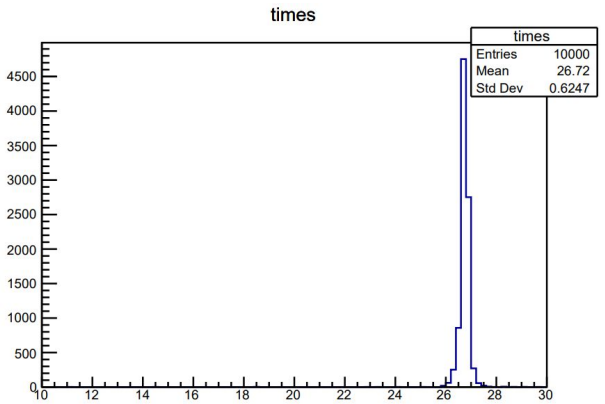




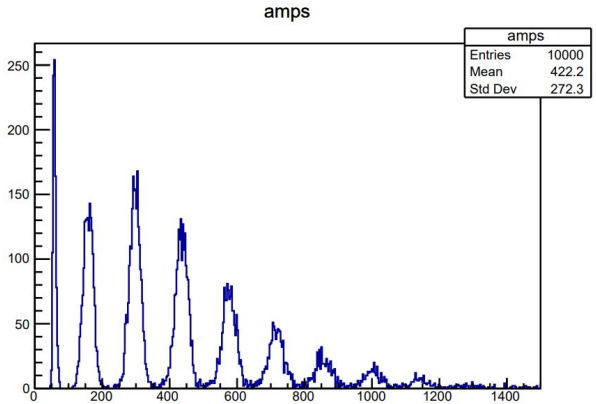
Background iterated 80 times

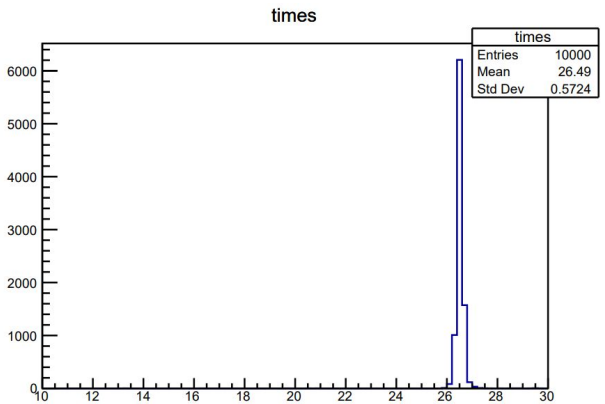
Difference between background and original waveform





Signal waveform extracted using Markov algorithm



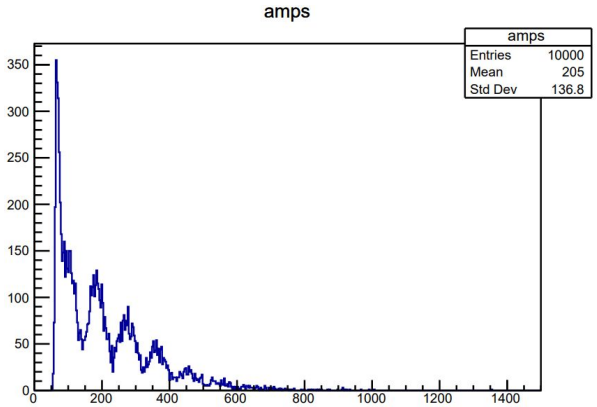


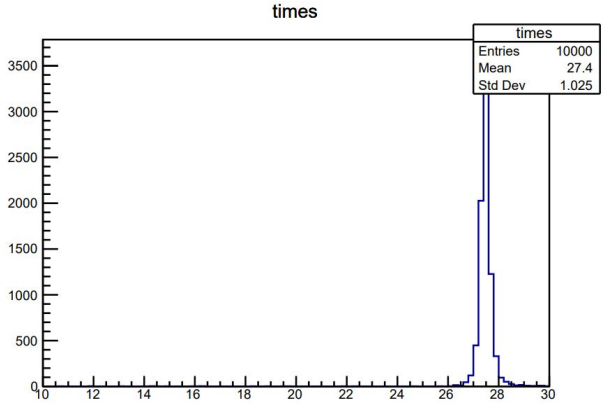
Markov parameters tuning using SiPM #15

Jakub Kandra, INFN Padova

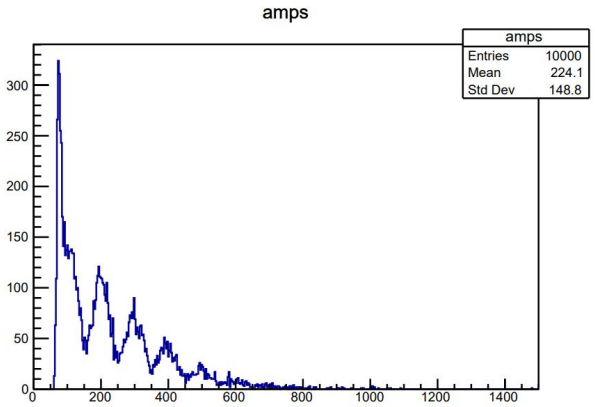
Background iterated 10 times

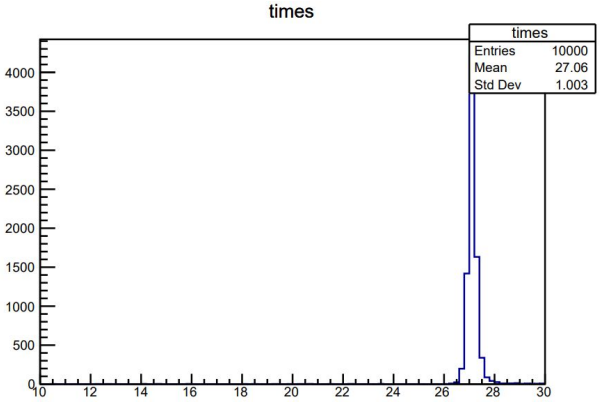
Difference between background and original waveform





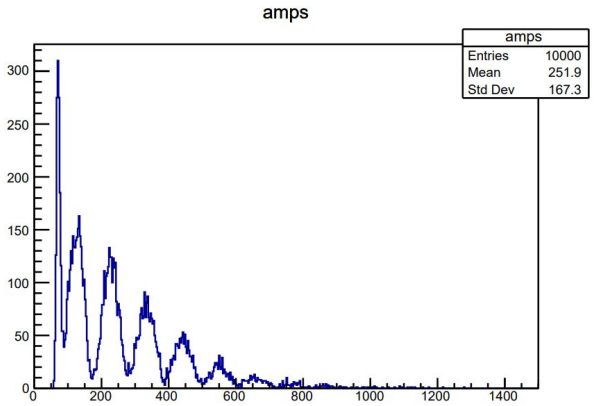
Signal waveform extracted using Markov algorithm

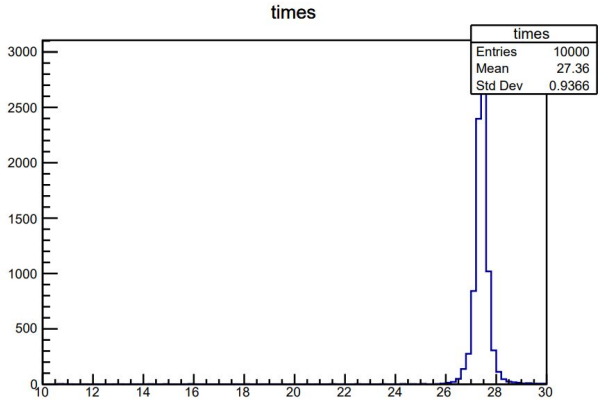




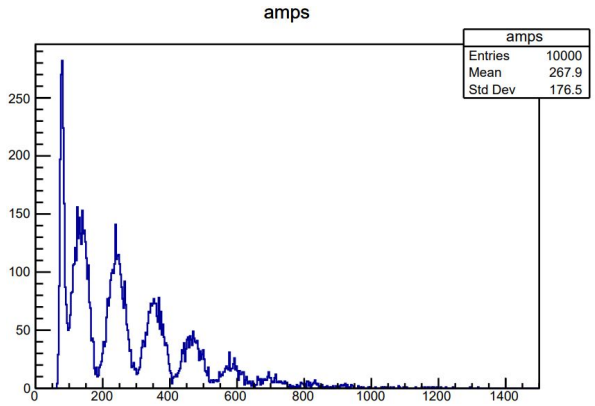
Background iterated 20 times

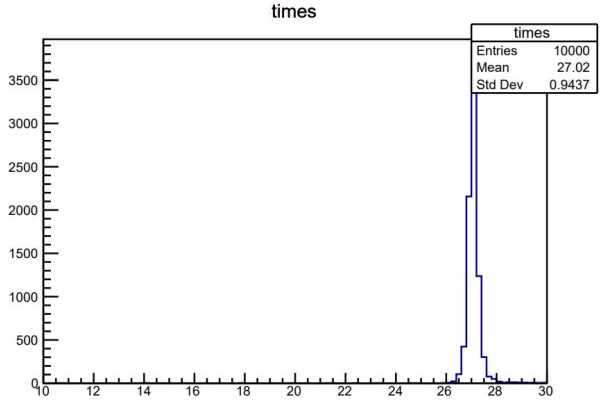
Difference between background and original waveform





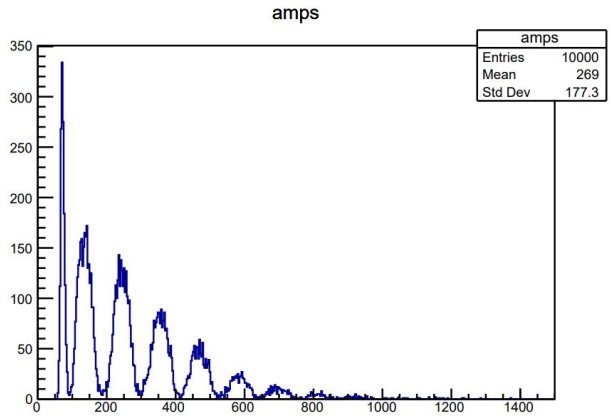
Signal waveform extracted using Markov algorithm

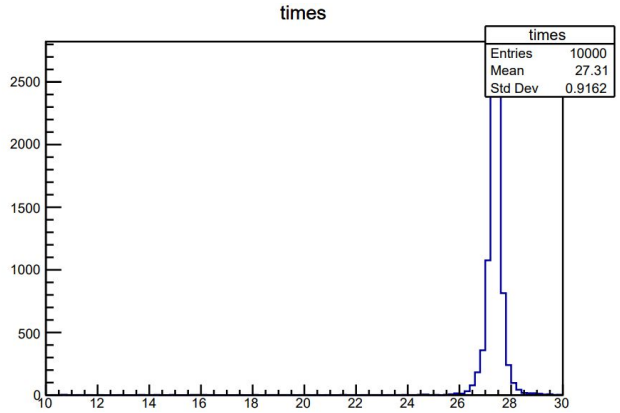




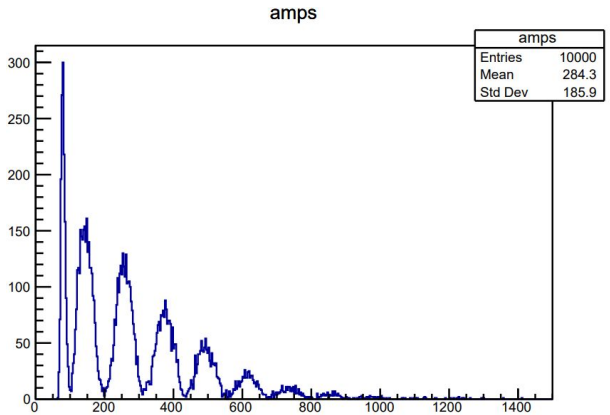
Background iterated 30 times

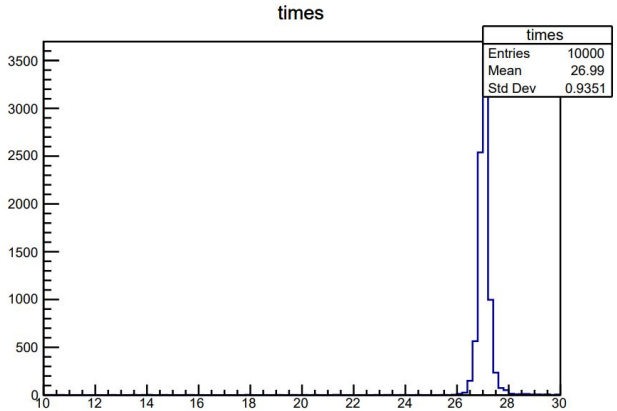
Difference between background and original waveform





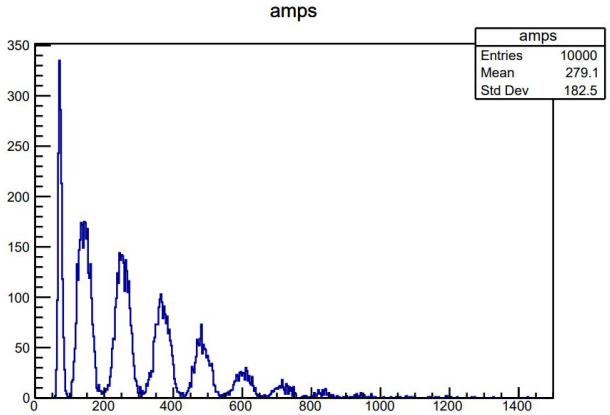
Signal waveform extracted using Markov algorithm

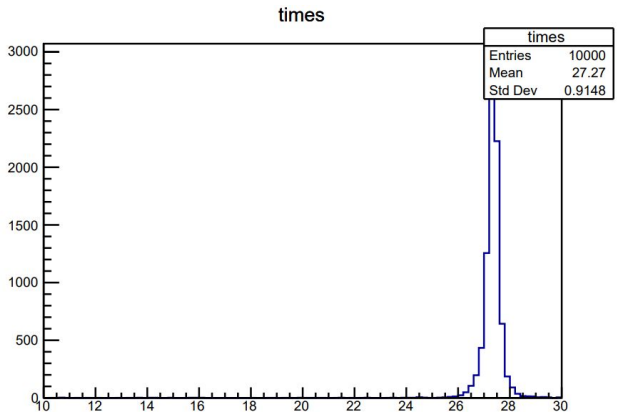




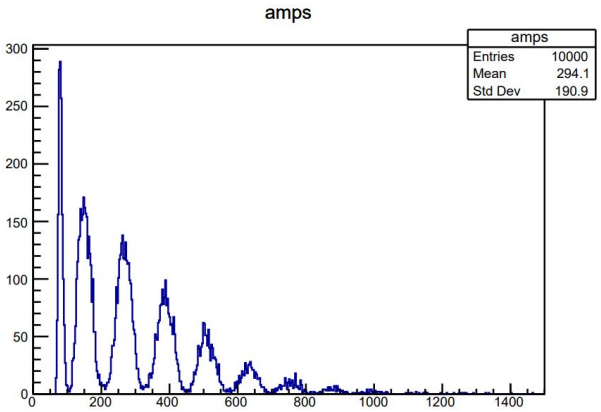
Background iterated 40 times

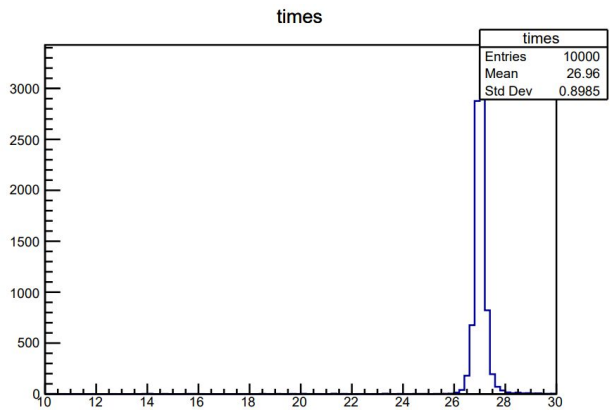
Difference between background and original waveform





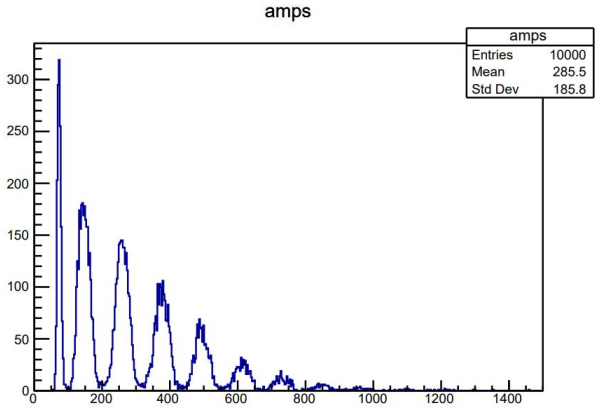
Signal waveform extracted using Markov algorithm

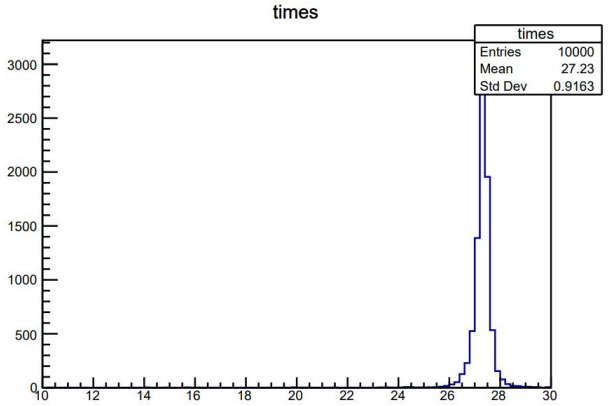




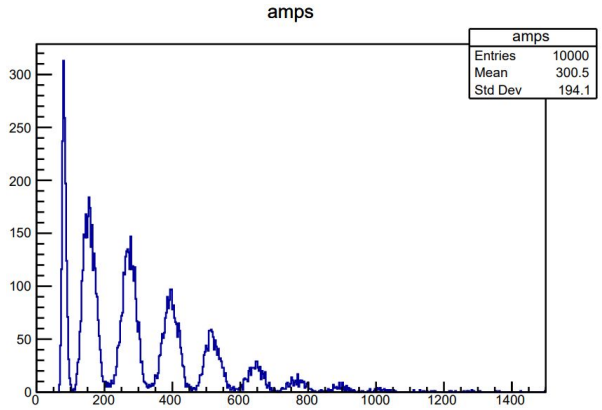
Background iterated 50 times

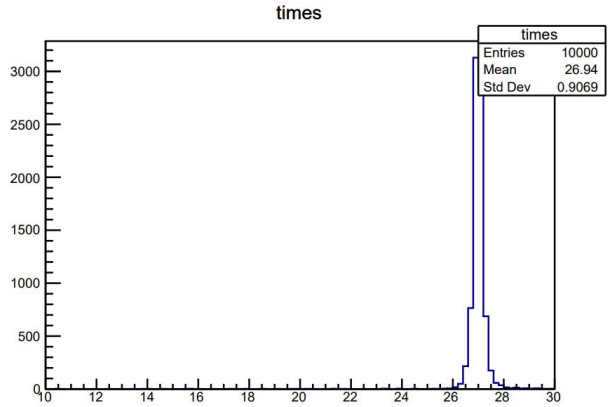
Difference between background and original waveform





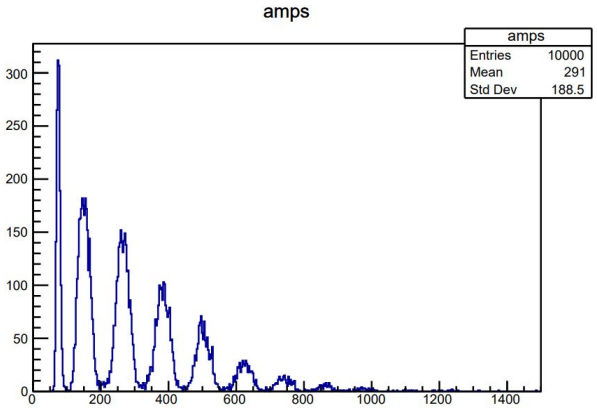
Signal waveform extracted using Markov algorithm

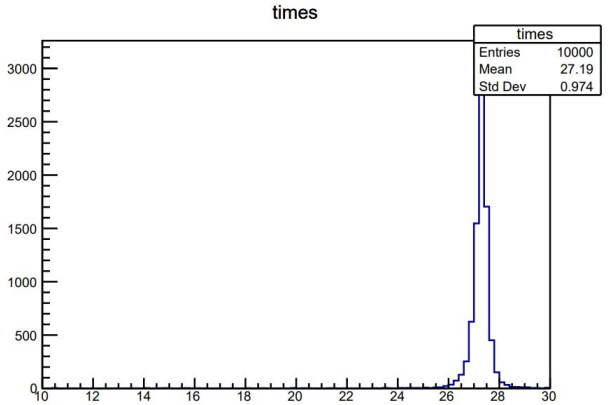




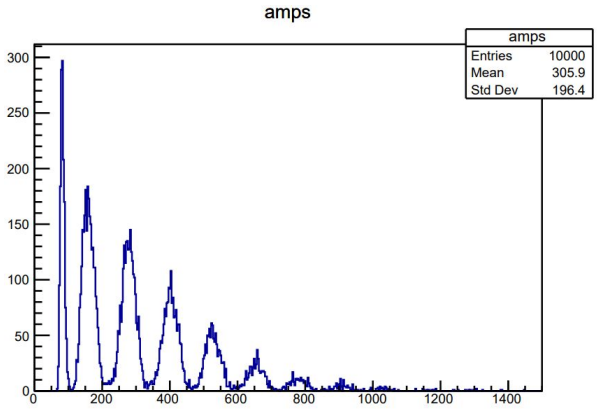
Background iterated 60 times

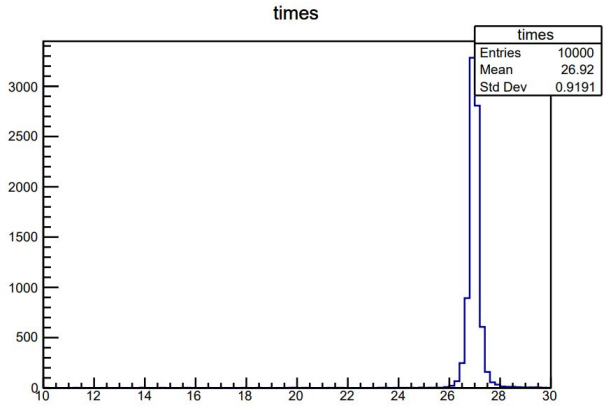
Difference between background and original waveform





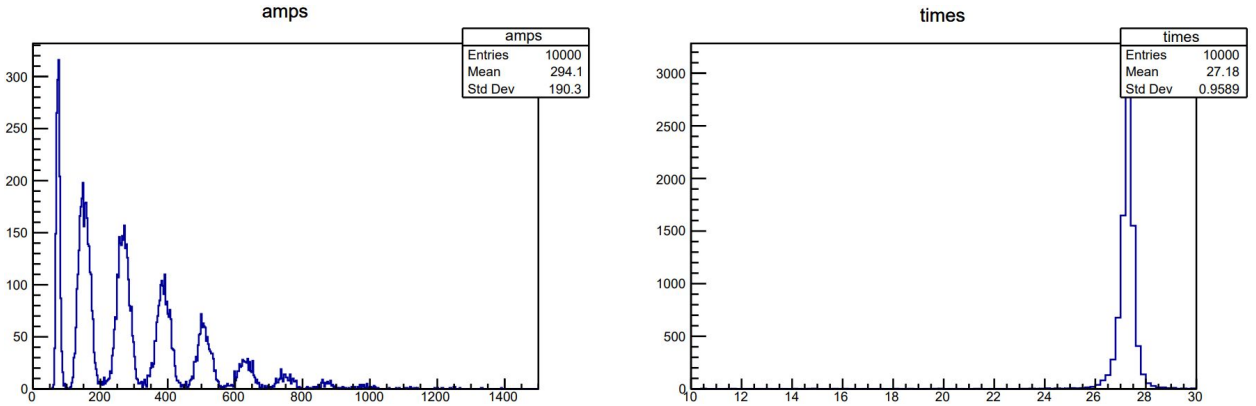
Signal waveform extracted using Markov algorithm



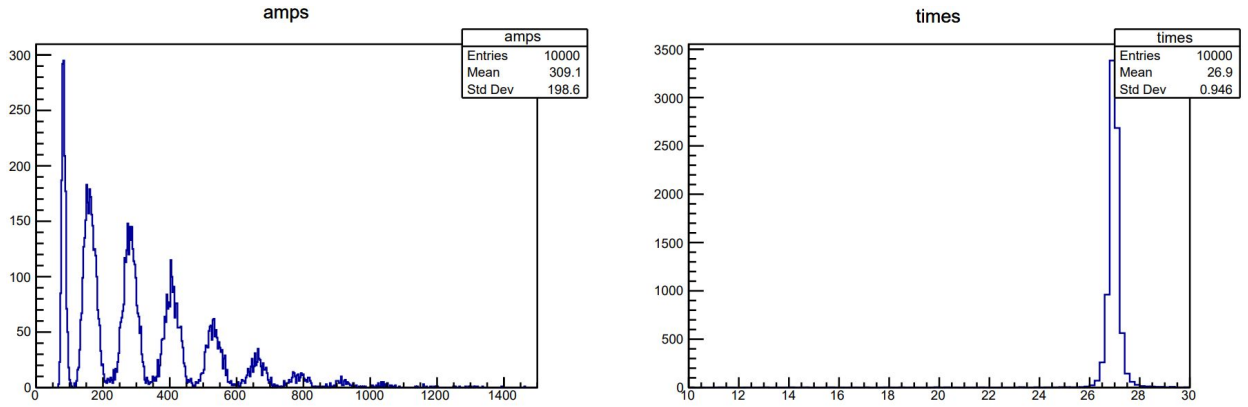


Background iterated 70 times

Difference between background and original waveform

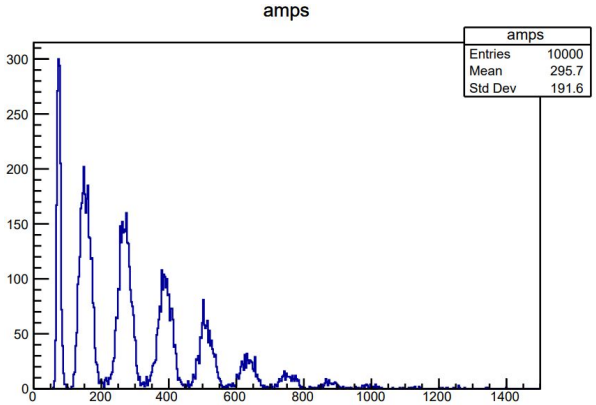


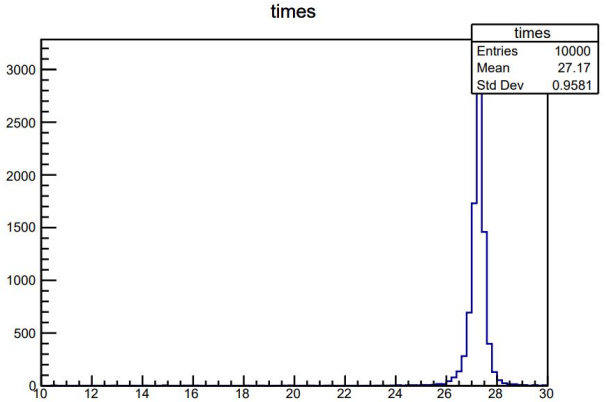
Signal waveform extracted using Markov algorithm



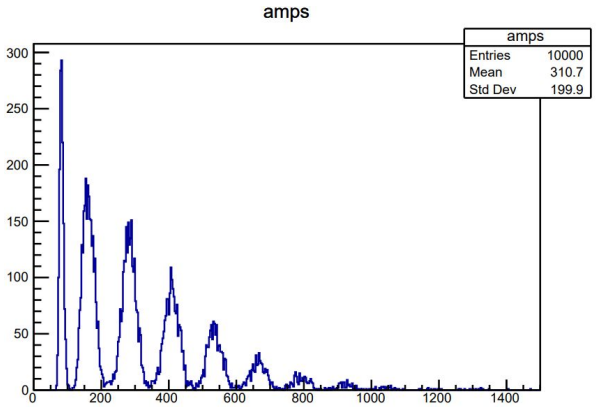
Background iterated 80 times

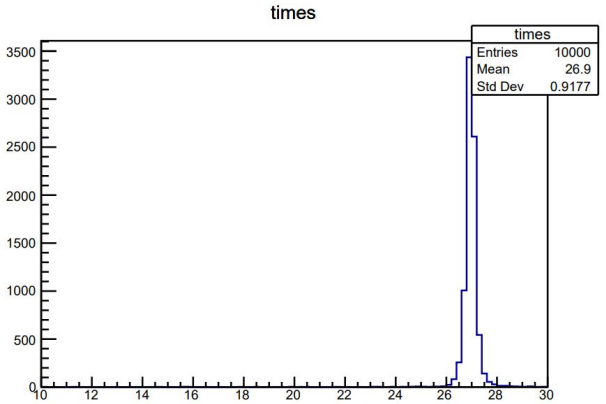
Difference between background and original waveform





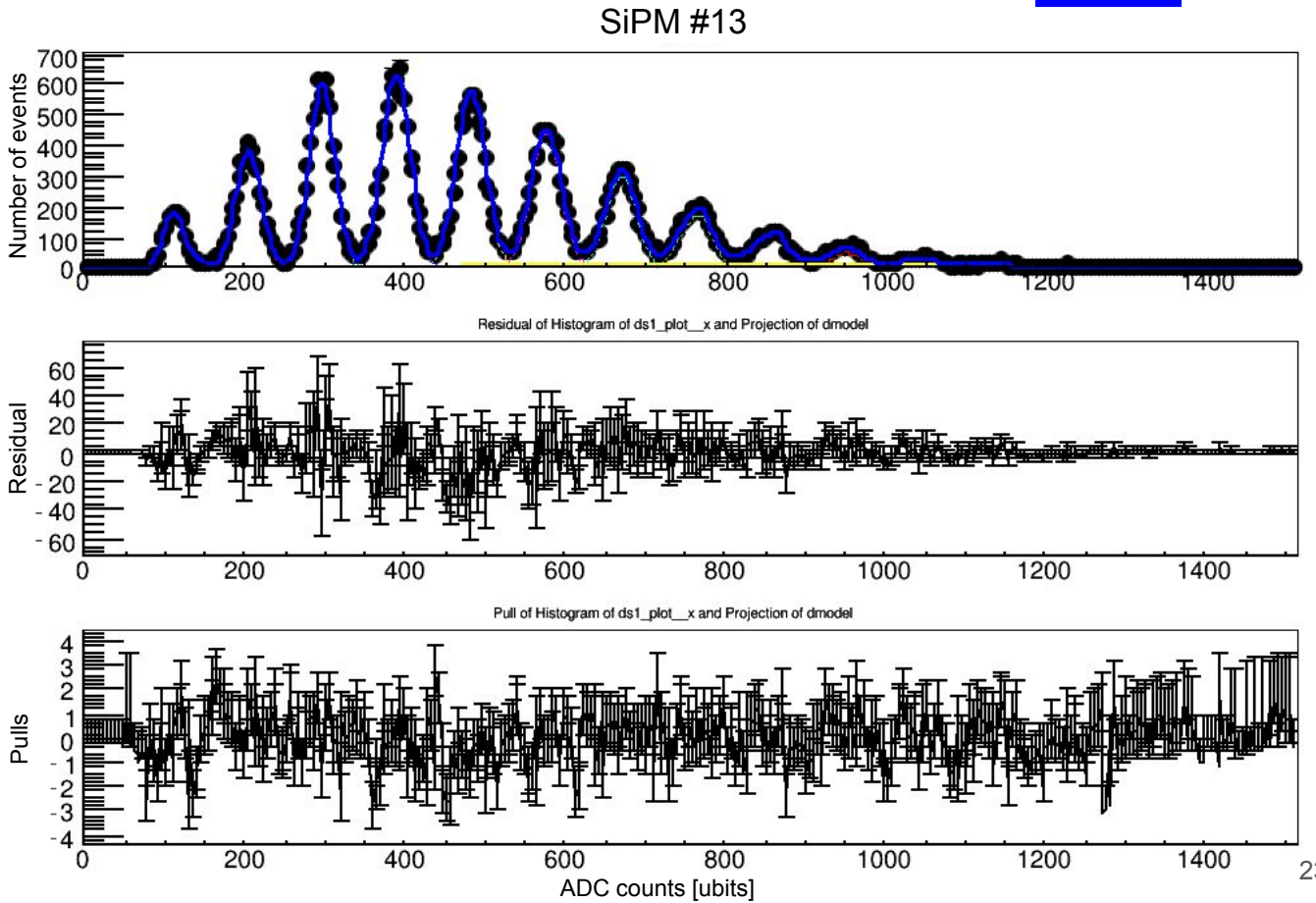
Signal waveform extracted using Markov algorithm





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



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)