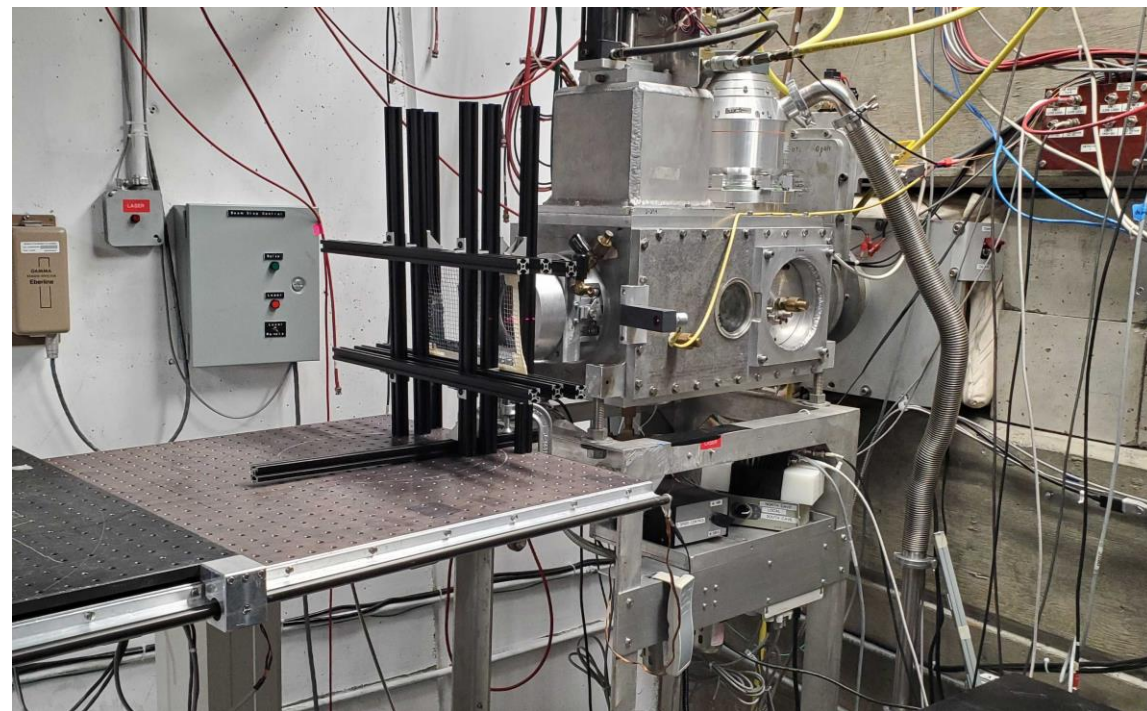


# First results for SiPM irradiation tests at the UC Davis Cyclotron

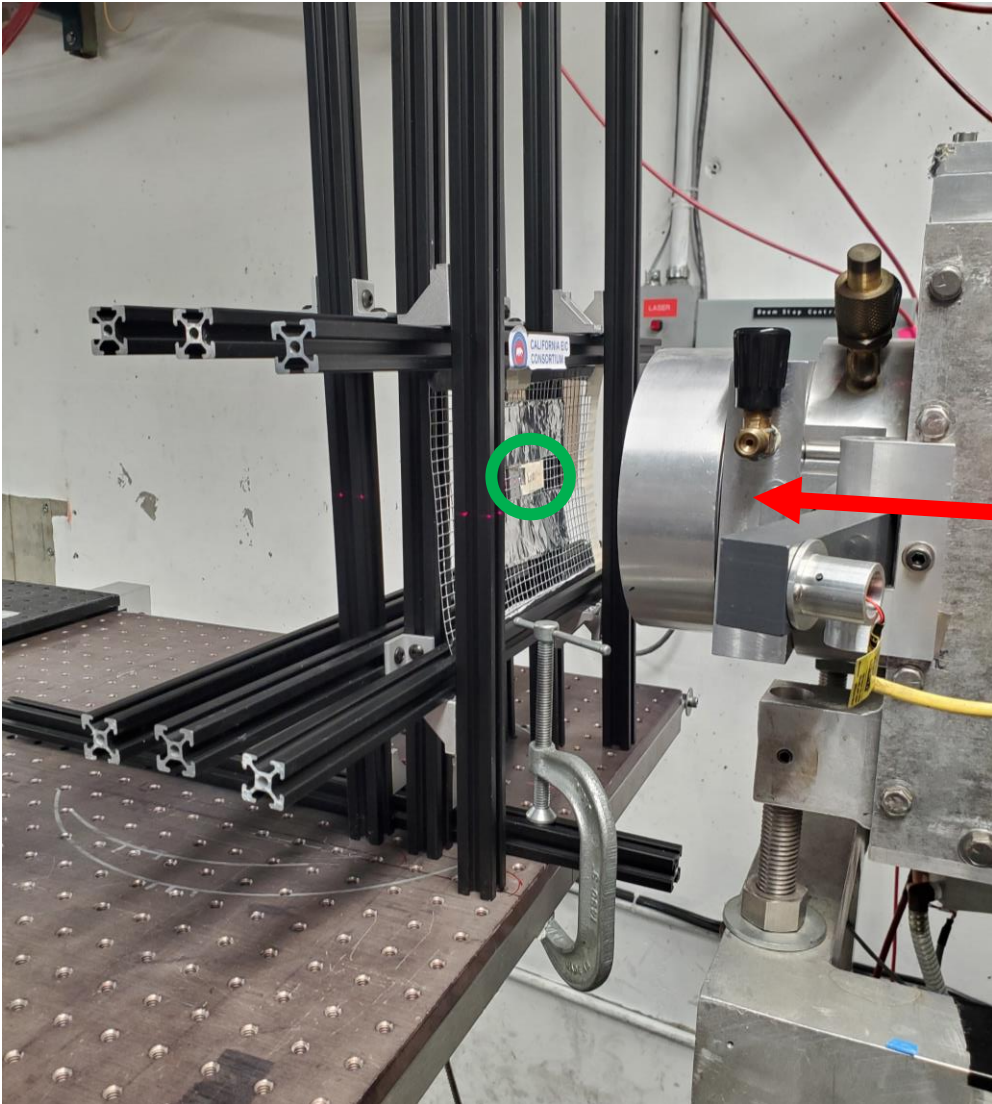
Miguel Arratia (UCR), Justin Frantz (OU), JiaJun Huang (UCR), Sean Preins (UCR), Miguel Rodriguez (UCR), Barak Schmookler (UCR), Ryan Tsiao (UCR)

# Overview

- The test was conducted on May 14<sup>th</sup> and 15<sup>th</sup>. The beam used was a 64 MeV proton beam.
- We irradiated 7 different types of SiPMs over a range of proton fluences between  $10^8$  and  $10^{13}$  /cm<sup>2</sup>.
- SiPMs attached to readout boards and scintillator tiles were irradiated as well.
- Additional tests on electronics were performed by the BNL group.
- The dark current vs. voltage characteristics of many of the irradiated SiPMs were measured several hours and 1 day after irradiation.
- A first set of measurements with cosmic events was also made.



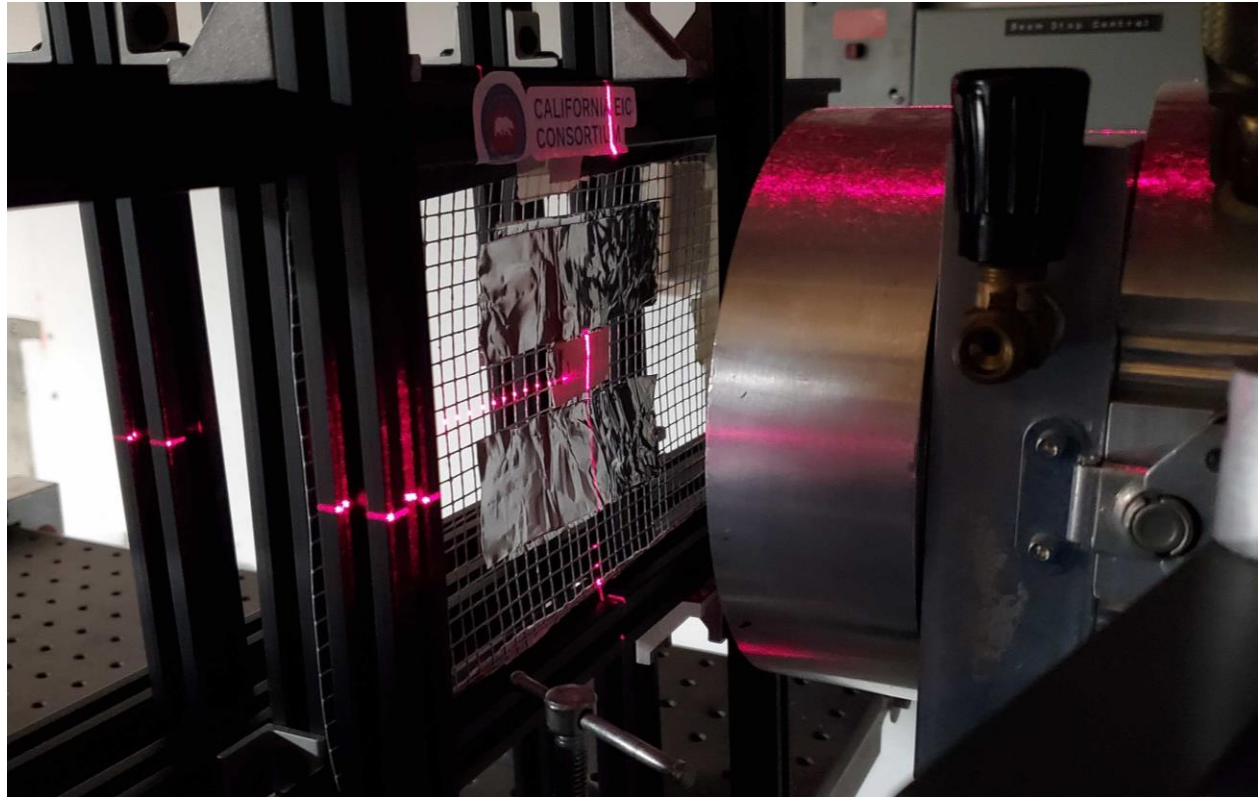
# Setup – mount



The 64 MeV **proton beam** enters from the right.

The **SiPM sample** is placed about 15 cm away from the Kapton exit window (located in the metal cylinder).

# Setup – beam centering



The 64 MeV **proton beam** enters from the right.

The **SiPM sample** is placed about 15 cm away from the Kapton exit window (located in the metal cylinder).

The sample is centered on the beam spot using the laser system.

# Setup – SiPM and layer ID



- Each SiPM had a unique ID.
- Each layer was labelled based on the radiation dose.

## L12

3015A12  
3015B12  
3015C12

S13A12  
S13B12

6050A12  
6050B12  
6050C12  
6050D12

1315A12  
1315B12  
1315C12

6015A12  
6015B12



# Accumulated fluence

1.5 cm radius

2.5 cm radius



## Run info for $10^{12}$ fluence setting

Beam Type: Proton Target: Si File Name:  
 Beam E (MeV): 64.0 dE/dx (MeV·cm<sup>2</sup>/g): 8.334 c:\ref\_user\UC Riverside\UC-Riverside\_5-14-24.html  
 Date: 5/14/2024

5/14/2024 FC Lkg (A): -4.800E-13 ± 1.056E-13  
 8:46:03 SEM Lkg (A): 1.299E-11 ± 1.328E-12  
 8:47:05 FC/SEM Ratio: 1.8896E+00 ± 4.0255E-03

Run #1	Run Time (s)	Mean Current (A)	Std Dev <I> (A)	Incr Dose (rad)	Acc Dose (rad)	Incr Fluence (p/cm <sup>2</sup> )	Acc Fluence (p/cm <sup>2</sup> )	Avg Dose Rate (rad/s)	Beam Profile
9:00:35	789.401	1.016E-08	1.751E-09	1.336E+05	1.336E+05	1.001E+12	1.001E+12	1.693E+02	0 - 0.5 cm
L12				1.329E+05	1.329E+05	9.957E+11	9.957E+11	1.684E+02	0.5 - 1.5 cm
				1.303E+05	1.303E+05	9.757E+11	9.757E+11	1.650E+02	1.5 - 2.5 cm

# Accumulated fluence

1.5 cm radius  
2.5 cm radius



## Run info for $10^{12}$ fluence setting

Beam Type: Proton Target: Si File Name:  
Beam E (MeV): 64.0 dE/dx (MeV·cm<sup>2</sup>/g): 8.334 c:\ref\_user\UC Riverside\UC-Riverside\_5-14-24.html  
Date: 5/14/2024

5/14/2024 FC Lkg (A): -4.800E-13 ± 1.056E-13  
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Run #1	Run Time (s)	Mean Current (A)	Std Dev <I> (A)	Incr Dose (rad)	Acc Dose (rad)	Incr Fluence (p/cm <sup>2</sup> )	Acc Fluence (p/cm <sup>2</sup> )	Avg Dose Rate (rad/s)	Beam Profile
9:00:35	789.401	1.016E-08	1.751E-09	1.336E+05	1.336E+05	1.001E+12	1.001E+12	1.693E+02	0 - 0.5 cm
L12				1.329E+05	1.329E+05	9.957E+11	9.957E+11	1.684E+02	0.5 - 1.5 cm
				1.303E+05	1.303E+05	9.757E+11	9.757E+11	1.650E+02	1.5 - 2.5 cm

Between 1.5 and 2.5 cm radius, the total fluence relative decreases by ~2.5% compared to r = 0.

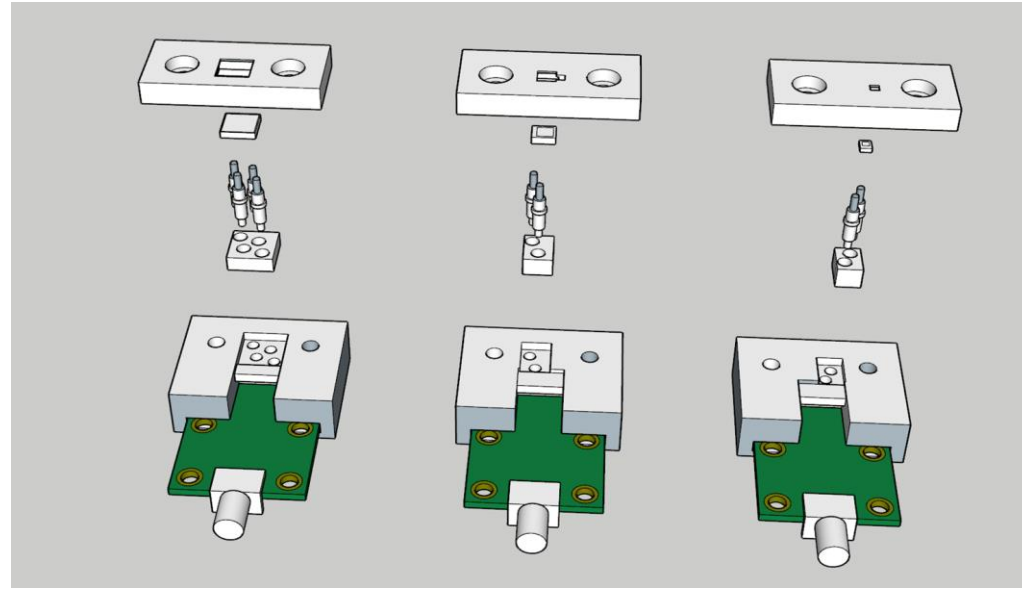
The absolute beam fluence is measured to about 2% precision.

# List of irradiated SiPMs

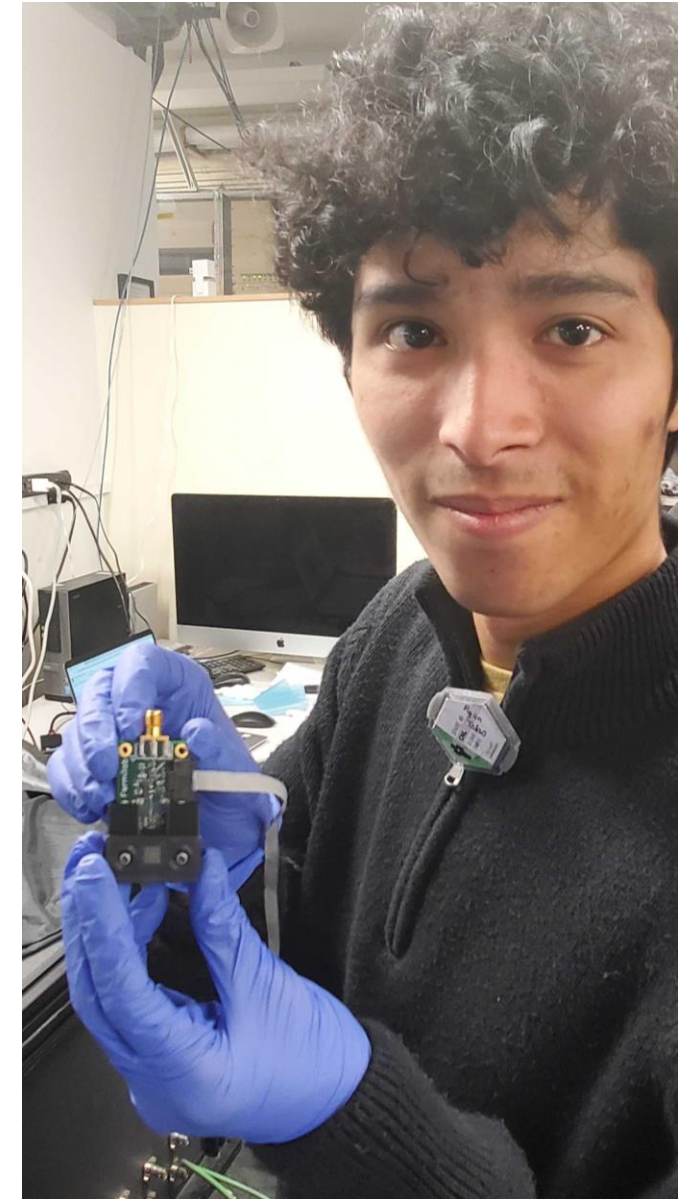
SiPM type	Number Irradiated	Proton fluence range (1/cm <sup>2</sup> )	Under consideration for which ePIC Calorimeter(s)
S14160-6050HS	20	$10^8 - 10^{13}$	PECal, FHCAL(Insert), ZDC, BECAL
S14160-6015PS	16	$10^8 - 10^{13}$	PECal, EEEMC, BECAL
S13360-6050VE	10	$10^8 - 10^{12}$	BEMC
S14160-3015PS	18	$10^8 - 10^{13}$	FHCAL(Insert), ZDC, EEEMC
S14160-3010PS	8	$3.5 \times 10^8 - 5.4 \times 10^{10}$	EEEMC
S14160-1315PS	15	$10^8 - 10^{13}$	FHCAL(Insert), ZDC
S13360-1350CS	6	$10^9 - 10^{11}$	None (comparison)



# I-V test setup

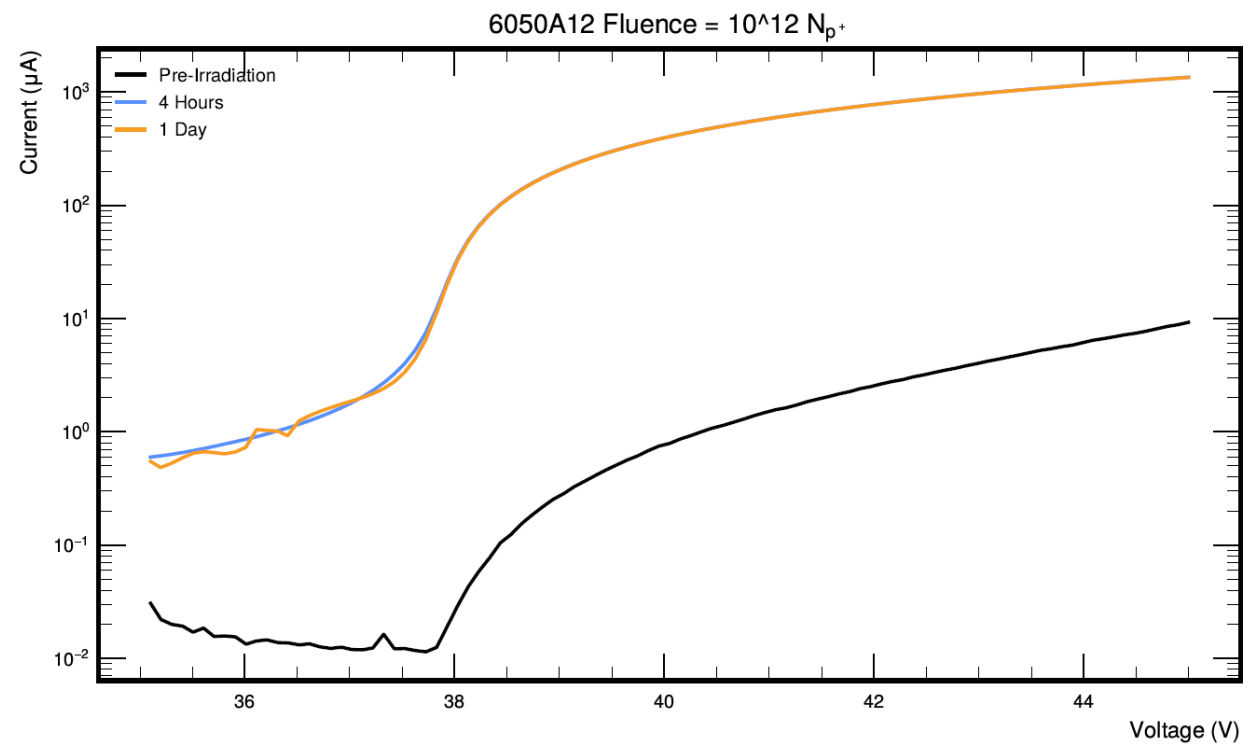
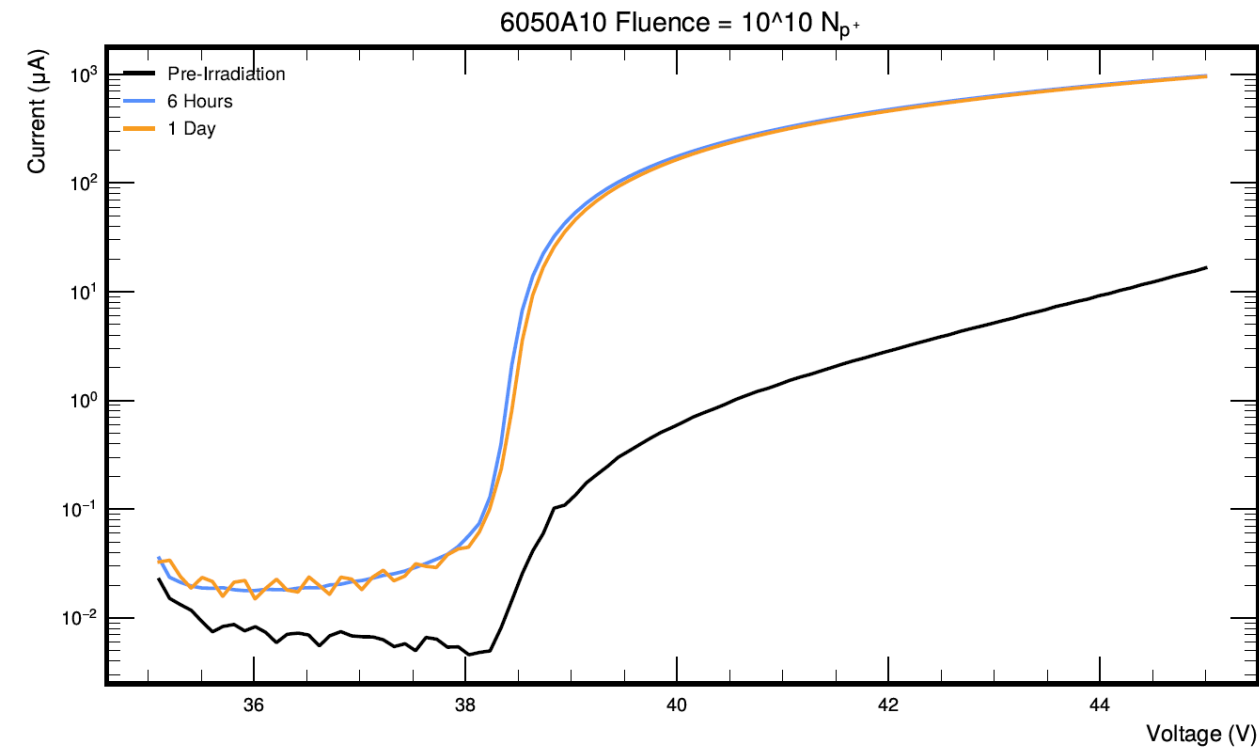


**“Non-destructive” test, in which we use pogo pins to perform measurement before and after irradiation (i.e no soldering). Also allows to quickly test a variety of SiPMs.**



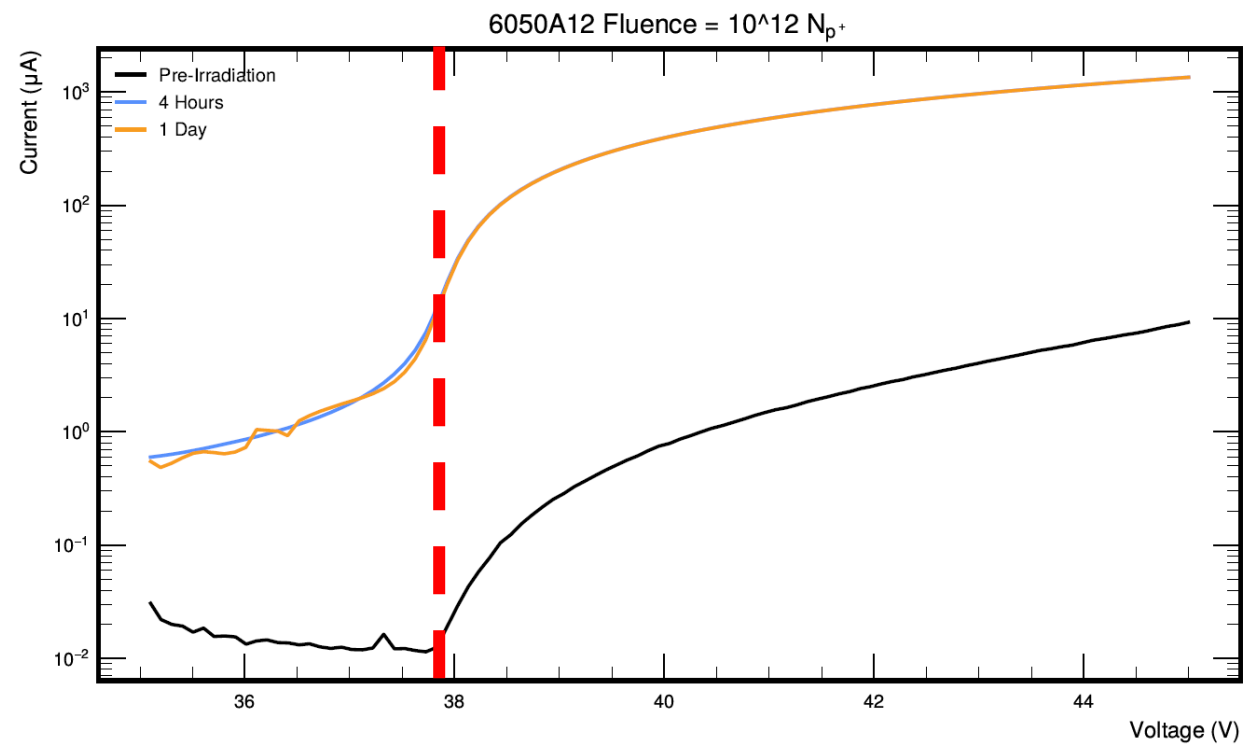
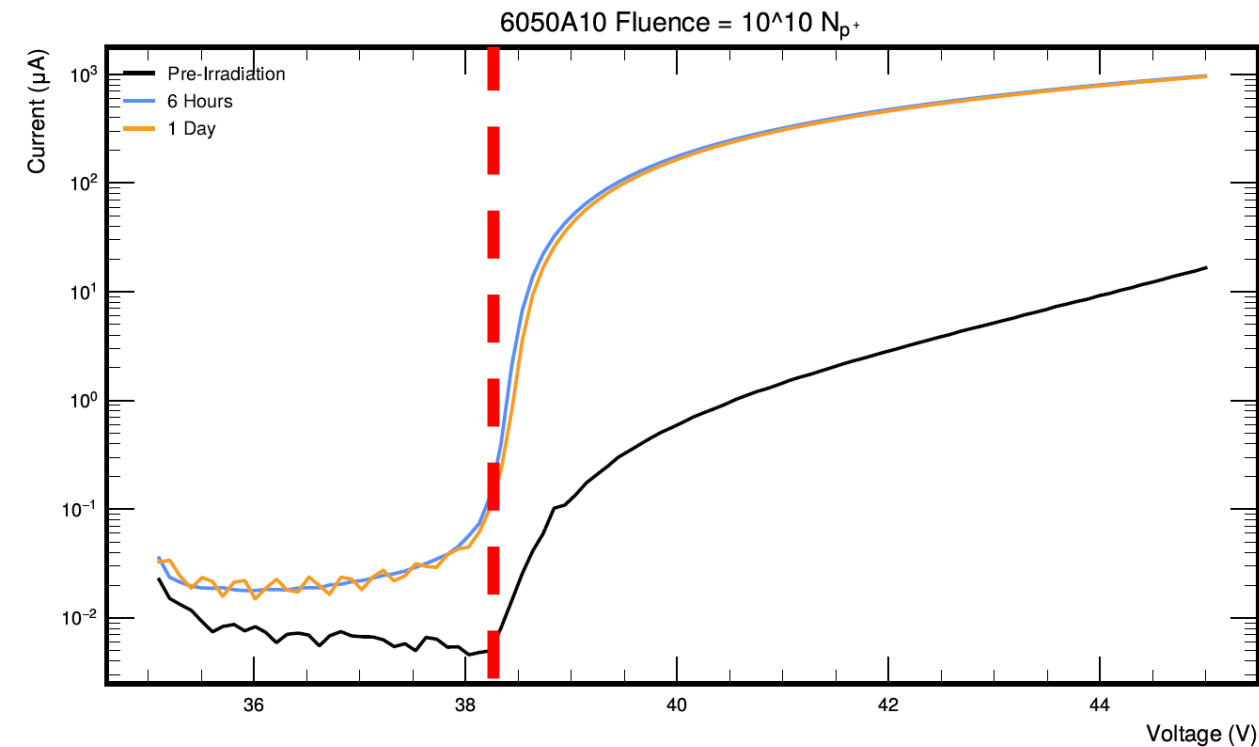
# Results for S14160-6050HS

I-V scans taken in a dark box pre-irradiation, several hours after irradiation, and one day after irradiation. All SiPMs have been tested and stored at room temperature.



# Results for S14160-6050HS

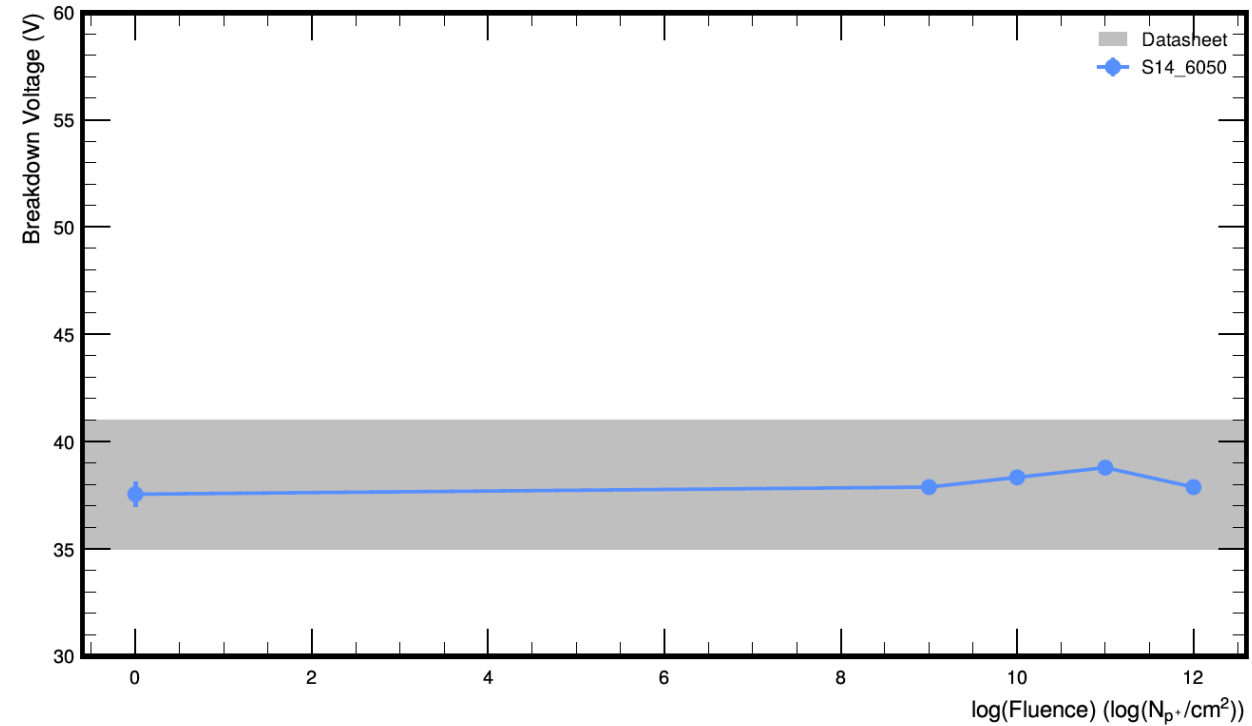
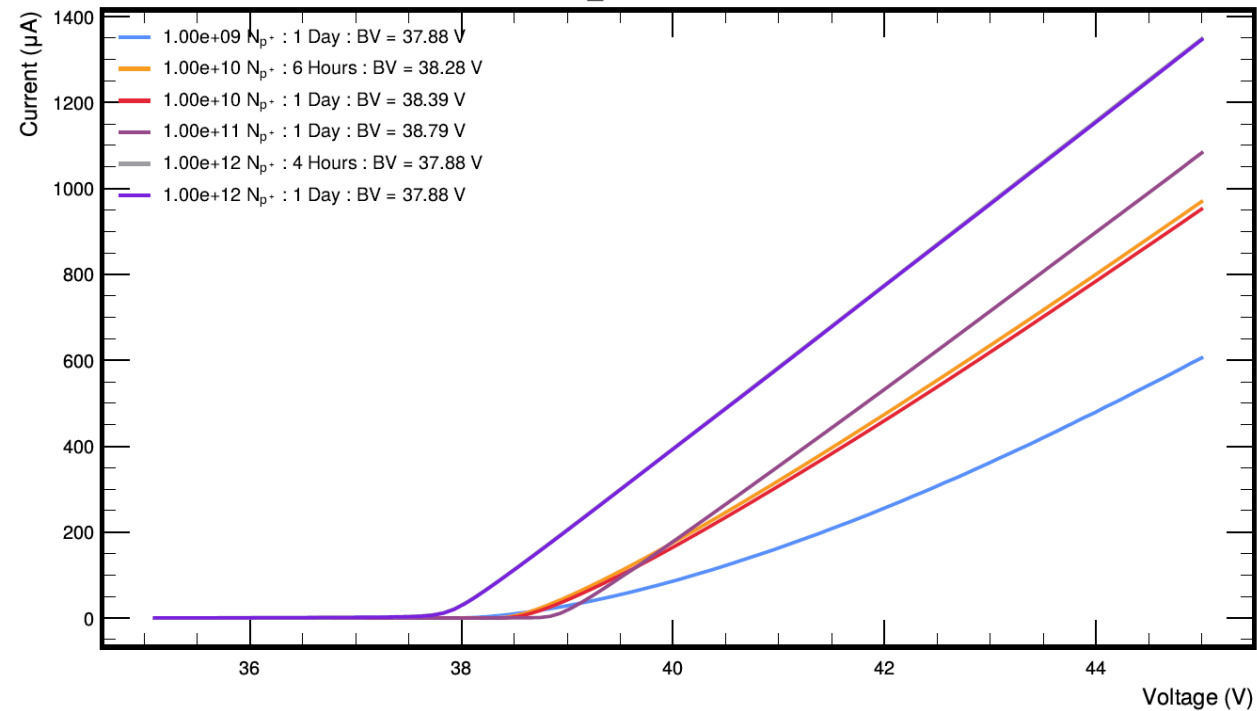
I-V scans taken in a dark box pre-irradiation, several hours after irradiation, and one day after irradiation. All SiPMs have been tested and stored at room temperature.



# Results for S14160-6050HS

Additional SiPMs irradiated to  $10^{13}$  fluence – but they were a bit too ‘hot’ to test 1 day after irradiation.

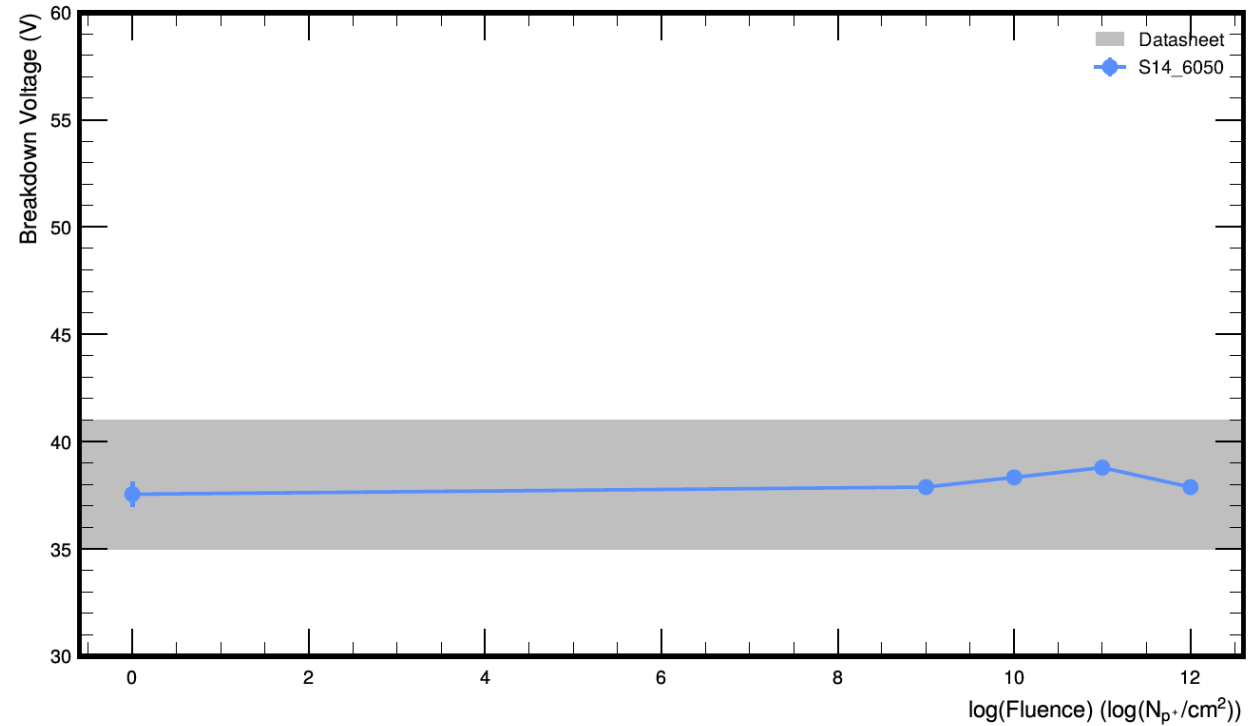
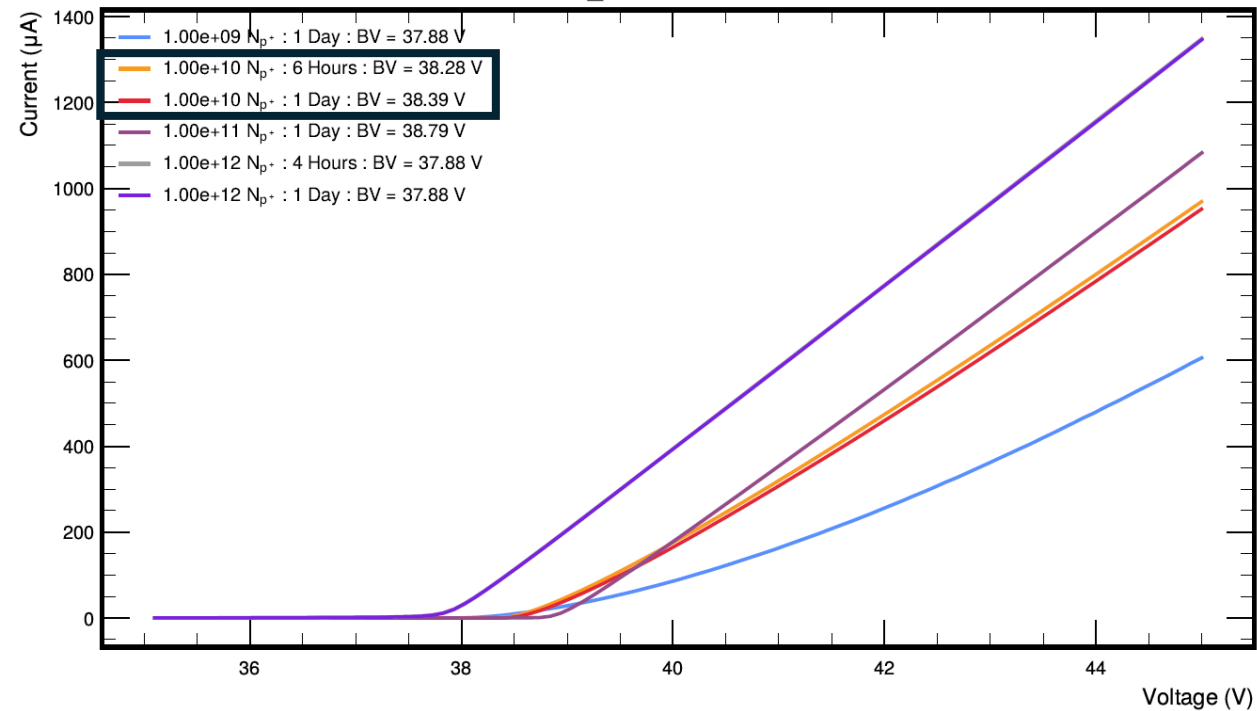
S14\_6050 Irradiated IV



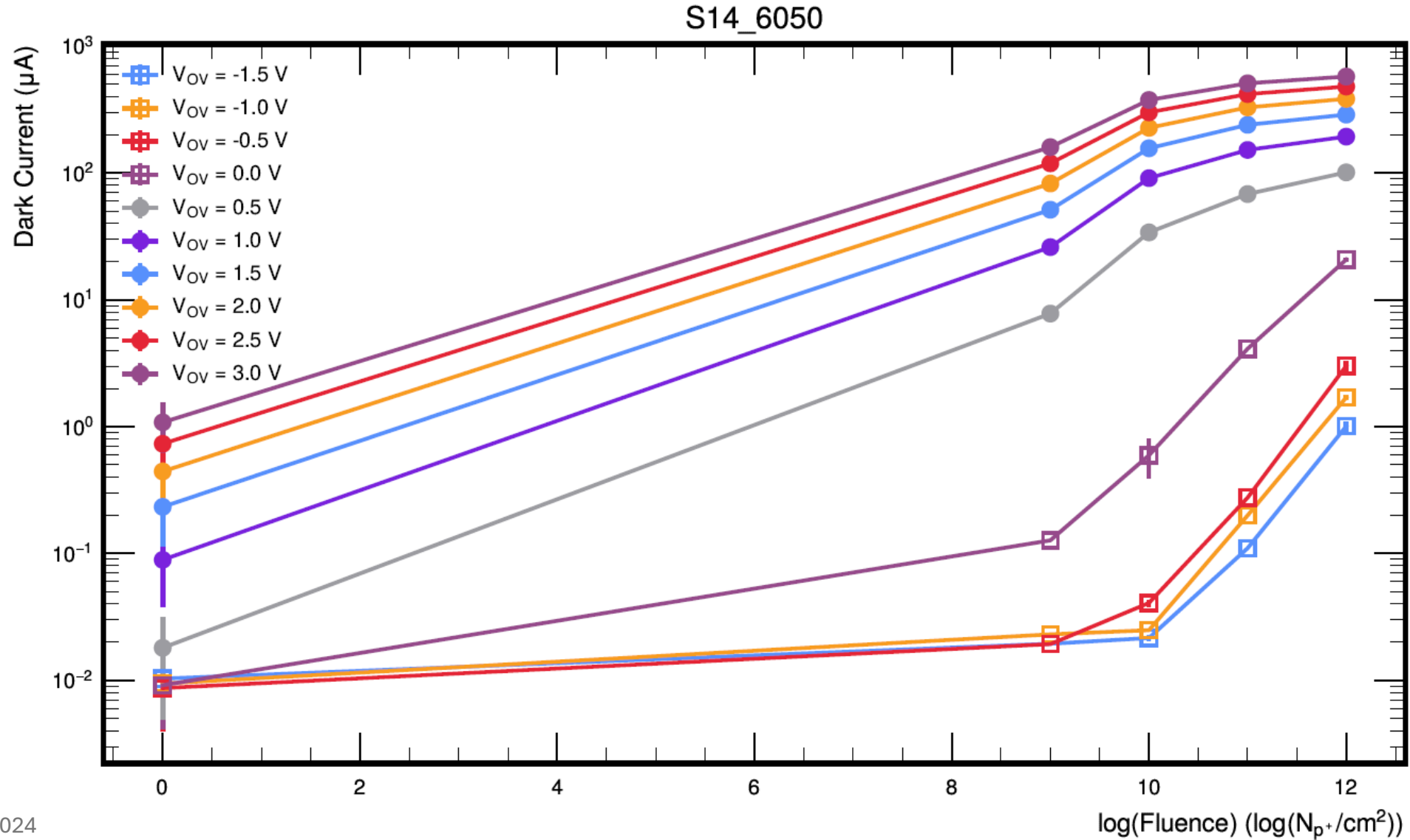
# Results for S14160-6050HS

Same SiPM tested at 2 different times. We see a very small decrease in the dark current from 6 hours to 1 day.

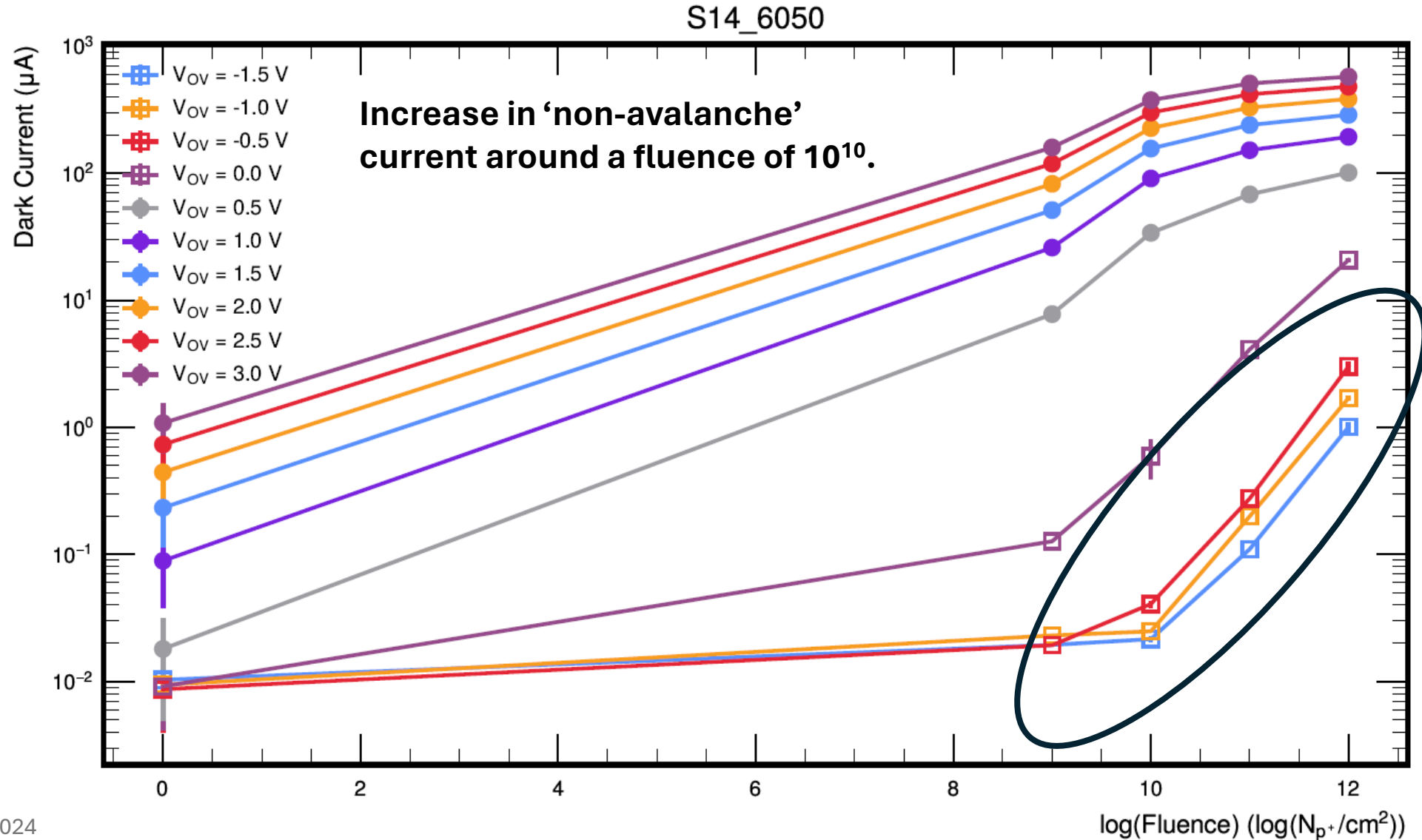
S14\_6050 Irradiated IV



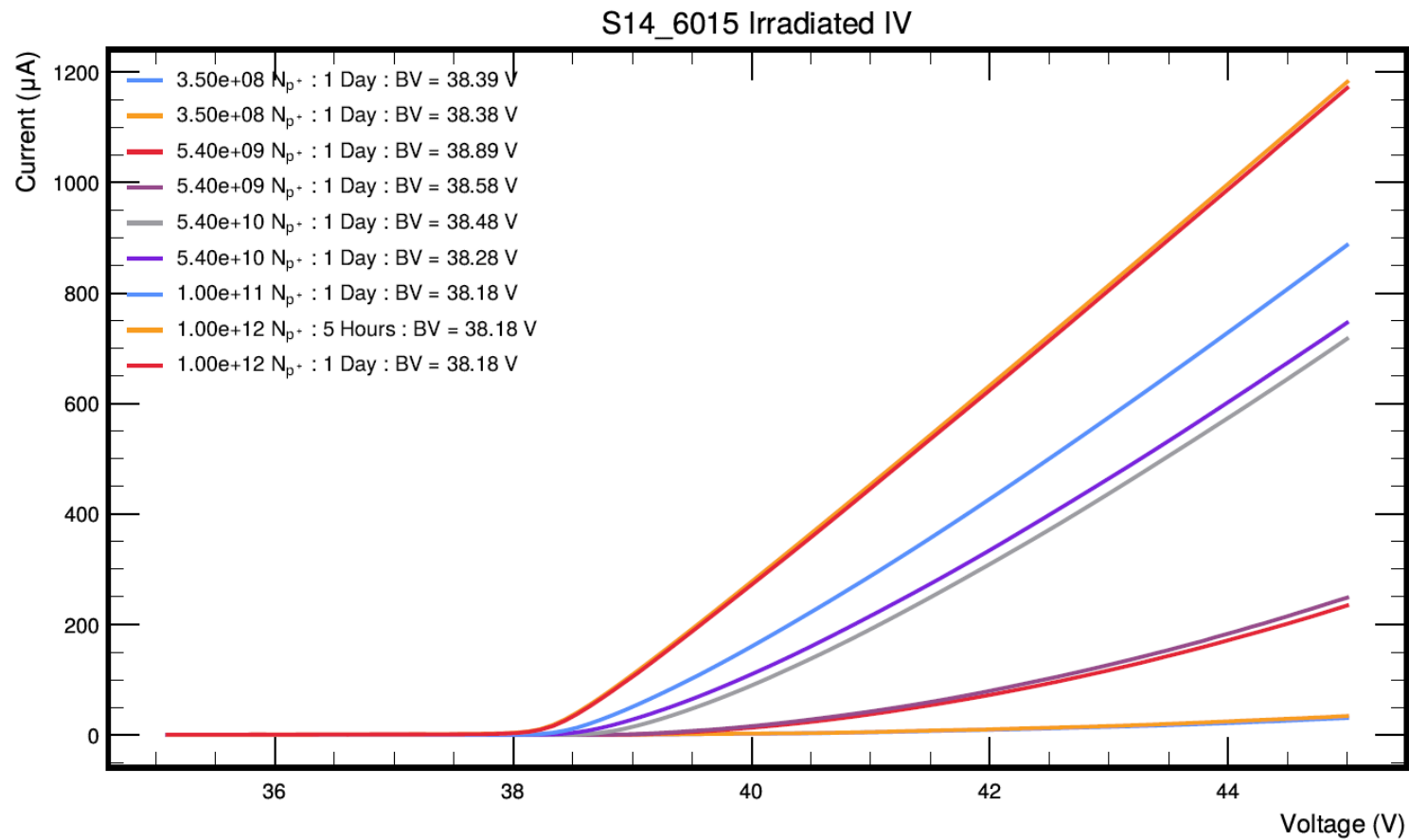
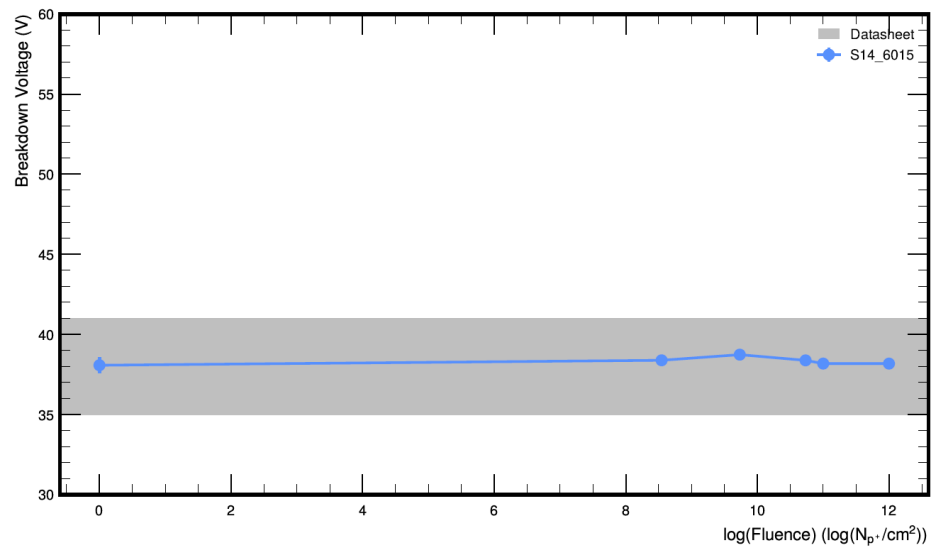
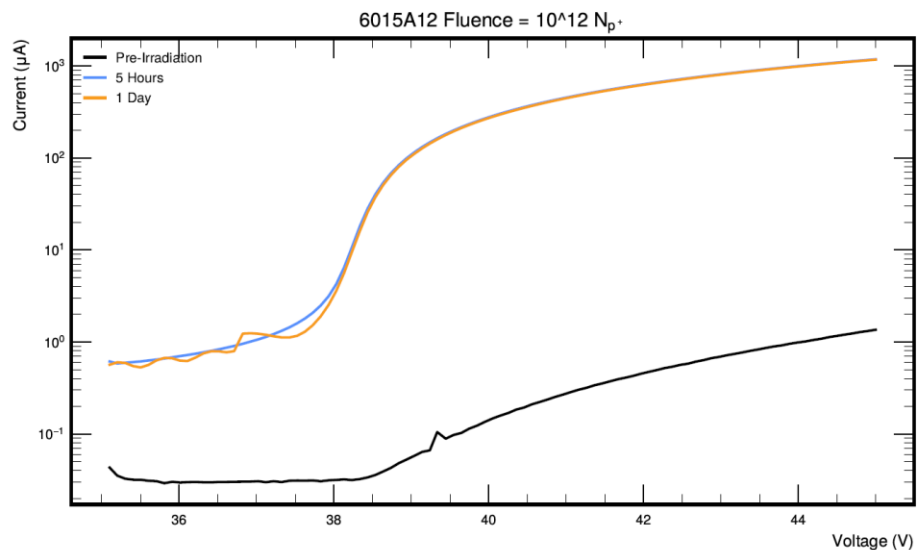
# Results for S14160-6050HS



# Results for S14160-6050HS

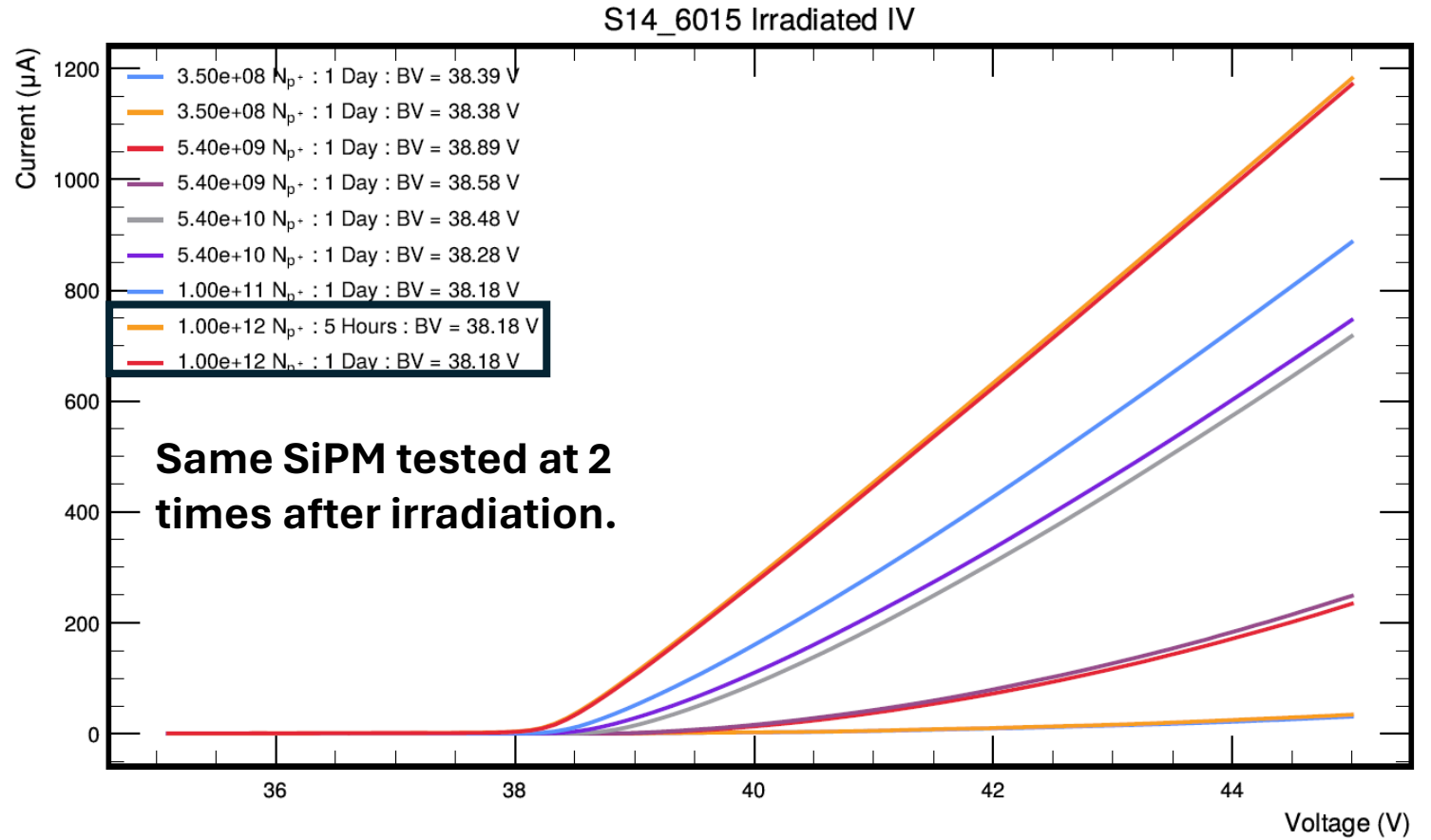
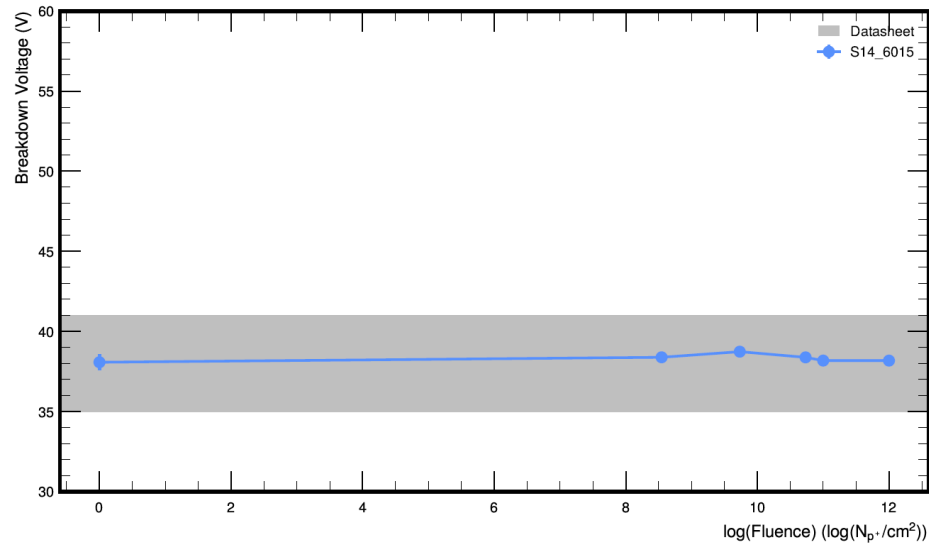
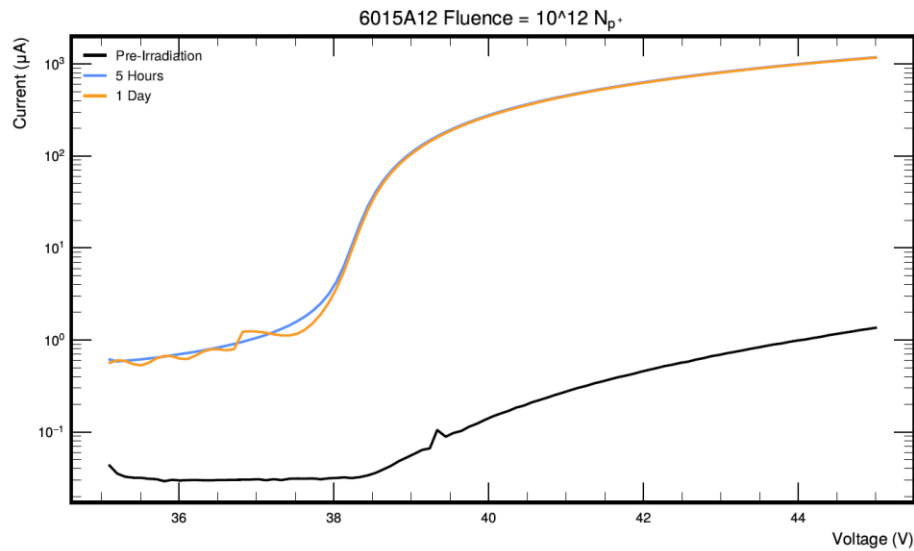


# Results for S14160-6015PS

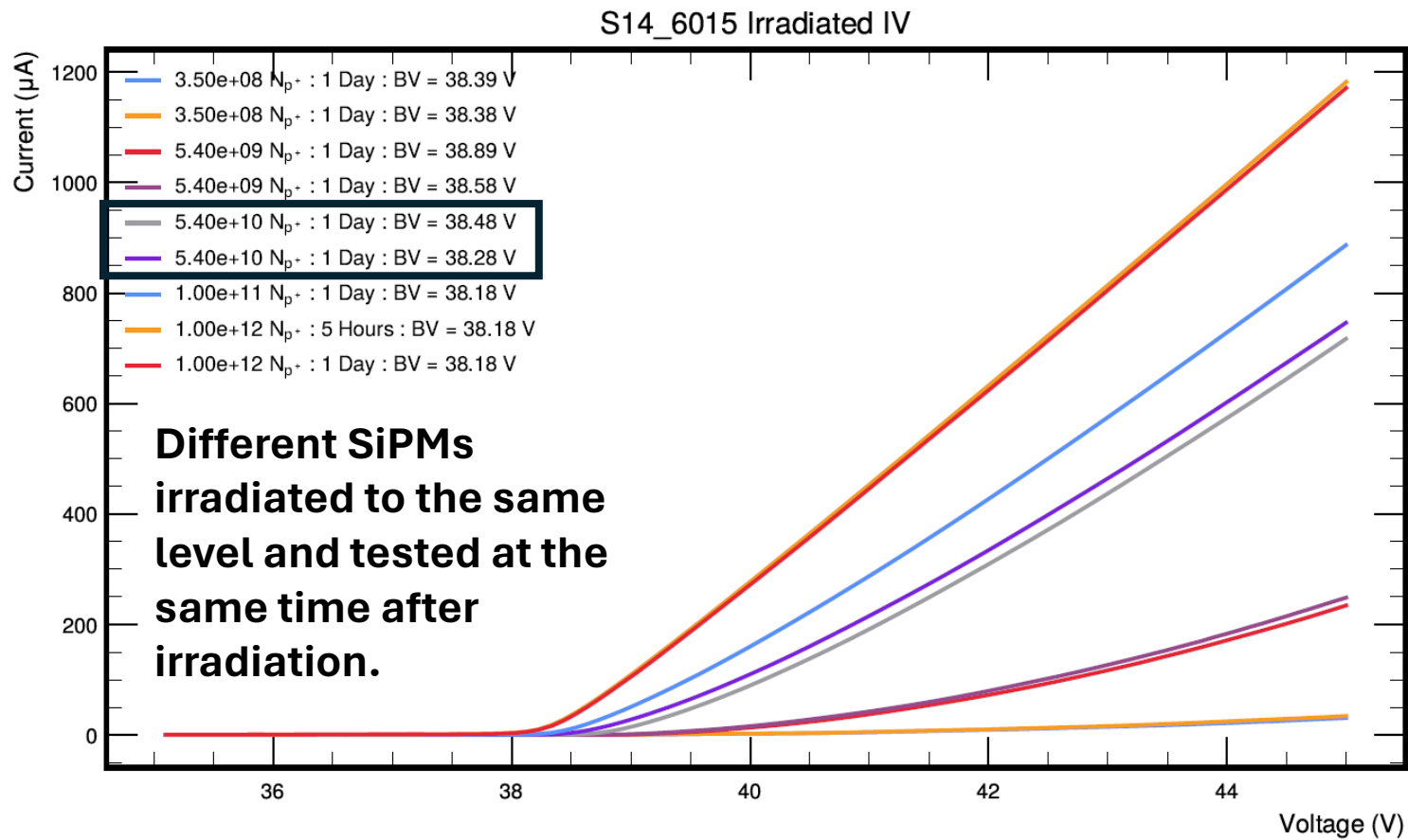
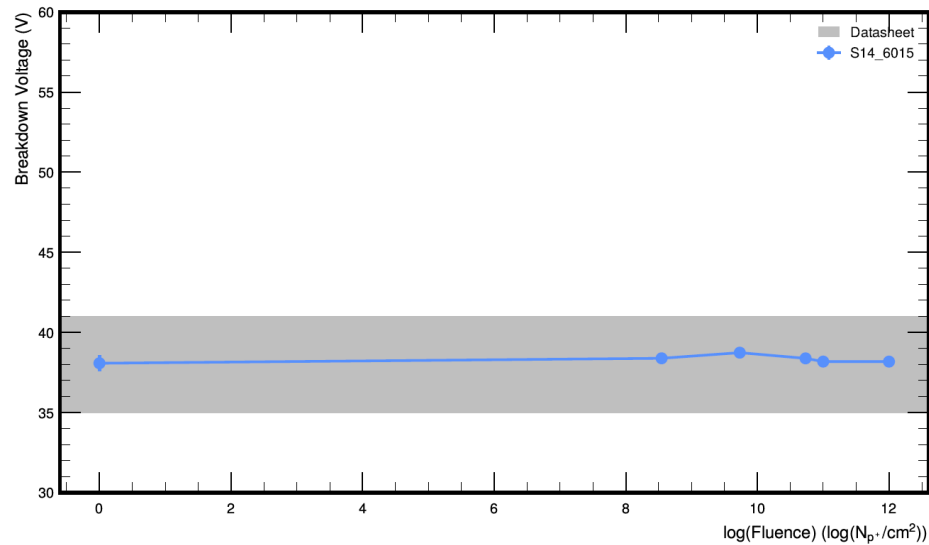
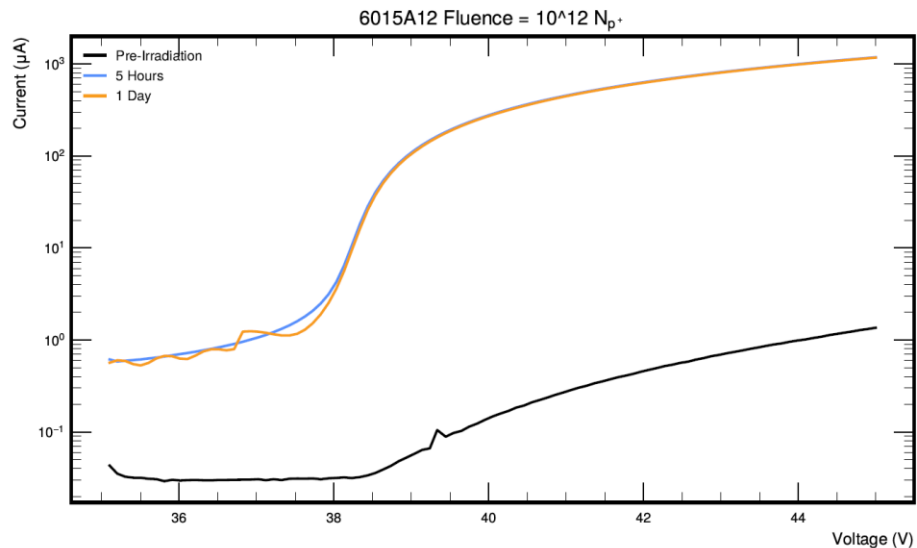




# Results for S14160-6015PS

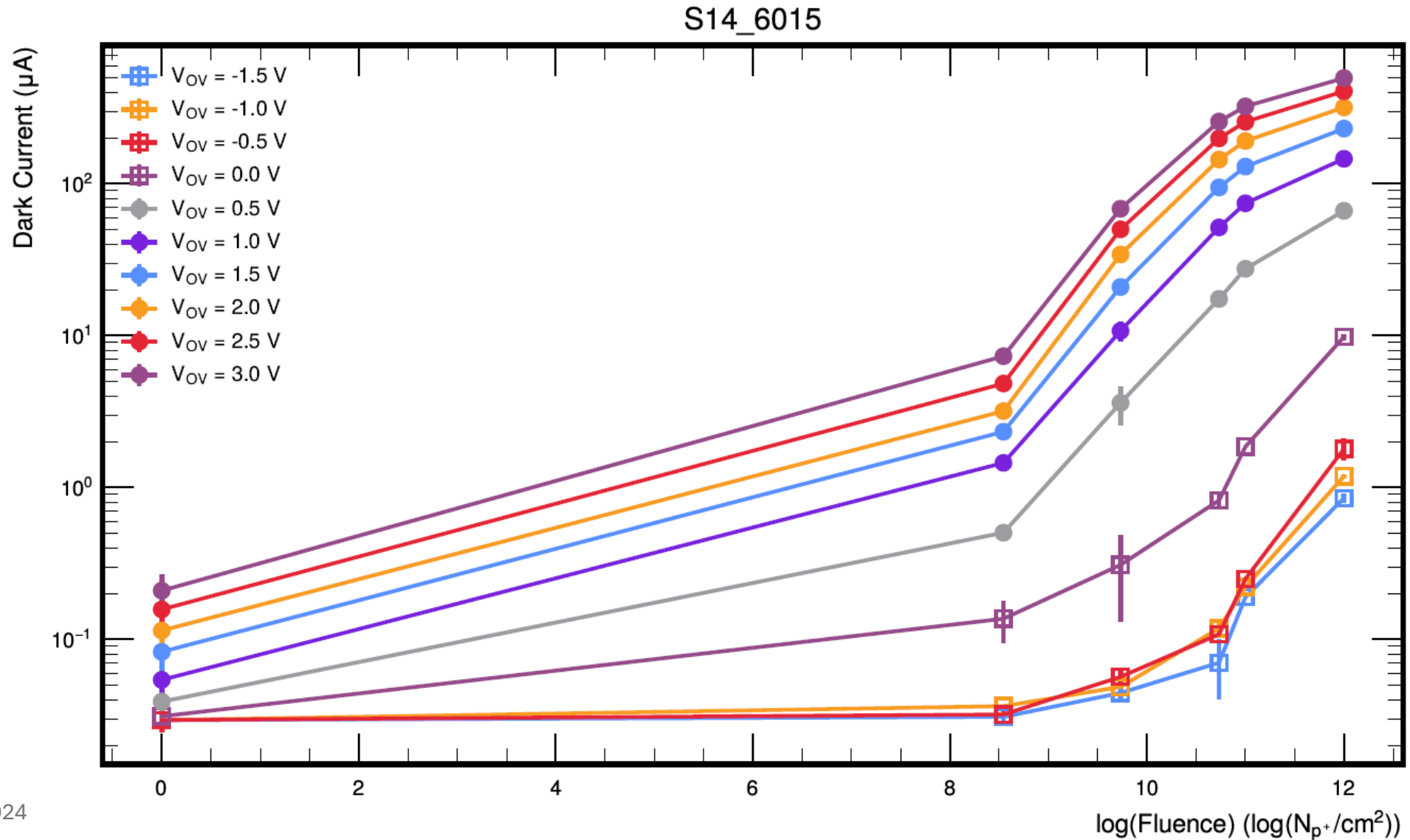


# Results for S14160-6015PS

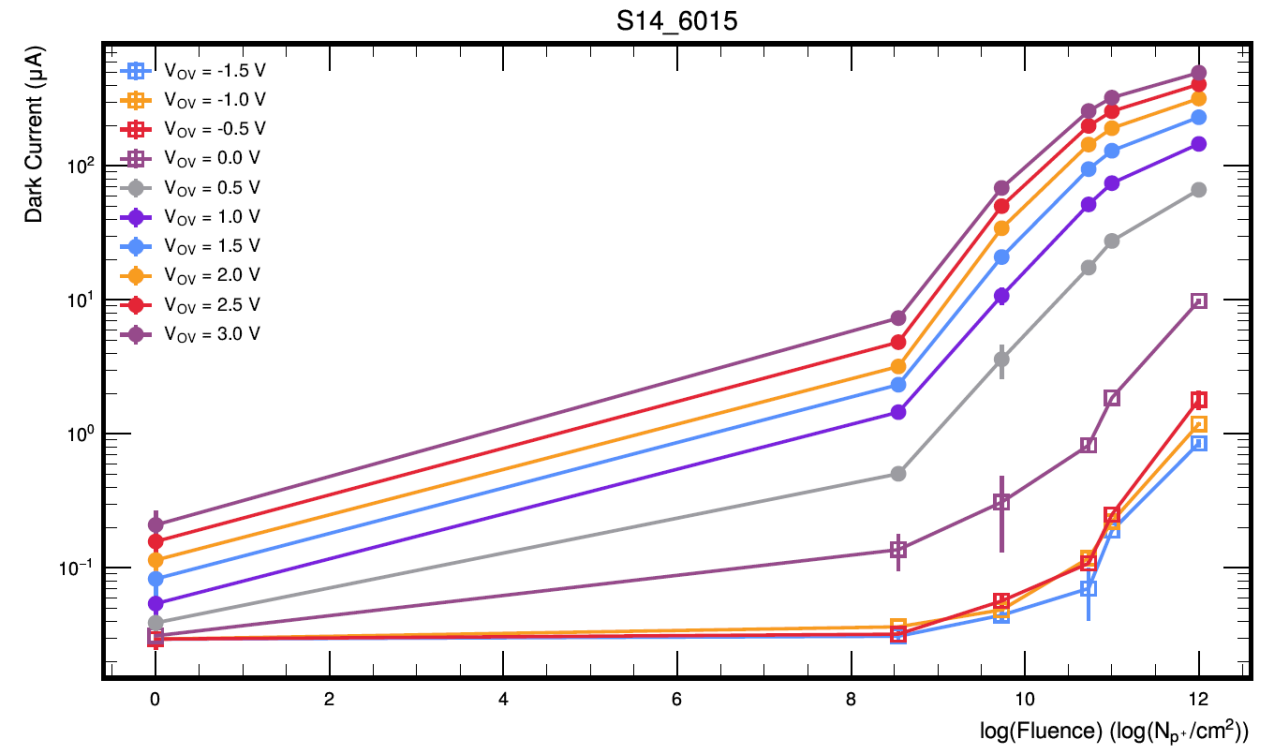
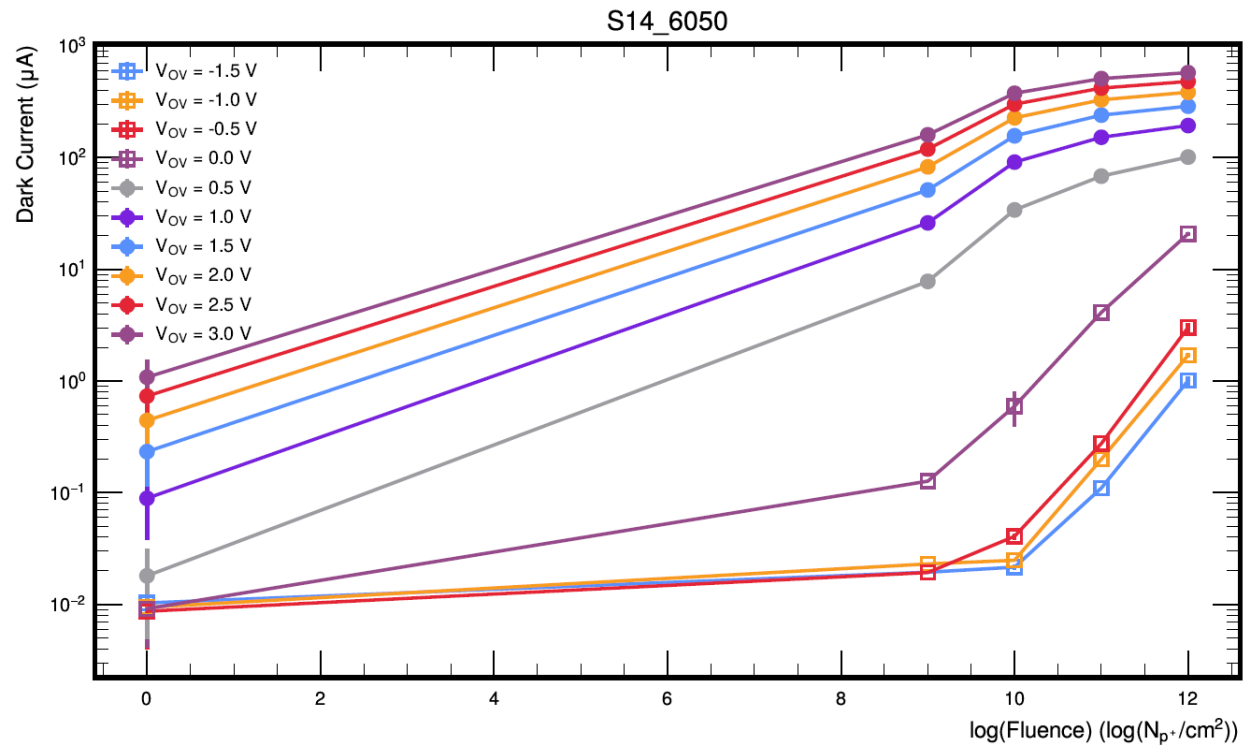


# Results for S14160-6015PS

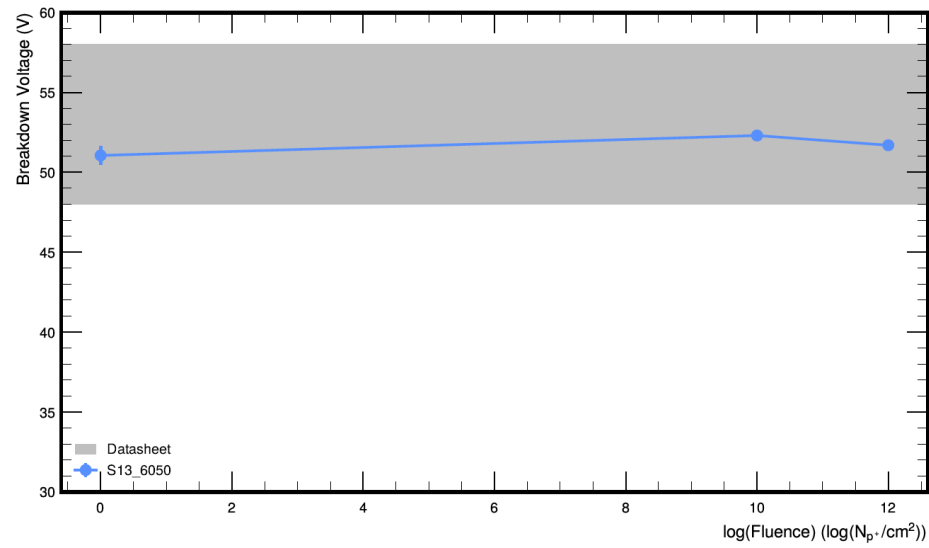
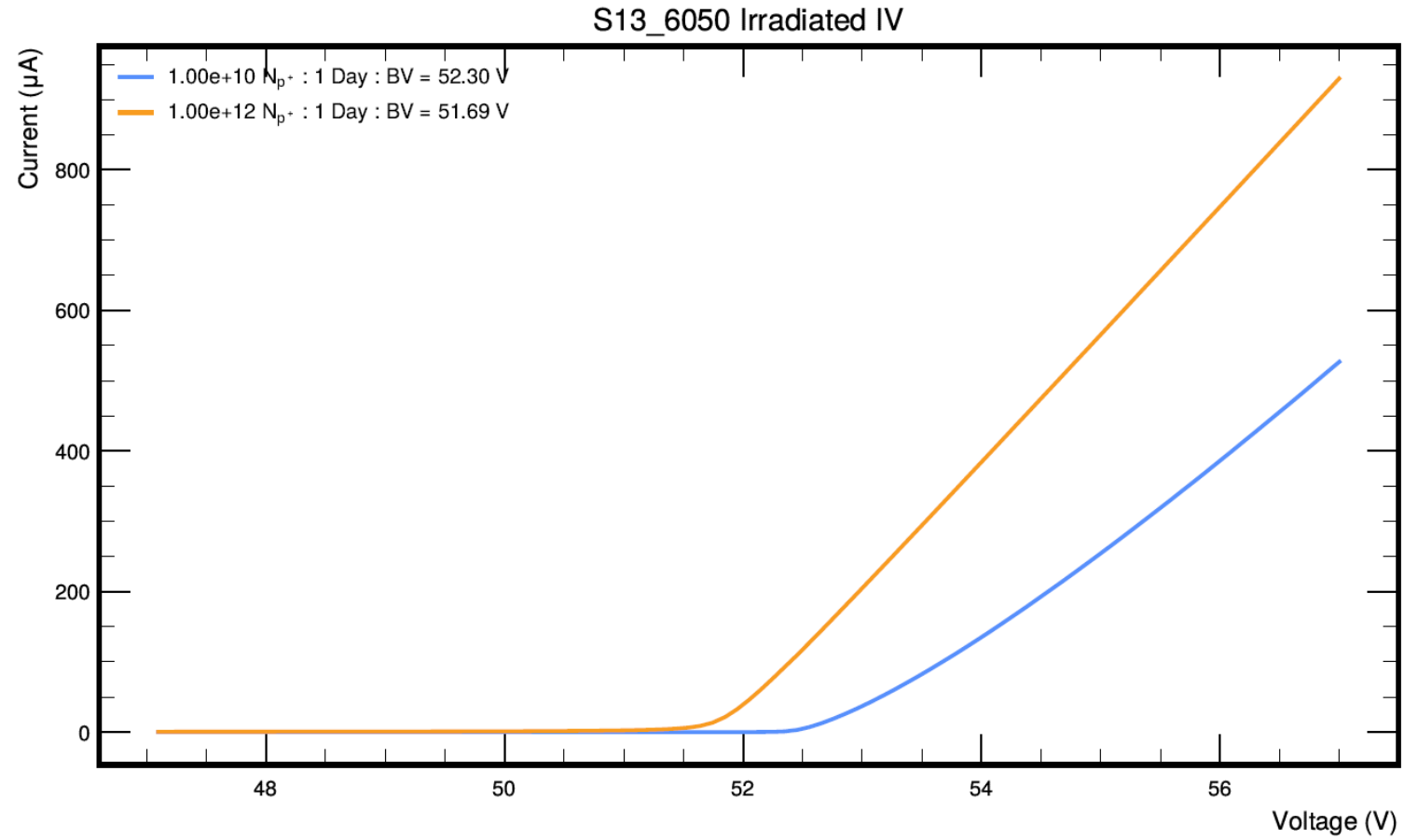
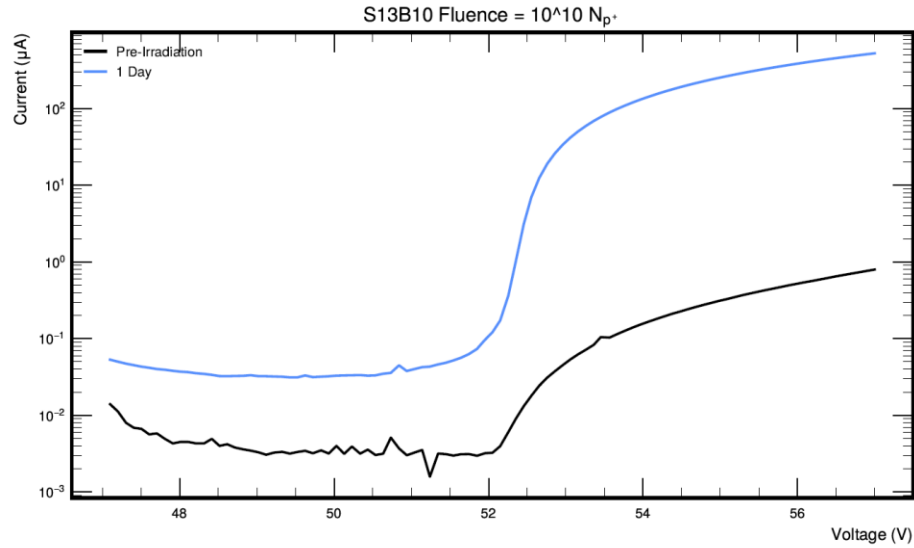
Additional SiPMs irradiated to  $10^{13}$  fluence



# Comparison of S14160-6050HS and S14160-6015PS results

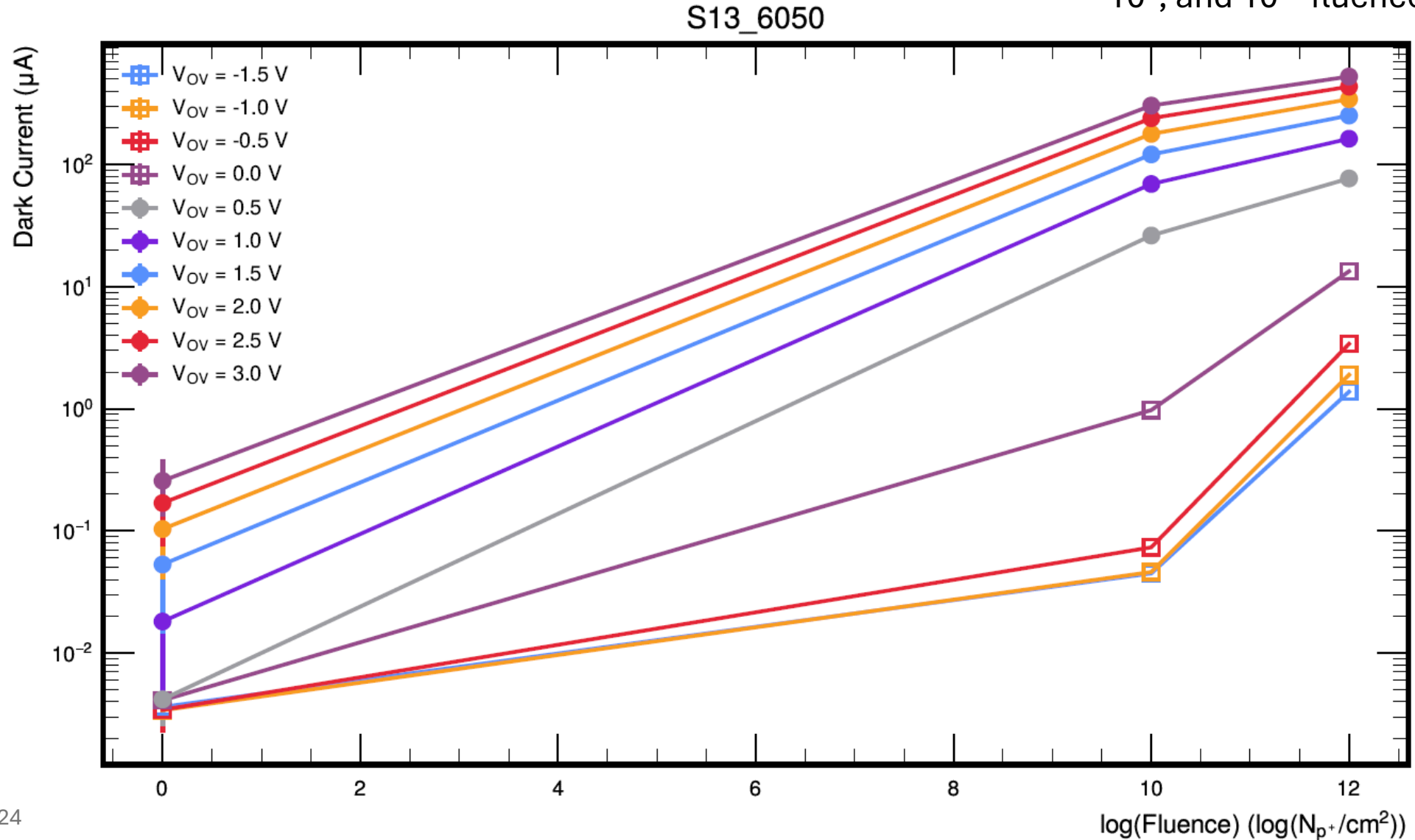


# Results for S13360-6050VE



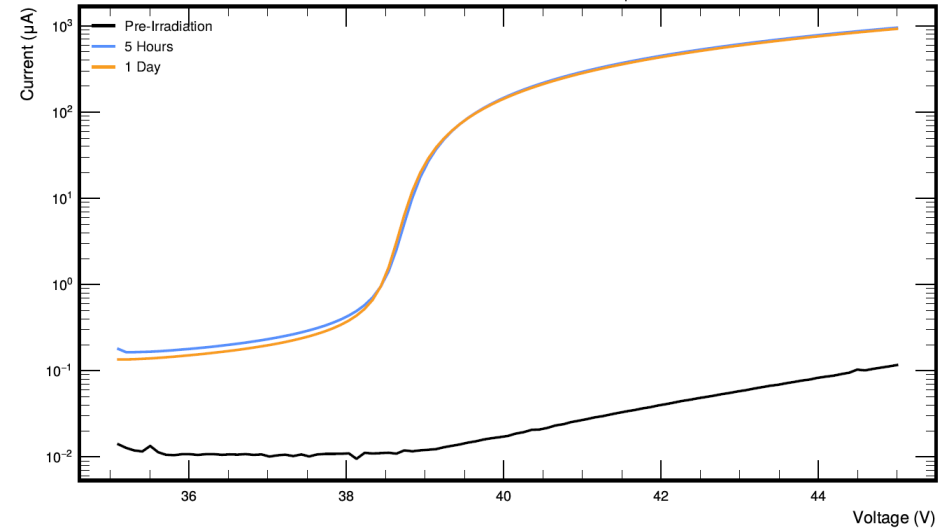
# Results for S13360-6050VE

Additional SiPMs irradiated to  $10^8$ ,  $10^9$ , and  $10^{11}$  fluence

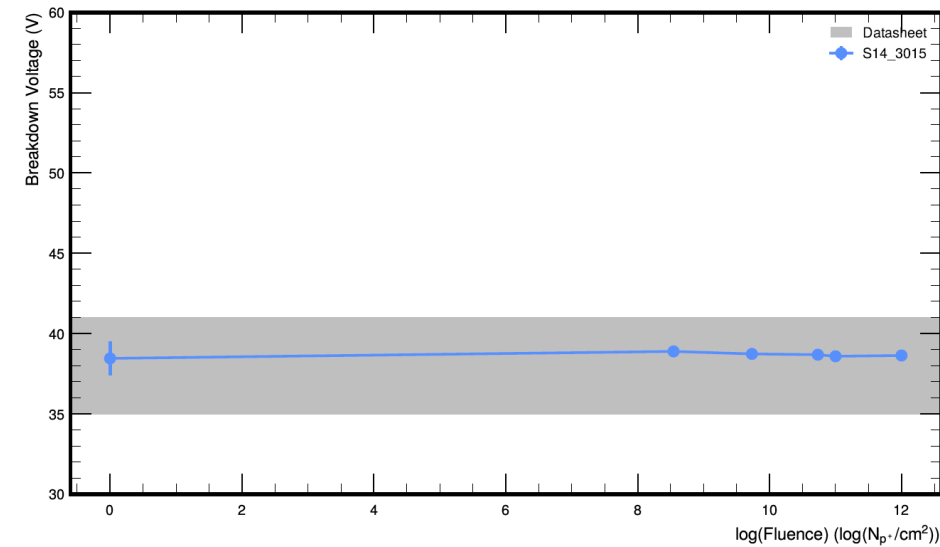
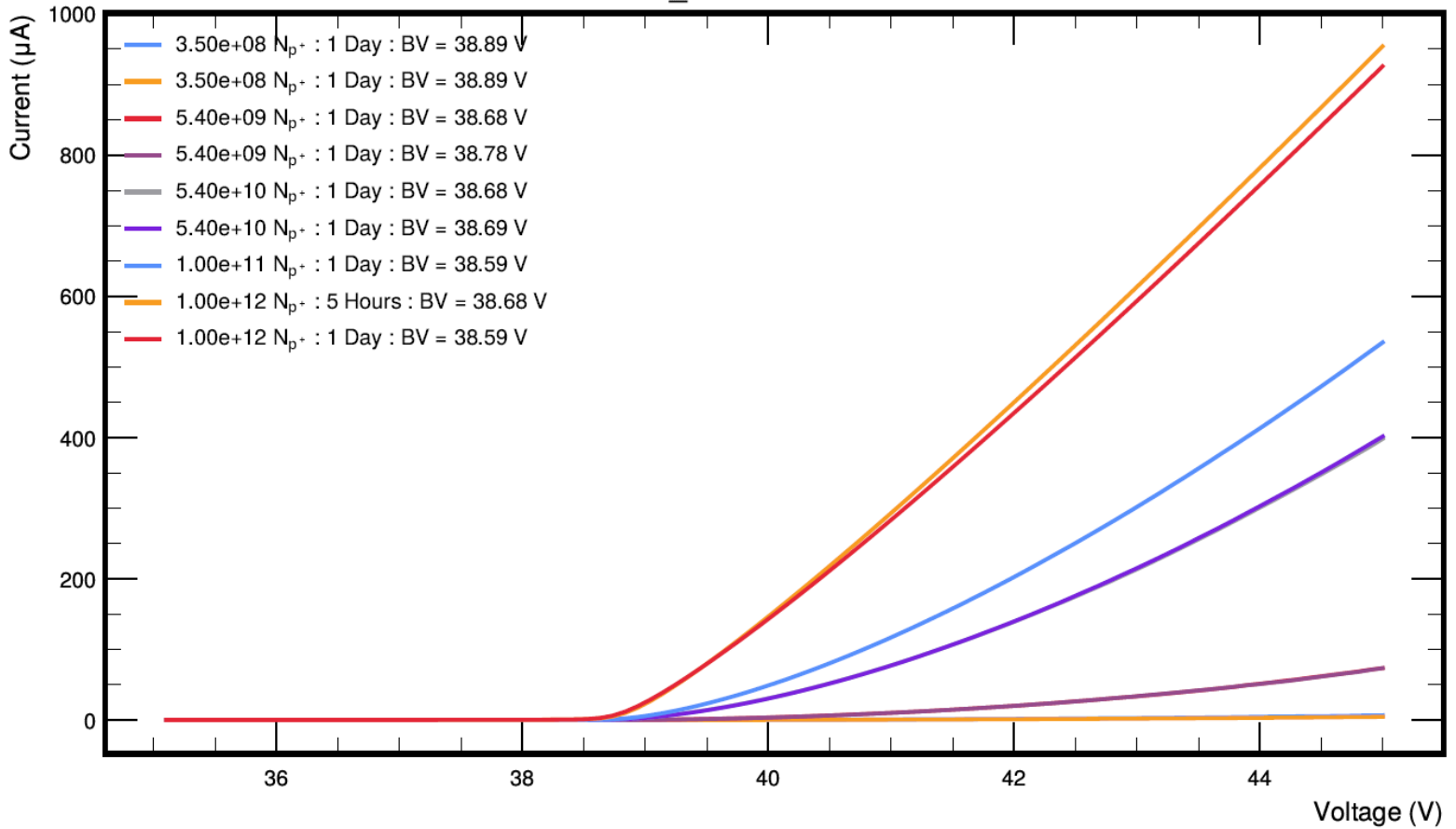


# Results for S14160-3015PS

3015A12 Fluence =  $10^{12}$   $N_p$

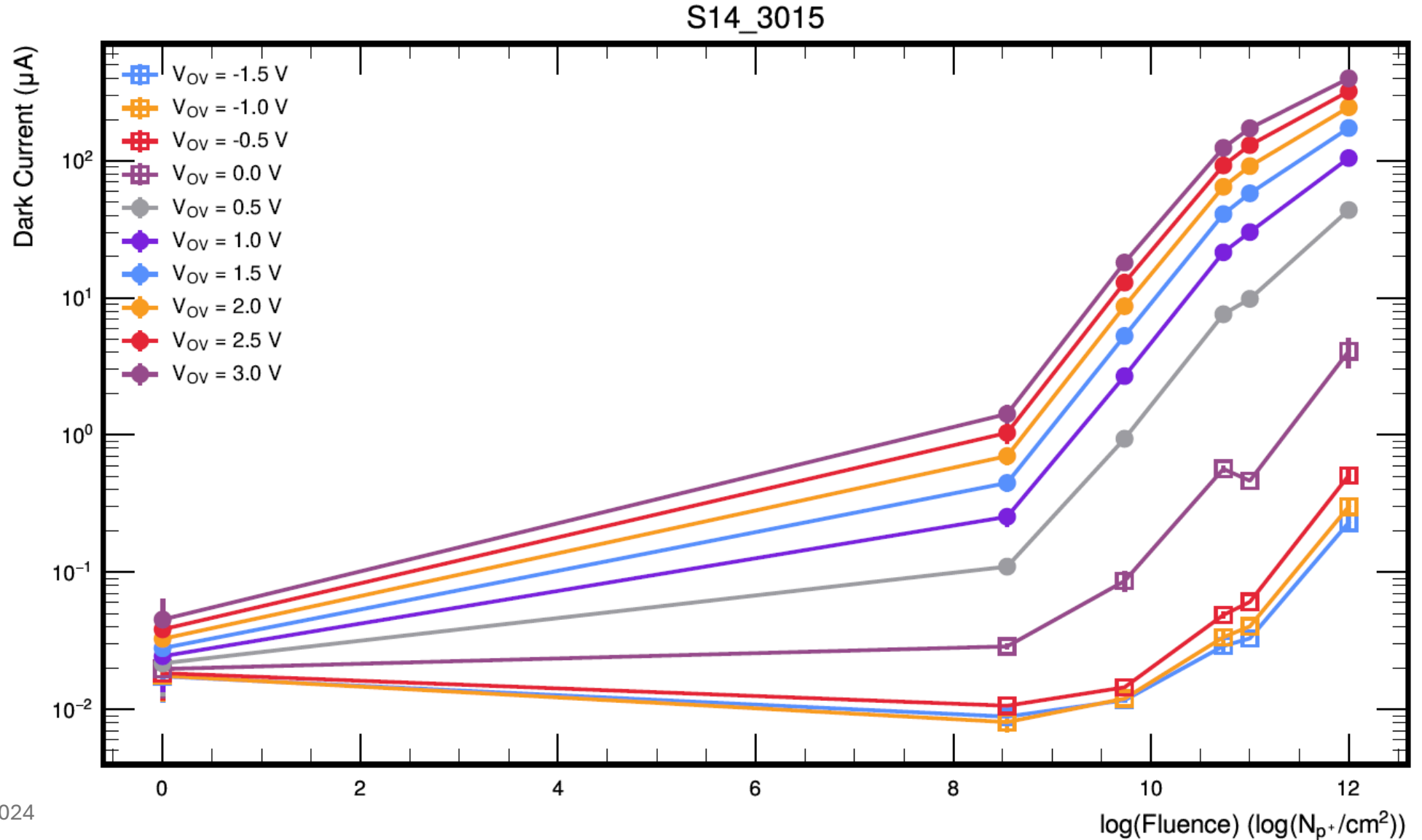


S14\_3015 Irradiated IV



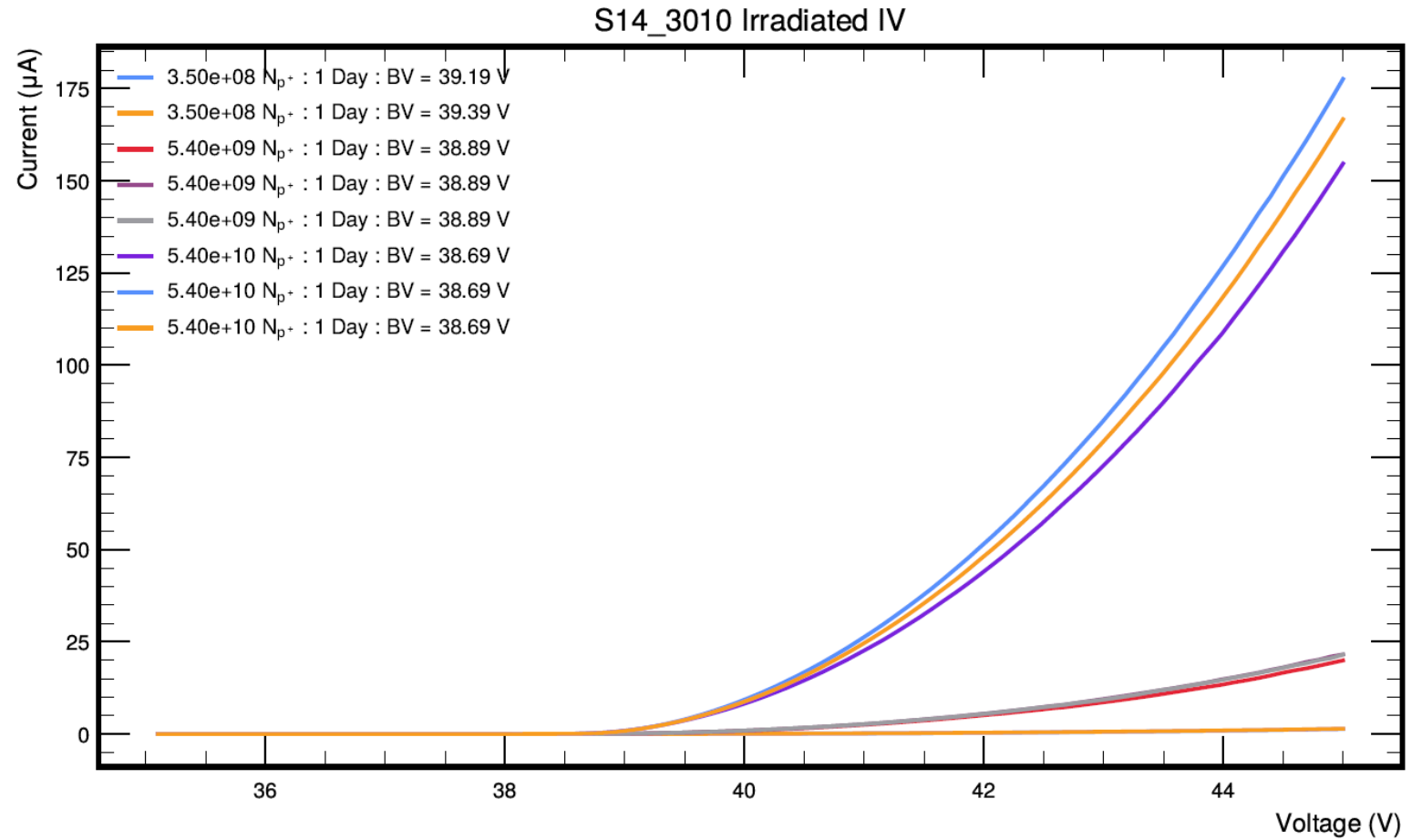
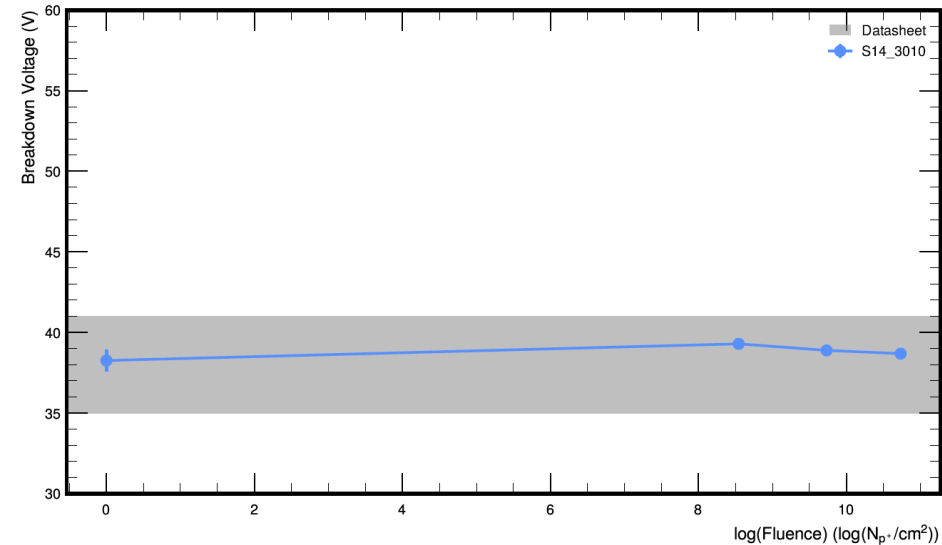
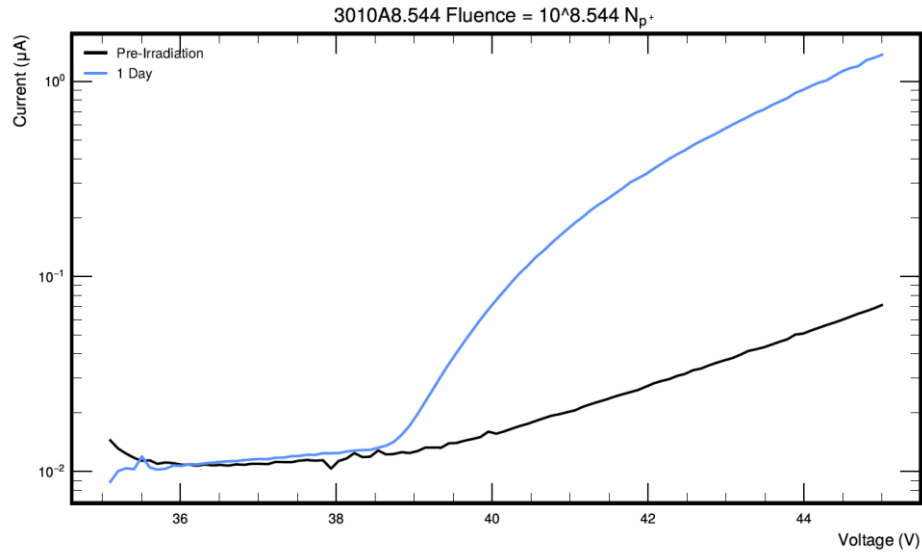
# Results for S14160-3015PS

Additional SiPMs irradiated to  $10^{13}$  fluence

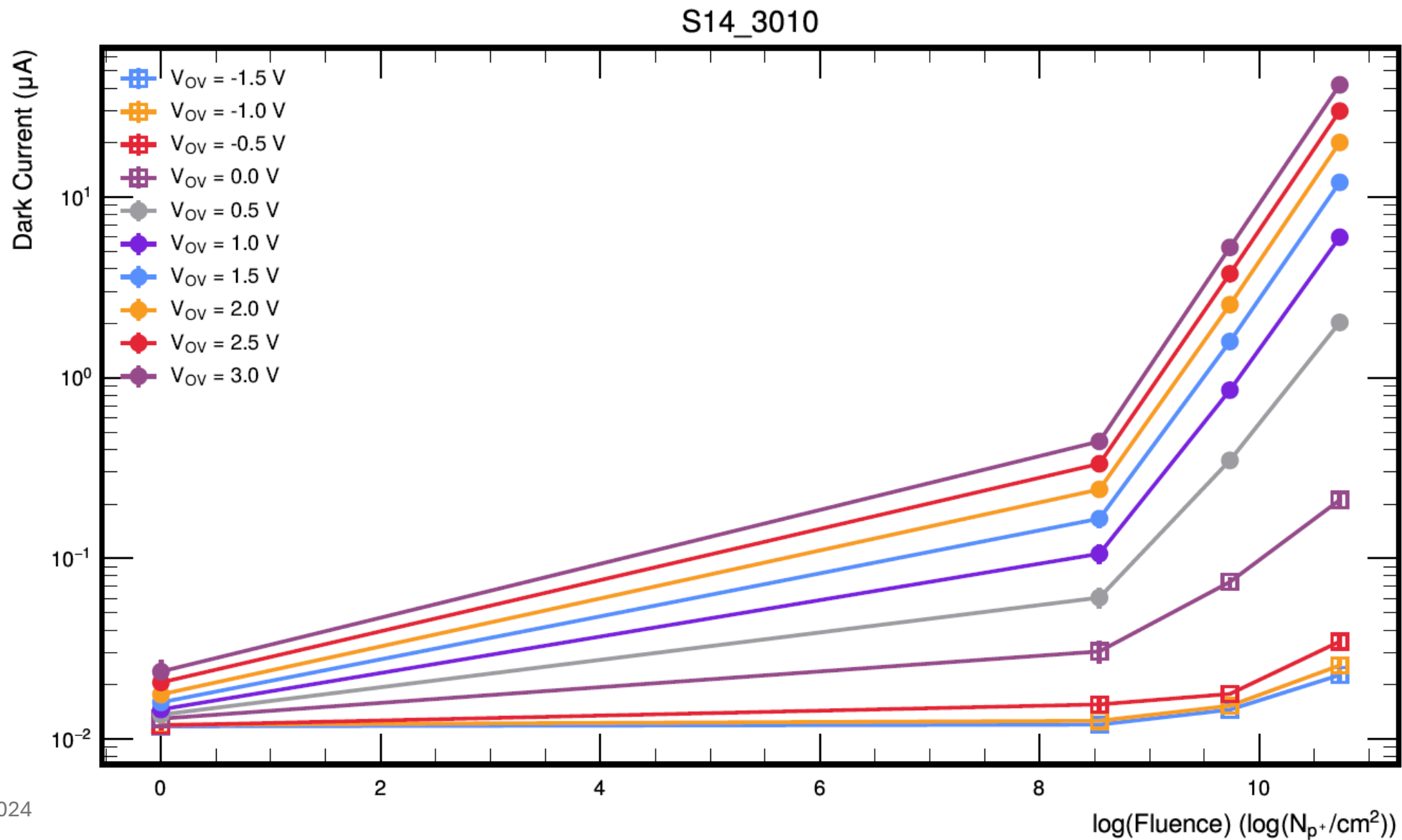




# Results for S14160-3010PS



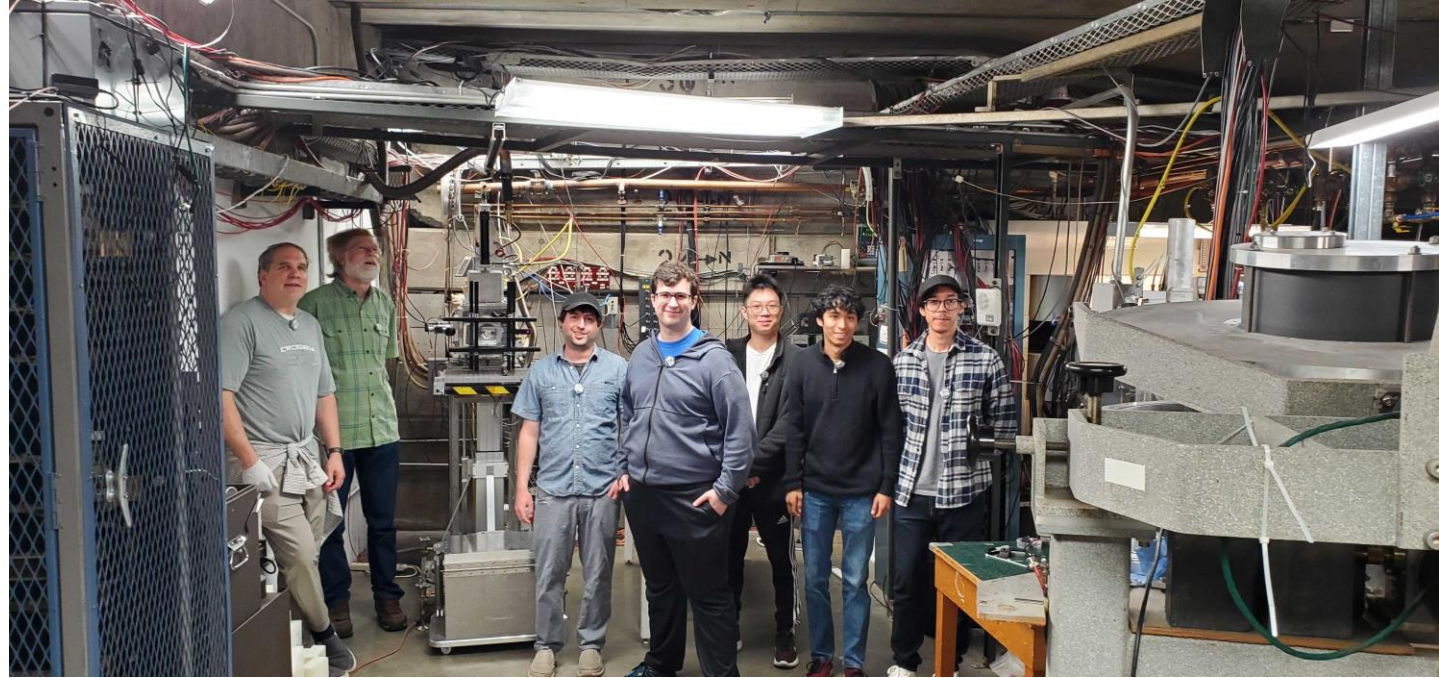
# Results for S14160-3010PS



# Summary and next steps

- We irradiated a variety of SiPMs over a range of fluences using a 64 MeV proton beam.
- We have presented initial results of dark current vs. overvoltage for these SiPMs.
- The next steps are to repeat these I-V scans for the already tested SiPMs – a month or so after irradiation – as well as measure I-V curves the other irradiated SiPMs which were not tested immediately after irradiation.
- Additional studies using low-intensity LED light will be performed, as well as cosmic studies of the irradiated tiles and boards.
- We also plan on studying the ability of high-temperature annealing to recover some of the SiPM performance.

# UC Davis beam test – May 14<sup>th</sup> - 15<sup>th</sup>, 2024



Additional photos