Radiation Report

Single-Event Effects (SEE) Radiation Report of the OPA4H838-SEP

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the OPA4H838-SEP. Heavy-ions with LET_{EFF} of 45.6MeV·cm^2 /mg are used to irradiate production devices. Flux of 10^5 ions×cm^2/s and fluence of 10^7 ions/cm^2 per run are used for the characterization. The results demonstrated that the OPA4H838-SEP is SEL-free up to 45.6MeV·cm^2/mg at T = 125°C.

SET transients performance for output voltage excursions ≥ |10%| from the nominal voltage are presented and discussed.

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1 Introduction

The OPA4H838-SEP precision amplifier is an ultra-low noise, fast-settling, zero-drift, zero-crossover device that provide rail-to-rail input and output operation. These features and excellent ac performance, combined with only 2.25μV of offset and 0.005μV/°C of drift over temperature, makes the OPA4H838-SEP a great choice for driving high-precision, analog-to-digital converters (ADCs) or buffering the output of high-resolution, digital-to-analog converters (DACs). This design results in excellent performance when driving analog-to-digital converters (ADCs) without degradation of linearity. The OPA4H838-SEP is offered in a plastic TSSOP-14 package. The OPA4H838-SEP is specified from –55°C to +125°C.

General device information and test conditions are listed in the overview information table. For more detailed technical specifications, user-guides, and application notes please go to device product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	OPA4H838-SEP
Orderable Part Number	OPA4H838MPWTSEP
VID/SMD Number	V62/25643-01XE
Device Function	Operational Amplifier
Technology	50HPA07 (CMOS)
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University
Heavy Ion Fluence per Run	10^7 ions/cm^2
Irradiation Temperature	25°C (for SET testing) and 125°C (for SEL testing)

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2 Single-Event Effects (SEE)

The primary concern for the OPA4H838-SEP is the robustness against the destructive single-event effects (DSEE): single-event latch-up (SEL).

SEL can occur if excess current injection caused by the passage of an energetic ion is high enough to trigger the formation of a parasitic cross-coupled PNP and NPN bipolar structure (formed between the p-sub and n-well and n+ and p+ contacts) [1,2]. The parasitic bipolar structure initiated by a single-event creates a high-conductance path (inducing a steady-state current that is typically orders-of-magnitude higher than the normal operating current) between power and ground that persists (is "latched") until power is removed, the device is reset, or until the device is destroyed by the high-current state.

The OPA4H838-SEP is tested for SEL at 125°C at the maximum recommended operating conditions of *5.5V*. Output conditions are tested with no load. During testing of the three devices, the OPA4H838-SEP did not exhibit any SEL with heavy-ions with LET_{EFF} = 45.6MeV×cm^2 /mg at flux ≈10^5 ions×cm^2/s , fluence of ≈10^7 ions/cm^2, and a die temperature of 125°C. To see the SEL results of the OPA4H838-SEP, please refer to Section 6.1.

The OPA4H838-SEP is characterized for SET at flux of 10^5 ions×cm^2/s , fluences of 10^7 ions/cm^2 at room temperature. The OPA4H838-SEP is characterized as a follower with the output set to one half the supply voltage. Heavy-ions with LET_{EFF} of 47.5MeV×cm^2/mg is used to characterize the transient performance. To see the SET results of the OPA4H838-SEP, please refer to Section 7.

3 Device and Test Board Information

The OPA4H838-SEP is packaged in a 14-pin plastic TSSOP (PW) package. The AMP-PDK-EVM evaluation module (EVM) is used to evaluate the performance and characteristics of the OPA4H838-SEP under heavy ion radiation. The OPA4H838-SEP devices are decapsulated to reveal the bare die face for all heavy-ion testing. The device under test (DUT) is inserted into a socket into the AMP-PDK-EVM to test various units with the same EVM. The plastic supporting bar across the top of the socket lid is removed. Each device is configured in the buffer configuration (Buffer Section). For more information about the AMP-PDK-EVM evaluation module, click here.

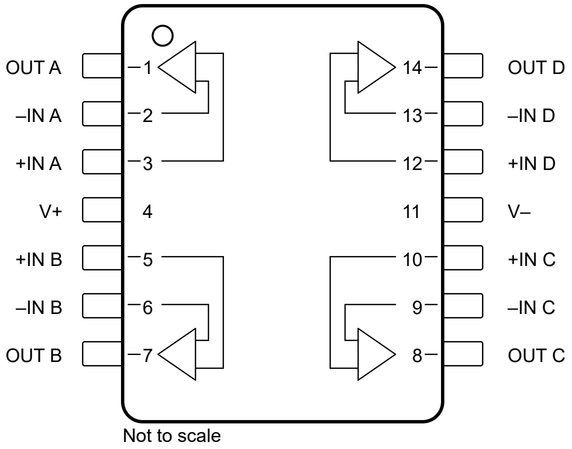

Figure 3-1. Pinout Diagram

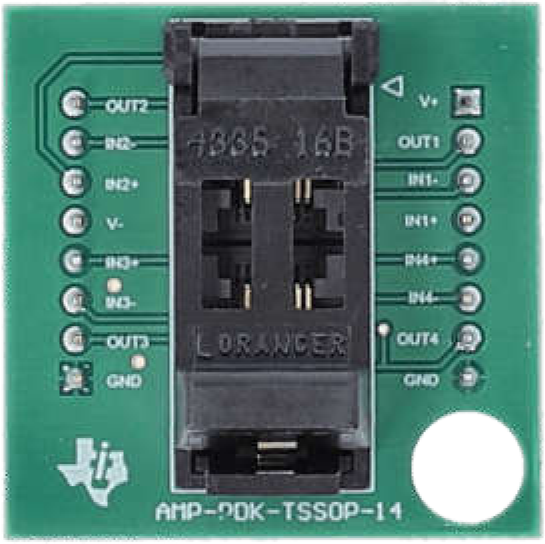

Figure 3-2. AMP-PDK-TSSOP-14 Socket

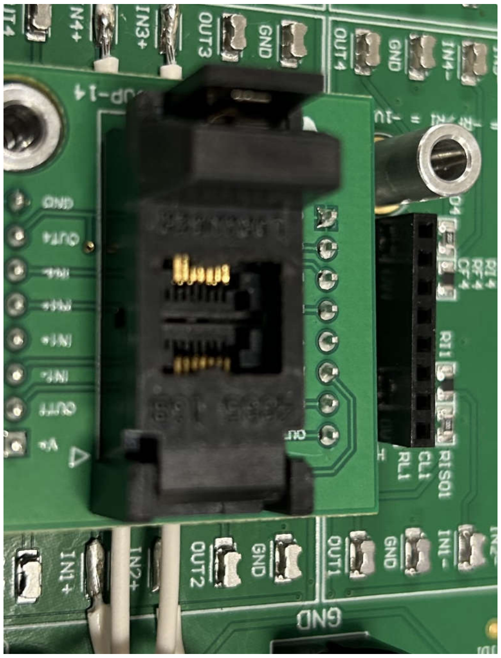

Figure 3-3. AMP-PDK-TSSOP-14 Socket - Plastic bar removed

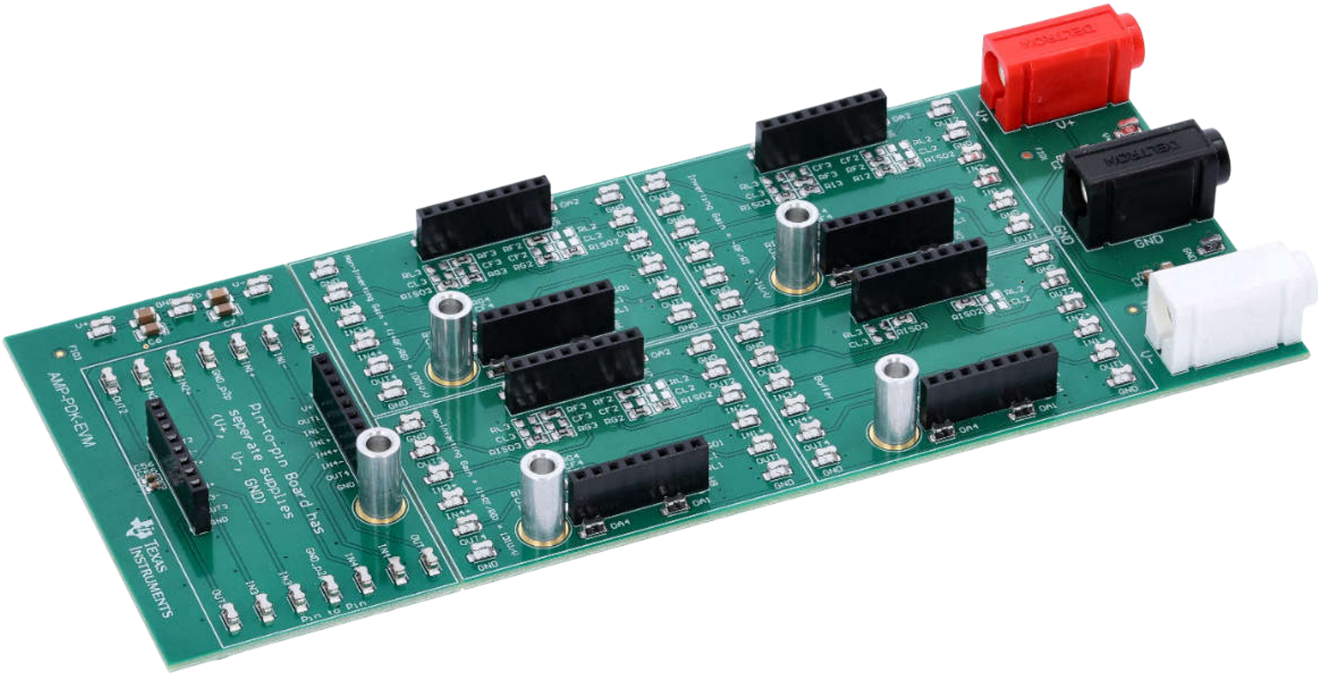

Figure 3-4. AMP-PDK-EVM Evaluation Module Used for OPA4H838-SEP SEE Testing Top View

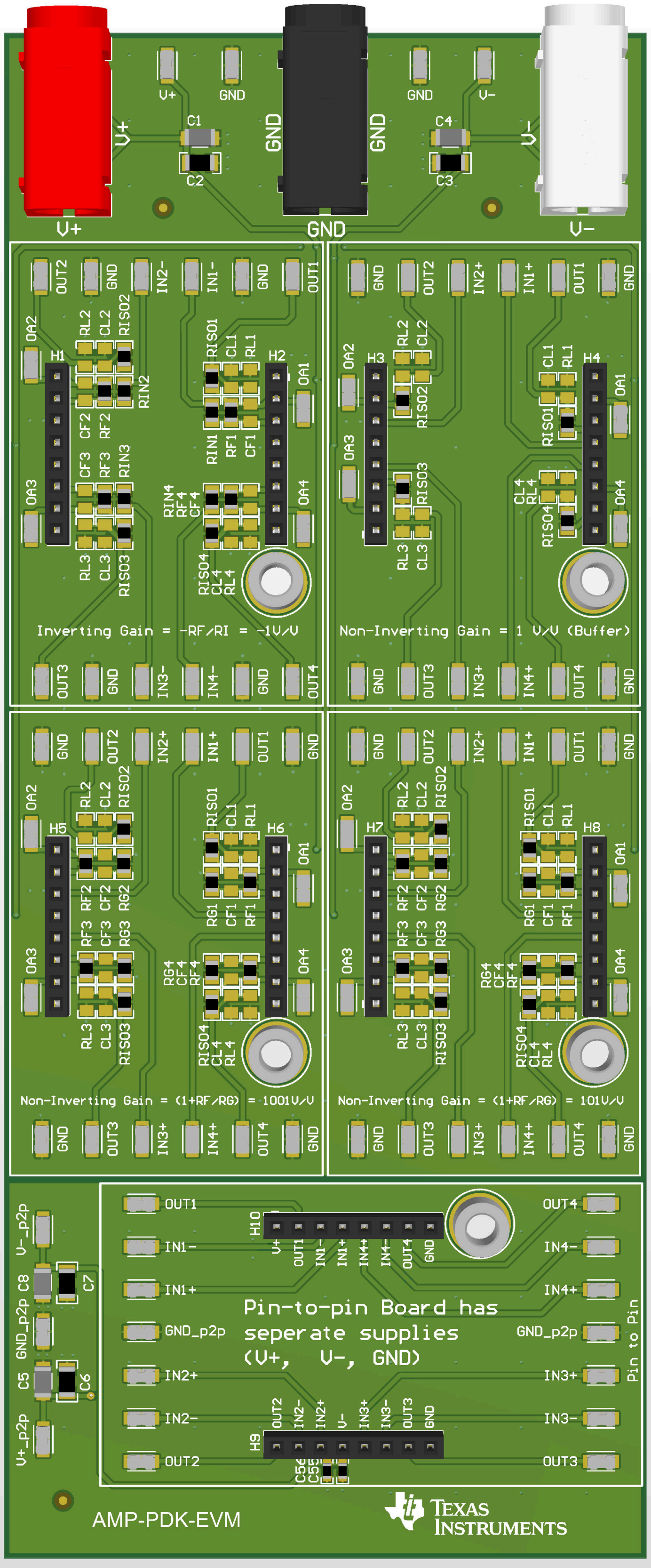

Figure 3-5. AMP-PDK-EVM Board

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product are provided and delivered by the TAMU Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 1in diameter circular cross-sectional area for the in-air station. Uniformity is achieved by magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For the bulk of these studies, ion flux of 10^5 ions/cm^2·s is used to provide heavy-ion fluences of 10^7 ions/cm^2. The TAMU facility uses a beam port that has a 1mil Aramica window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window is maintained at 40mm for all runs.

For these experiments Silver (^{109}Ag), Krypton (^{84}Kr), Copper (^{63}Cu), Argon (^{40}Ar), Neon (^{20}Ne) and Nitrogen (^{14}N) are used. The angle is held to 0°, but different distances between the device and beam are used to increment the LET_{EFF}. Ion beam uniformity for all tests is in the range of 92 to 97%.

Figure 4-1 shows the OPA4H838-SEP device under test (DUT) in the AMP-PDK-EVM used for data collection at the TAMU facility. Although not visible in this photo, the beam port has a 1mil Aramica window to allow in-air testing while maintaining the vacuum within the accelerator with only minor ion energy loss.

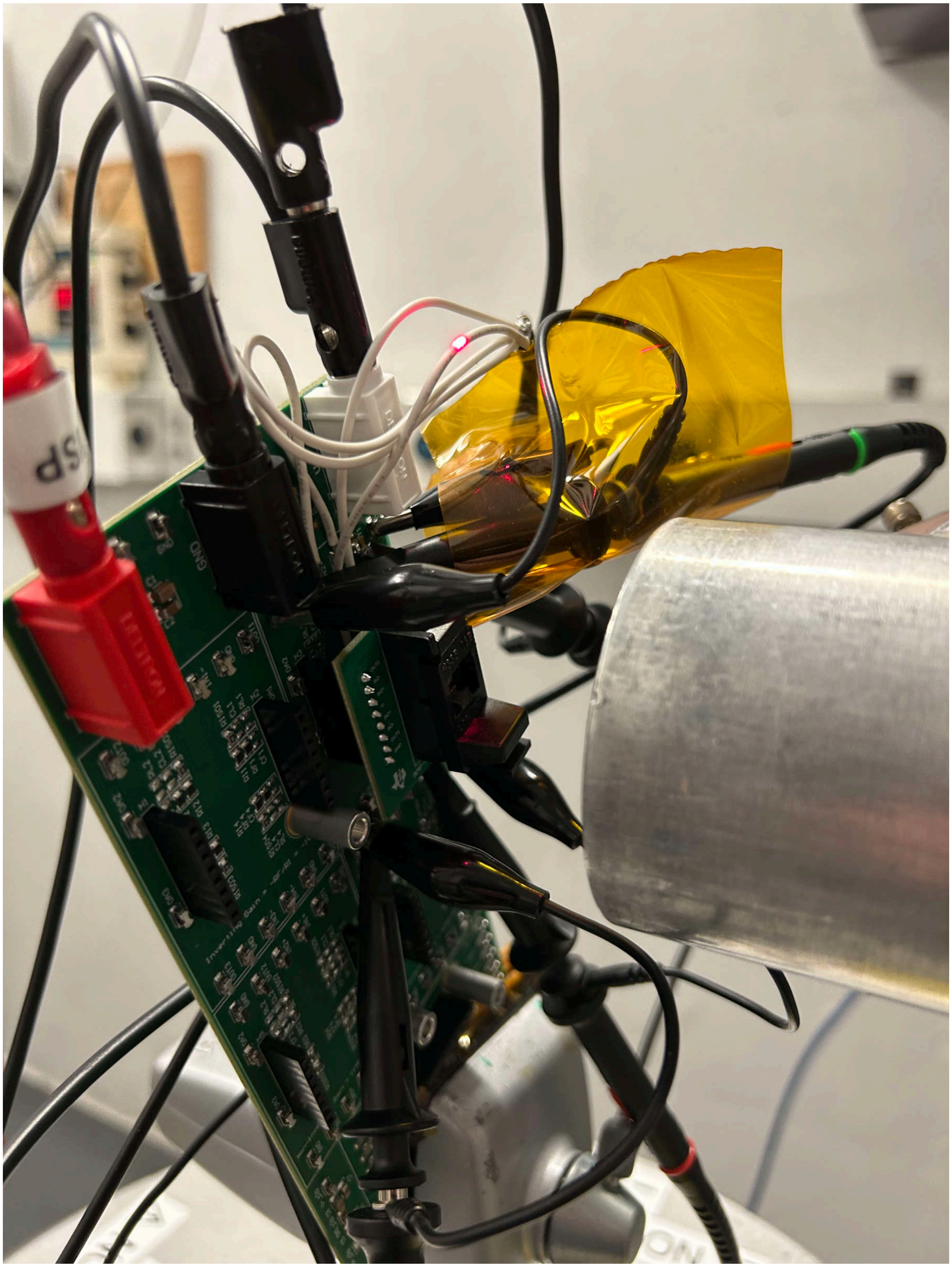

Figure 4-1. Photograph of the OPA4H838-SEP EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

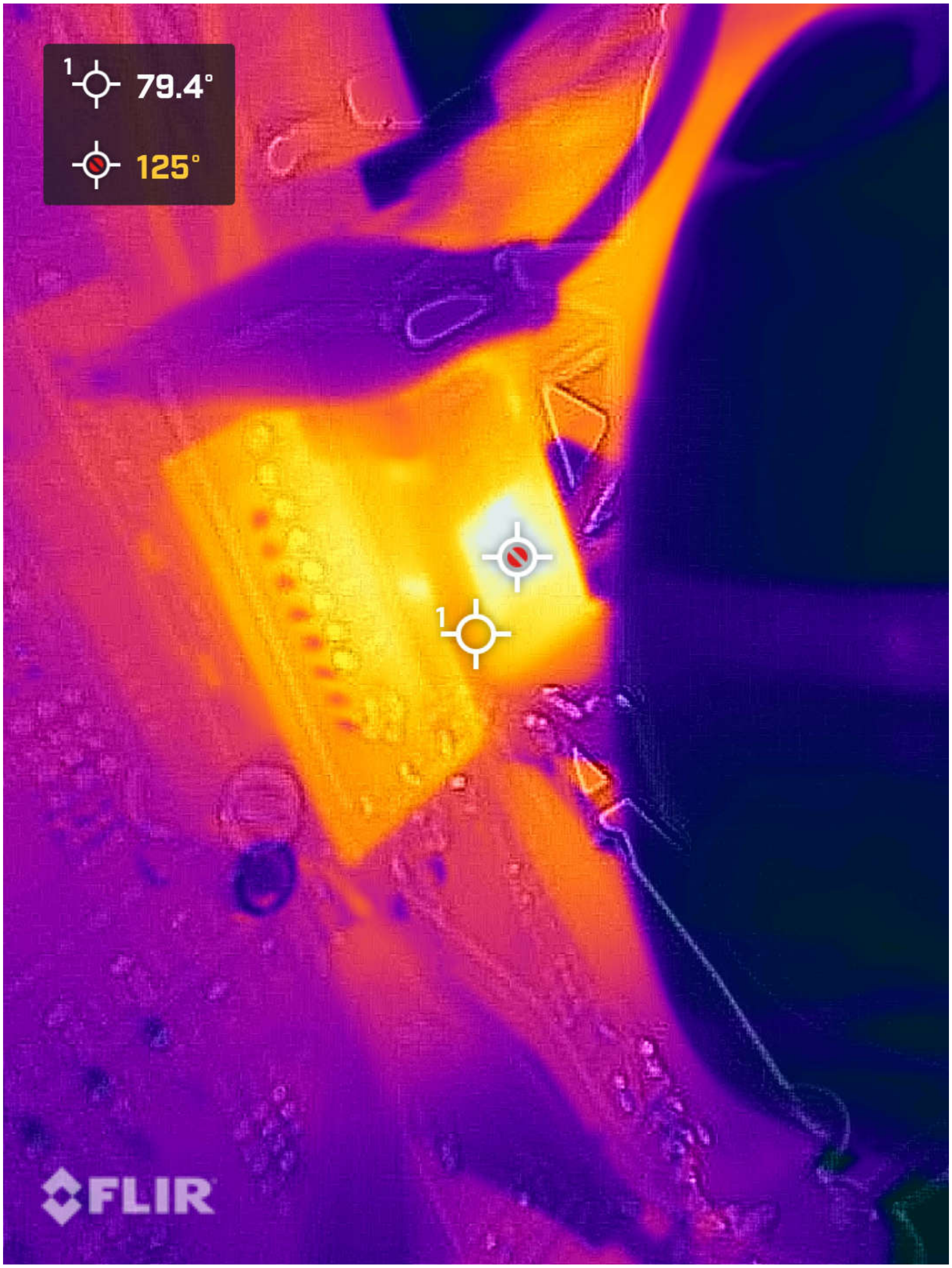

Figure 4-2. Photograph of the OPA4H838-SEP EVM Thermal Image for SEL

5 Test Setup and Procedures

SEE testing is performed on the OPA4H838-SEP device mounted on an EVM. For the single supply, V- is jumpered to GND. The OPA4H838-SEP is evaluated for DC performance in a buffer configuration as shown below in Figure 5-1.

For SEL testing, the V+ supply is set to 5.5V and the input (VIN) is set to 2.75V (mid-common-mode). In this configuration, the quiescent current and combined input bias current of the device is monitored and recorded using the PXIe-4139. The output is unloaded.

For SET testing, the supply voltage is set to 2.5V, 3.3V or 5.5V, and the input voltage (thus output voltage) is set to mid-supply (Vs/2) and the output voltage is monitored for events using the PXIe-5172. The trigger threshold for events is set to ±10% of the expected output voltage. Each output is loaded with a 10kΩ load to ground.

The power supply is controlled and monitored using a custom-develop LabView™ program (PXI-RadTest) running on a NI-PXIe-8135 controller. For the SEL testing the device is heated using a convection heat gun aimed at the die. The junction temperature is monitored by using a thermal imaging camera attached as close as possible to the die. See Figure 4-1 for thermal image.

Table 5-1 shows the connections, limits, and compliance values used during the testing. Figure 3-5 shows a schematic diagram of the setup used for SEE testing of the OPA4H838-SEP.

Table 5-1. Equipment Settings and Parameters Used During the SEL Testing of the OPA4H838-SEP

Pin Name	Equipment Used	Capability	Current Limit
V+	PXIe-4139	±60V, ±3A	20mA
VIN	PXIe-4139	±60V, ±3A	10mA
VOUT1-4	PXIe-5172	100MS/s	—

All boards used for SEL testing are fully checked for functionality and dry runs performed to verify that the test system is stable under all bias and load conditions prior to being taken to the TAMU facility. During the heavy-ion testing, the LabView control program powered up the OPA4H838-SEP device and set the external sourcing and monitoring functions of the external equipment. After functionality and stability had been confirmed, the beam shutter is opened to expose the device to the heavy-ion beam. The shutter remained open until the target fluence is achieved (determined by external detectors and counters).

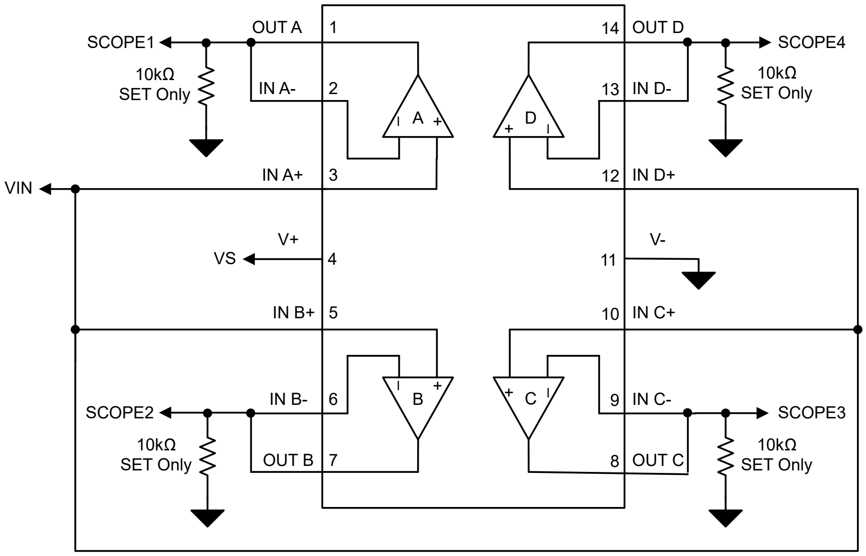

Figure 5-1. OPA4H838-SEP Bias Diagram

6 Destructive Single-Event Effects (DSEE)

6.1 Single-Event Latch-up (SEL) Results

All SEL characterizations are performed with forced hot air to maintain the die temperature at 125°C during the tests. The temperature of the die is verified using thermal camera prior to exposure to heavy ions.

The device is exposed to the heavy-ion beam incident on the die surface at 0°. The distance between the device and the beam is 40mm to achieve an effective LET of 45.6MeV-cm^2/mg. A flux of 10^5 ions/cm^2 -s and fluence of 10^7 ions/cm^2 per run is used in all runs.

The device is powered up and exposed to the heavy-ions using the maximum recommended maximum supply voltage of 5.5V. The device is configured as a buffer amplifier, with the output connected to the inverting input, and the common-mode voltage set to 2.75V. The outputs are unloaded. No SEL events are observed during all ten runs.

Table 6-1 shows the SEL test conditions and results. Figure 6-1 shows a plot of the current vs time for runs 9, 12 and 15.

Table 6-1. OPA4H838-SEP SEL Conditions and Results

Run	DUT	Ion	LET$_{EFF}$ (MeV-cm^2/mg)	Effective Fluence (ions/cm^2)	Average Flux (ions/cm^2 ·s)	Result
8	2	^{109}Ag	45.6	1.001E+07	1.074E+05	Pass
9	2	^{109}Ag	45.6	9.947E+06	1.059E+05	Pass
10	2	^{109}Ag	45.6	1.000E+07	1.178E+04	Pass
11	2	^{109}Ag	45.6	9.985E+06	1.291E+05	Pass
12	3	^{109}Ag	45.6	1.001E+07	1.288E+05	Pass
13	3	^{109}Ag	45.6	1.004E+07	1.273E+05	Pass
14	3	^{109}Ag	45.6	1.004E+07	1.305E+05	Pass
15	4	^{109}Ag	45.6	9.986E+06	1.110E+05	Pass
16	4	^{109}Ag	45.6	1.003E+07	1.189E+05	Pass
17	4	^{109}Ag	45.6	1.001E+07	1.253E+05	Pass

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the 10 runs at 125°C (10×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 3.69 \times 10^7$ cm^2/device for LET$_{EFF}$ = 45.6MeV×cm^2/mg and T = 125°C.

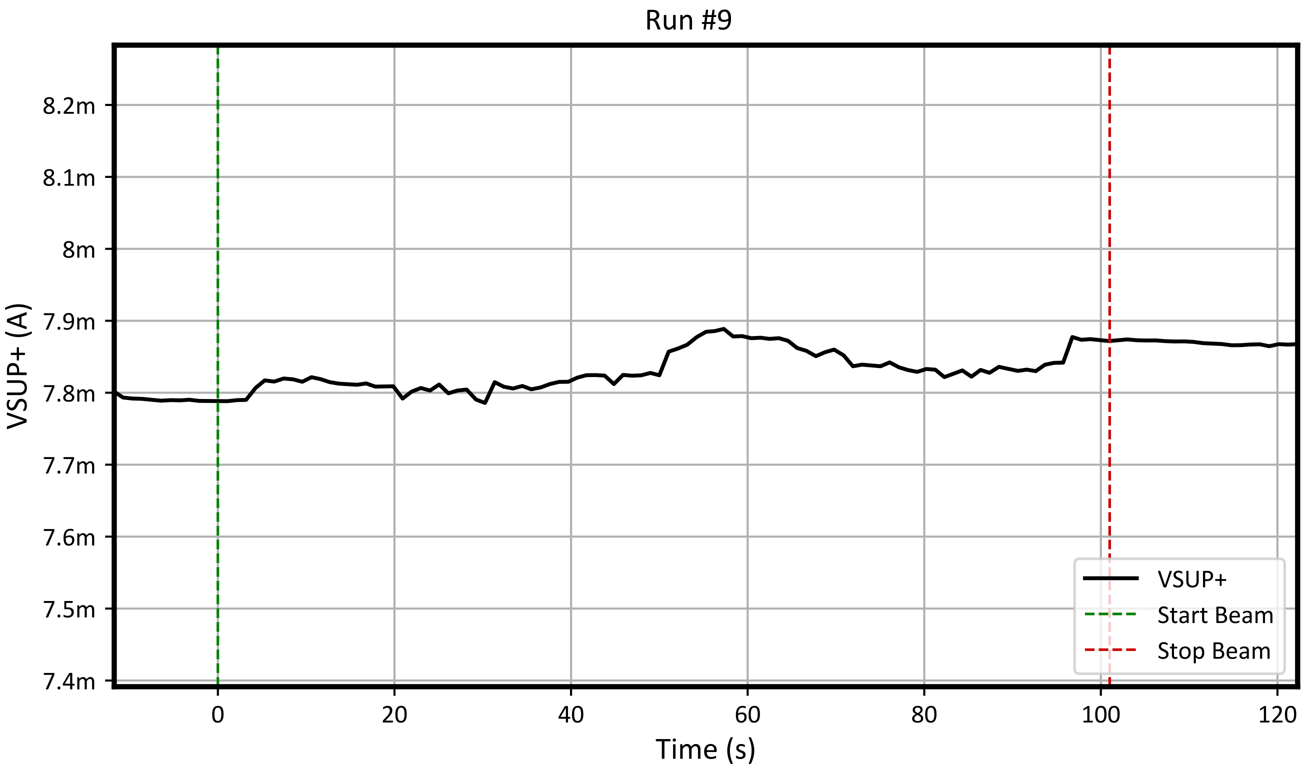

Figure 6-1. Run 9: Total Positive Supply Current versus Time

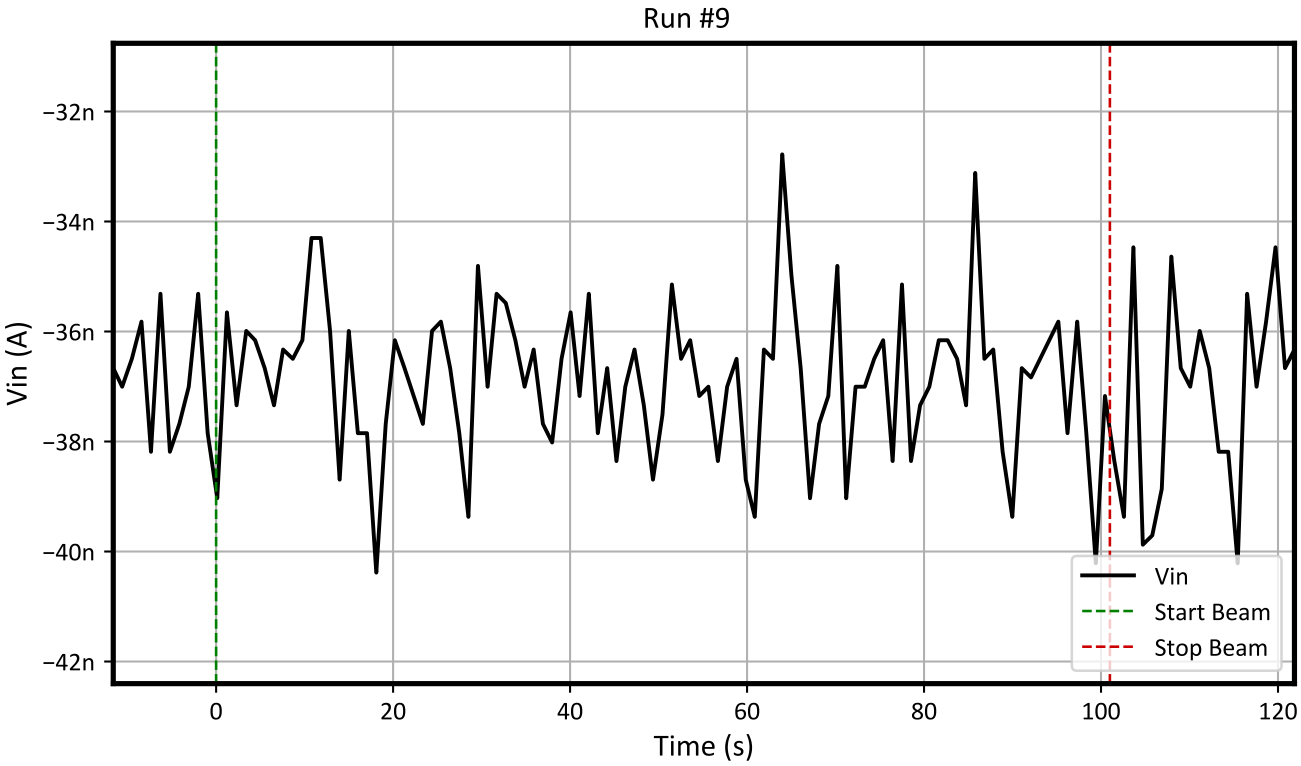

Figure 6-2. Run 9: Input Bias Current versus Time (All Channels)

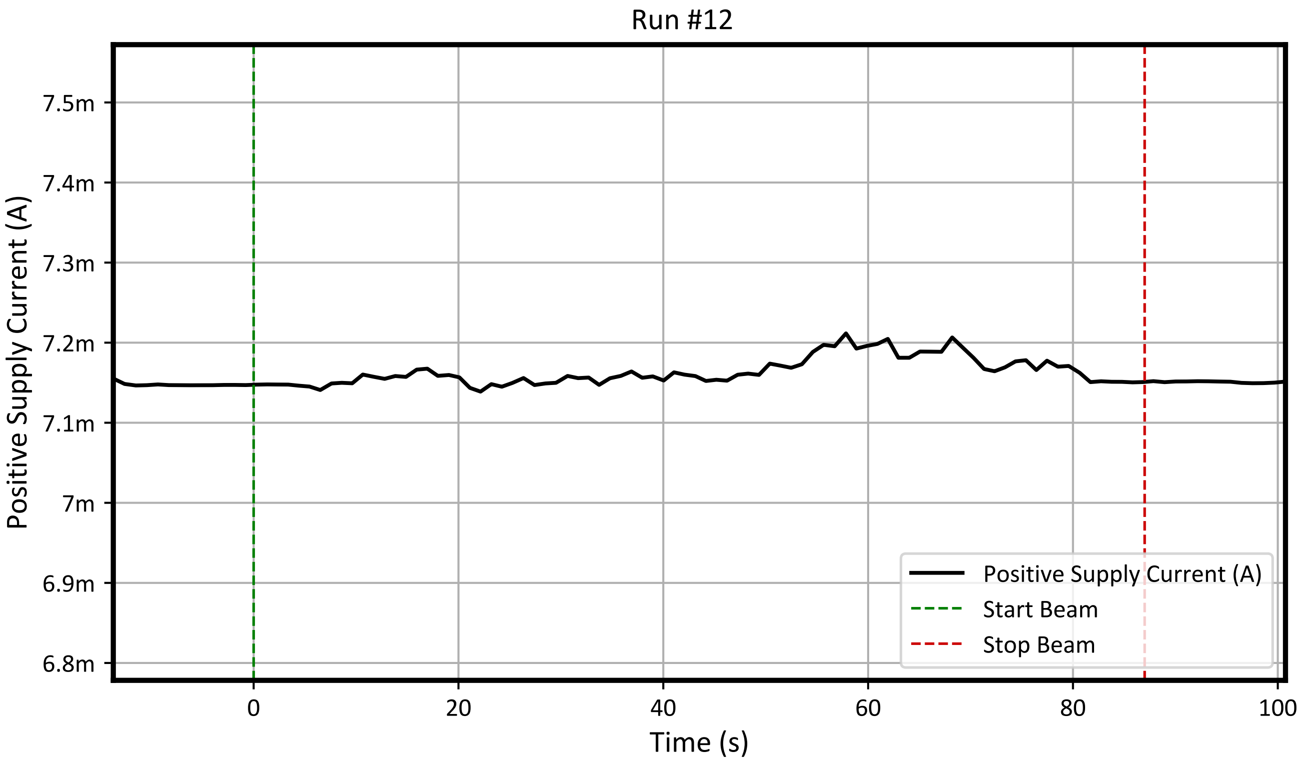

Figure 6-3. Run 12: Total Positive Supply Current versus Time

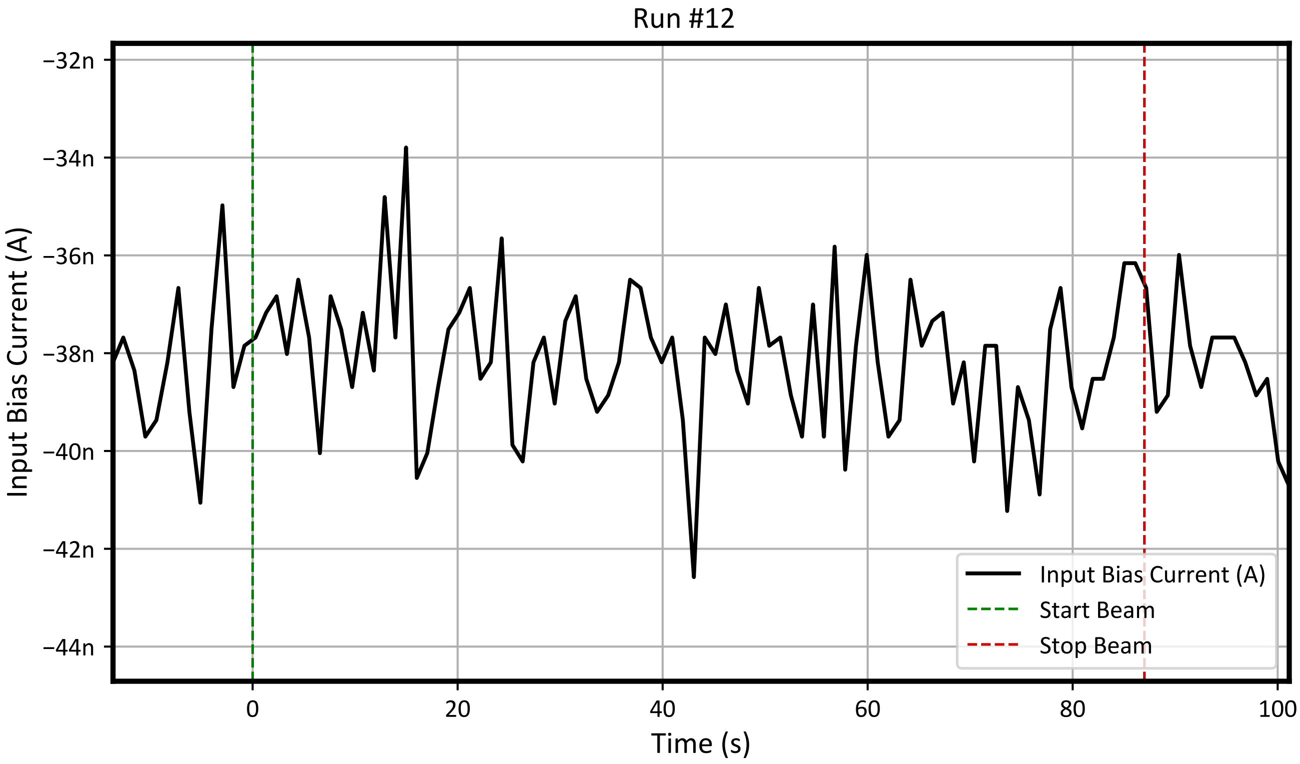

Figure 6-4. Run 12 Input Bias Current versus Time (All Channels)

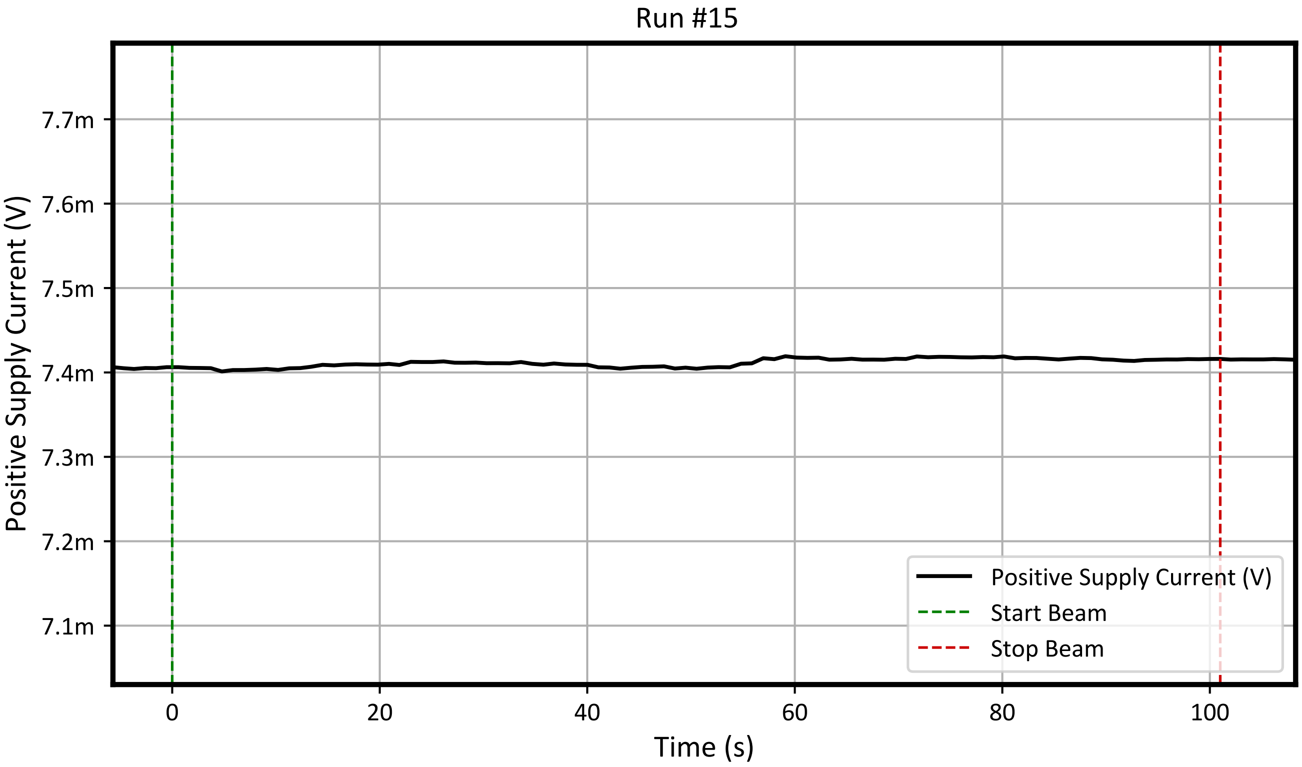

Figure 6-5. Run 15 Total Positive Supply Current versus Time

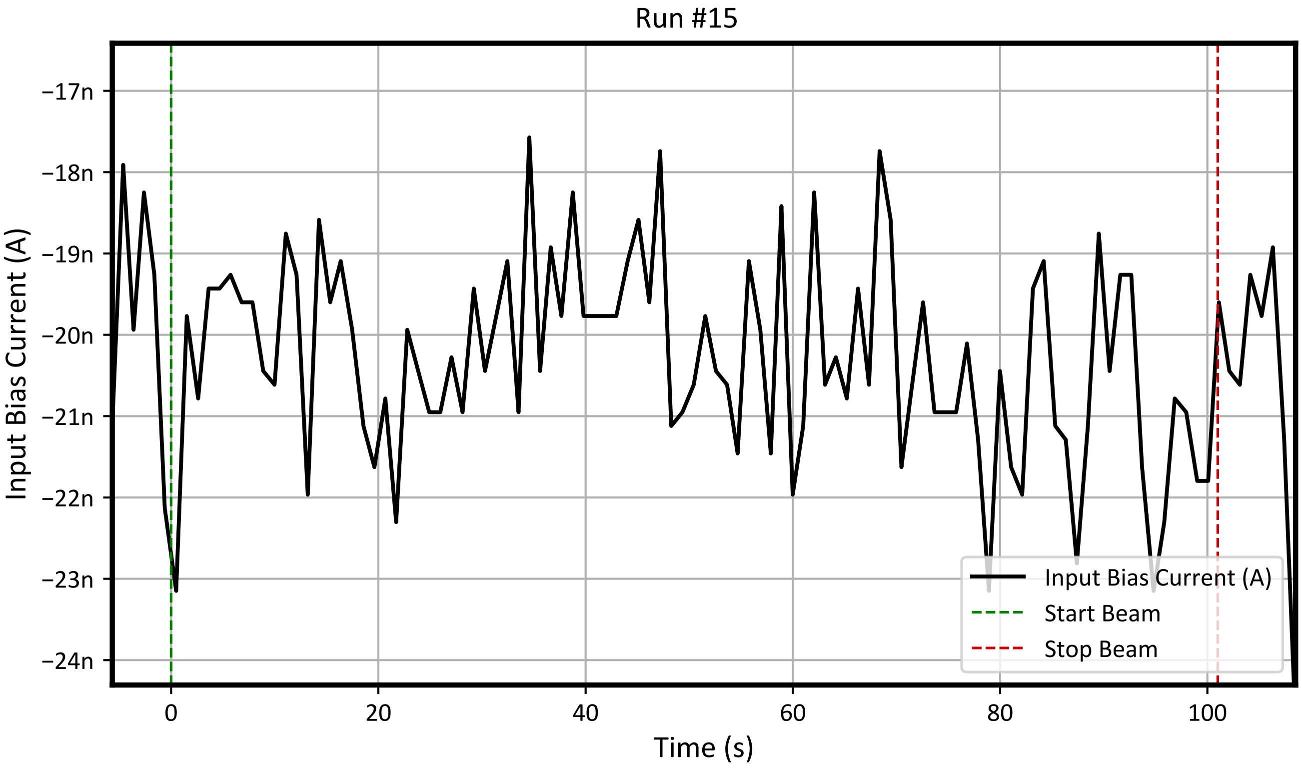

Figure 6-6. Run 15 Input Bias Current versus Time (All Channels)

7 Single-Event Transients (SET)

SET are defined as heavy-ion-induced transients upsets on the output of the OPA4H838-SEP.

Testing is performed at room temperature (no external temperature control applied). The heavy-ions species used for SET testing is Silver (^{109}Ag), Krypton (^{84}Kr), Copper (^{63}Cu), Argon (^{40}Ar), and Neon (^{20}Ne) and Nitrogen (^{14}N) for a LET_{EFF} of 48, 30, 20, 8.5, 2.7 and 1.34 MeV·cm^2/mg.

Flux of 10^5 ions×cm^2/s and a fluence of 10^7 ions/cm^2 per run are used for the SET characterization discussed in this chapter.

One unit is characterized from 47.5MeV down to 1.34MeV. A PXIe-5172 scope is used to monitor the four output channel signals of the OPA4H838-SEP triggering off a ±10% window. Table 7-1 summarizes the results for the unit tested. As the summary of results shows, the onset for the OPA4H838-SEP occurs at an LET_{EFF} above 1.34 MeV·cm^2/mg.

A plot of all overlayed transients for runs 3 and 10 are shown starting with Figure 7-1. Channels 1, 3 and 4 showed mostly consistent negative transients, while channel 2 showed a different behavior with both positive and negative transients. TI believes slight layout differences accounts for the difference.

The largest observed output transients are shown starting with Figure 7-17. Histograms of the observed transient deviation and width for run 3 are shown starting with Figure 7-9

Table 7-1. Summary of OPA4H838-SEP SET Test Condition and Results

Run	Supply Voltage (V)	Ion	LET_{EFF} (MeV-cm^2/mg)	Range (um)	Total Events (All Ch)	Effective Fluence (ions/cm^2)	Average Flux (ions/cm^2·s)
3	5.5	^{109}Ag	47.5	95.1	1620	9.975E+06	9.150E+04
5	3.3	^{109}Ag	47.5	95.1	519	1.000E+07	1.198E+05
7	2.5	^{109}Ag	47.5	95.1	632	9.950E+06	1.136E+05
8	2.5	^{84}Kr	30.1	114.6	670	9.995E+06	9.500E+04
9	3.3	^{84}Kr	30.1	114.6	525	1.000E+07	9.910E+04
10	5.5	^{84}Kr	30.1	114.6	449	9.970E+06	1.050E+05
11	5.5	^{63}Cu	19.9	121	399	1.002E+07	1.018E+05
12	3.3	^{63}Cu	19.9	121	425	1.000E+07	1.014E+05
14	2.5	^{63}Cu	19.9	121	574	1.01E+07	1.064E+05
15	2.5	^{40}Ar	8.53	177.7	310	1.000E+07	1.064E+05
17	3.3	^{40}Ar	8.53	177.7	218	1.002E+07	9.819E+04
18	5.5	^{40}Ar	8.53	177.7	196	1.002E+07	1.262E+05
19	5.5	^{20}Ne	2.76	258	6	1.000E+07	1.036E+05
20	3.3	^{20}Ne	2.76	258	5	9.990E+06	1.040E+05
21	2.5	^{20}Ne	2.76	258	10	1.002E+07	9.722E+04
22	2.5	^{14}N	1.34	368.4	0	9.973E+06	1.123E+05
23	3.3	^{14}N	1.34	368.4	0	9.980E+06	1.159E+05
24	5.5	^{14}N	1.34	368.4	0	1.003E+07	1.118E+05

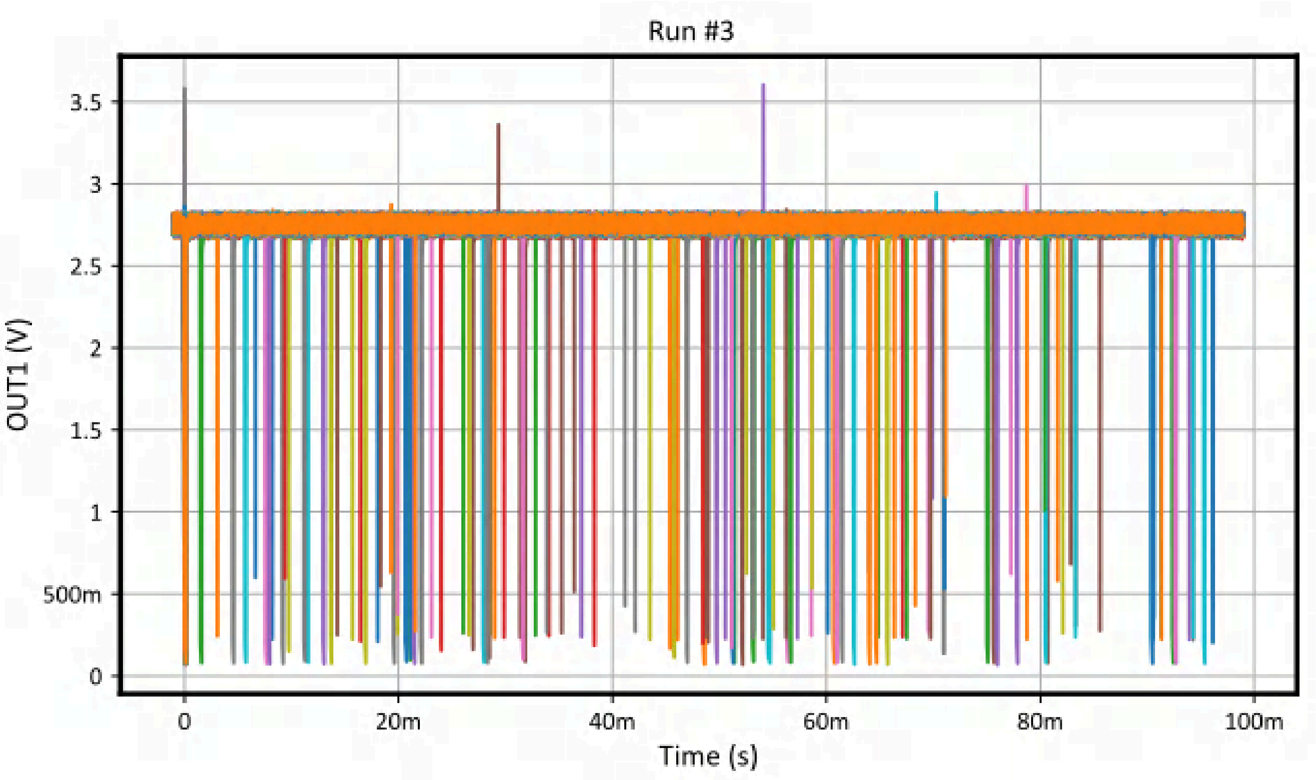

Figure 7-1. Run 3 (47.5MeV, 5.5V), Channel 1, All Transients

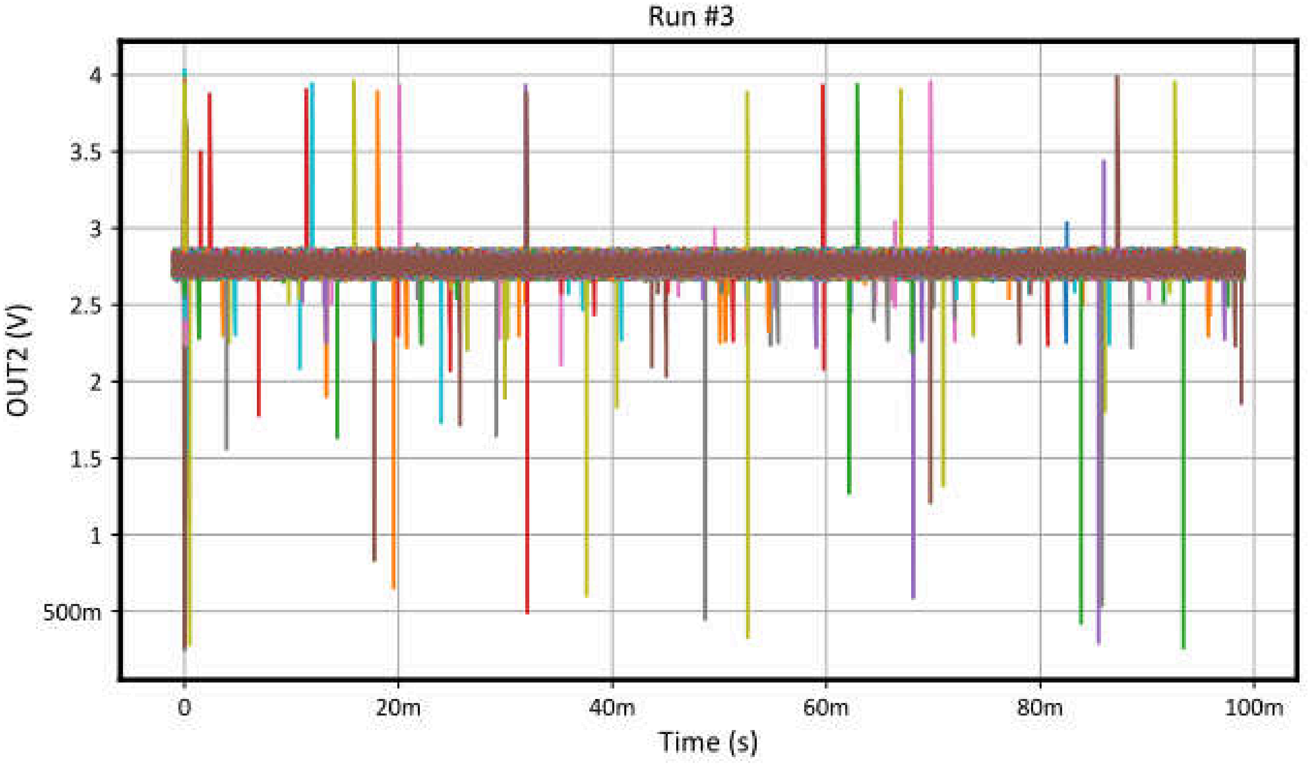

Figure 7-2. Run 3 (47.5MeV, 5.5V), Channel 2, All Transients

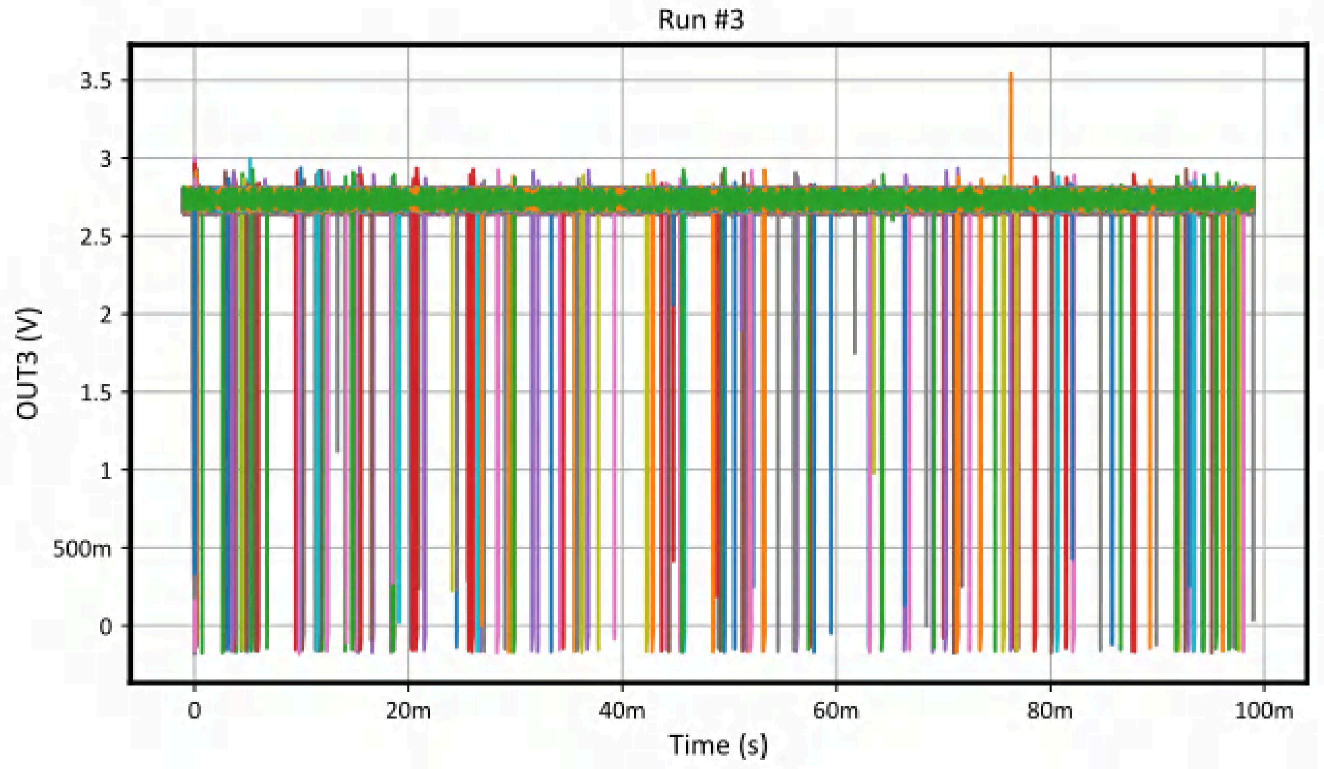

Figure 7-3. Run 3 (47.5MeV, 5.5V), Channel 3, All Transients

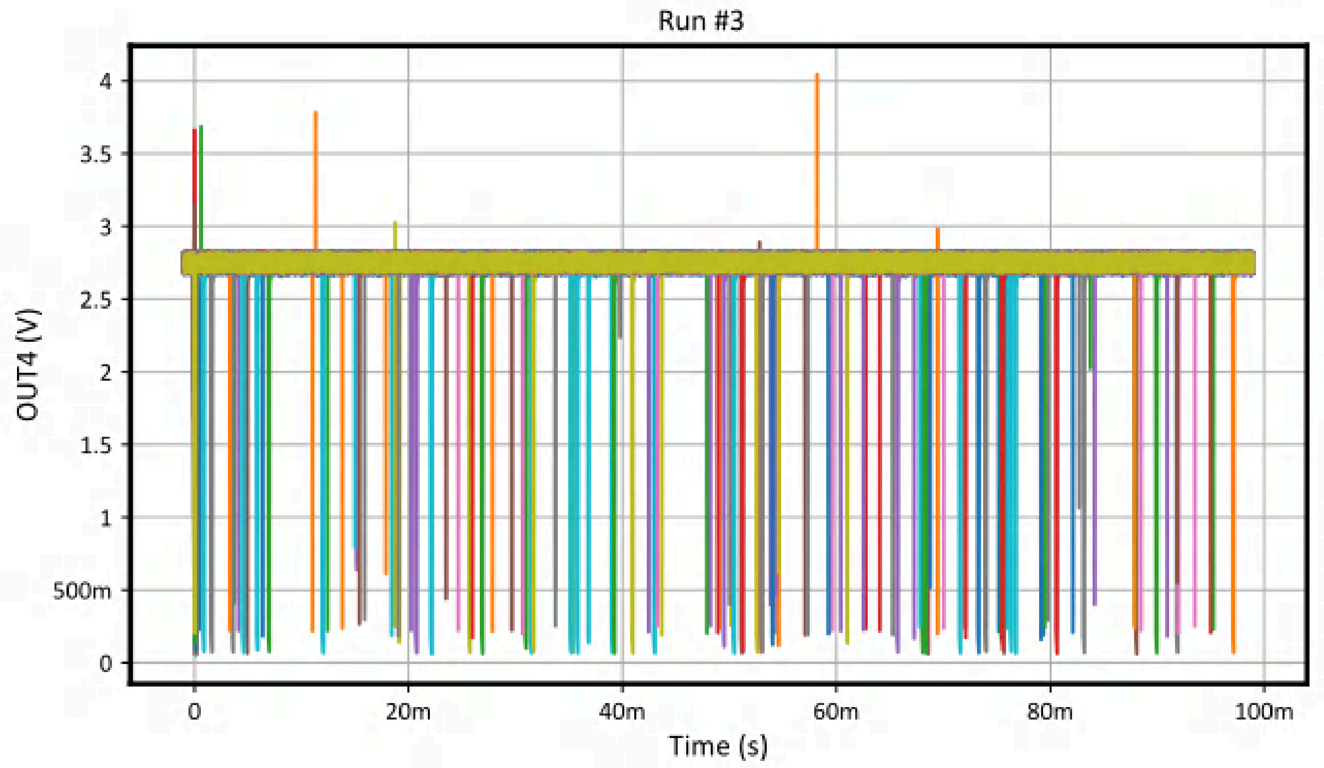

Figure 7-4. Run 3 (47.5MeV, 5.5V), Channel 4, All Transients

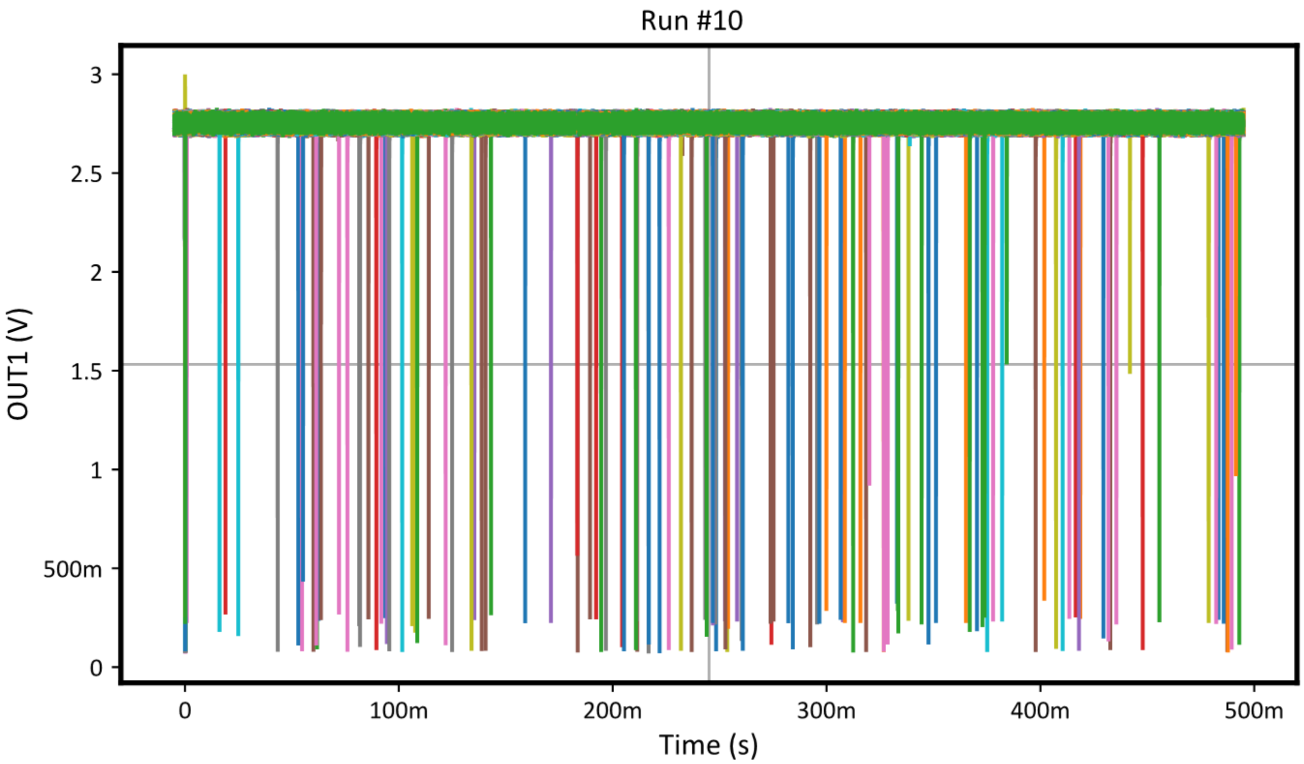

Figure 7-5. Run 10 (30.1MeV, 5.5V), Channel 1, All Transients

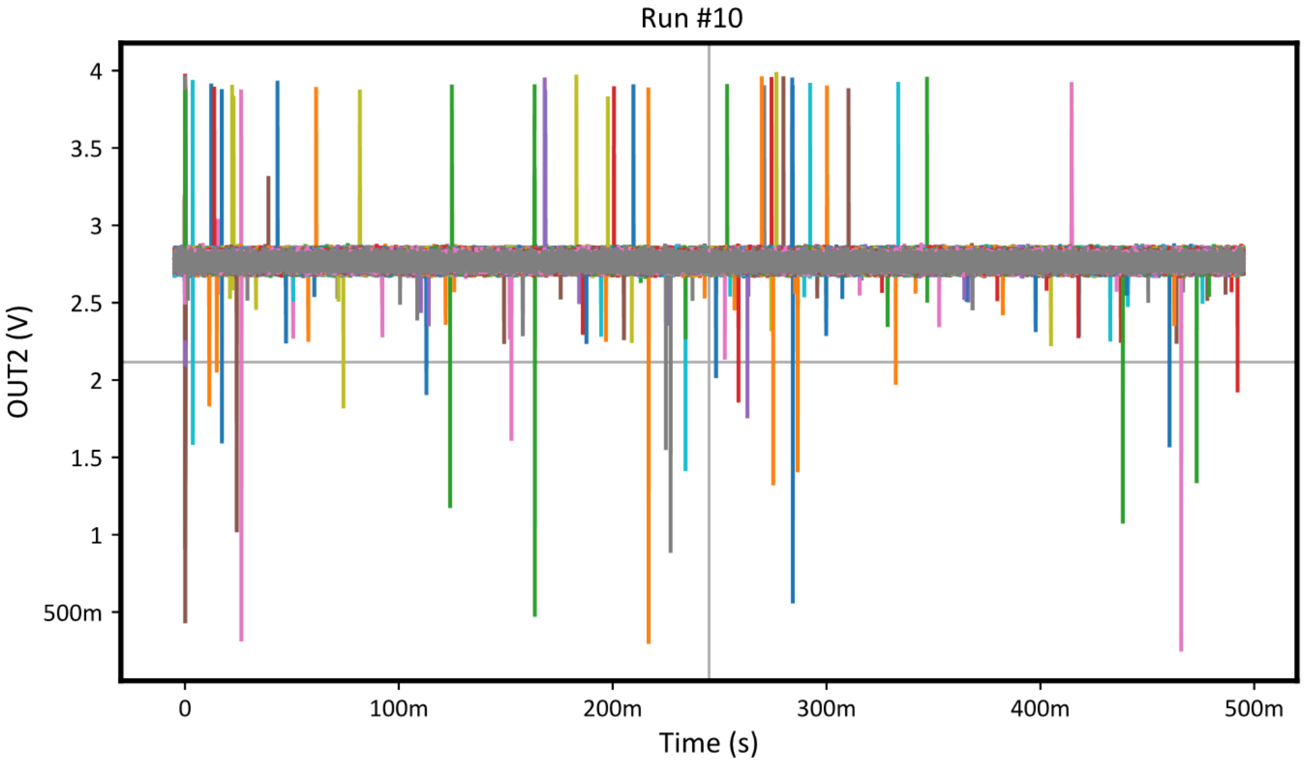

Figure 7-6. Run 10 (30.1MeV, 5.5V), Channel 2, All Transients

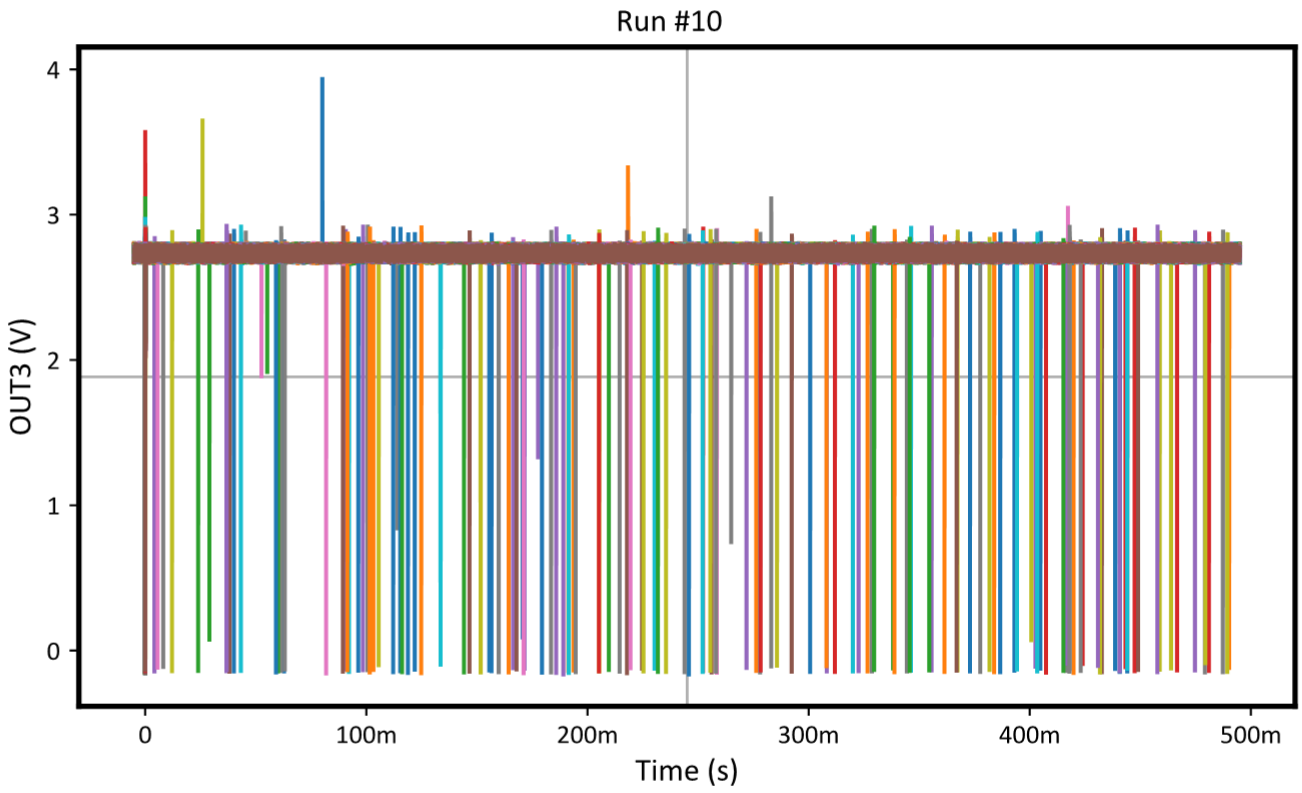

Figure 7-7. Run 10 (30.1MeV, 5.5V), Channel 3, All Transients

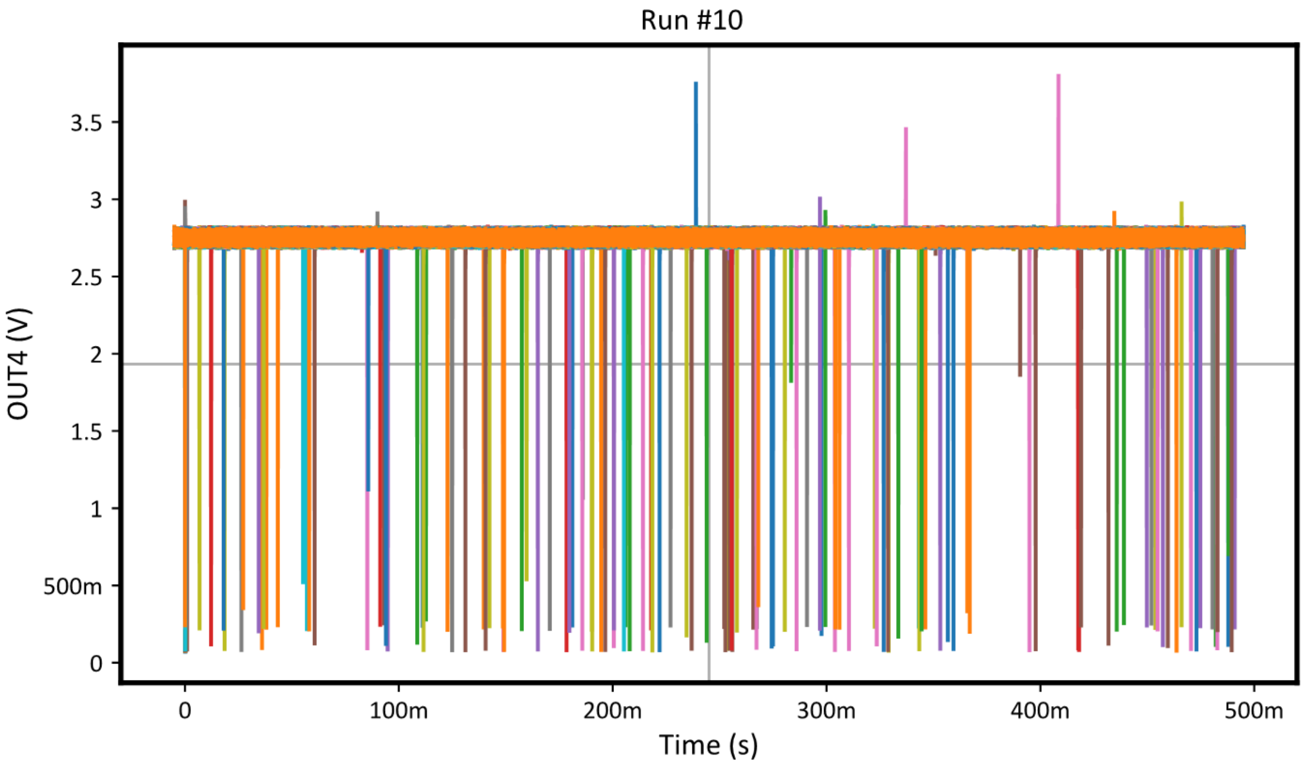

Figure 7-8. Run 10 (30.1MeV, 5.5V), Channel 4, All Transients

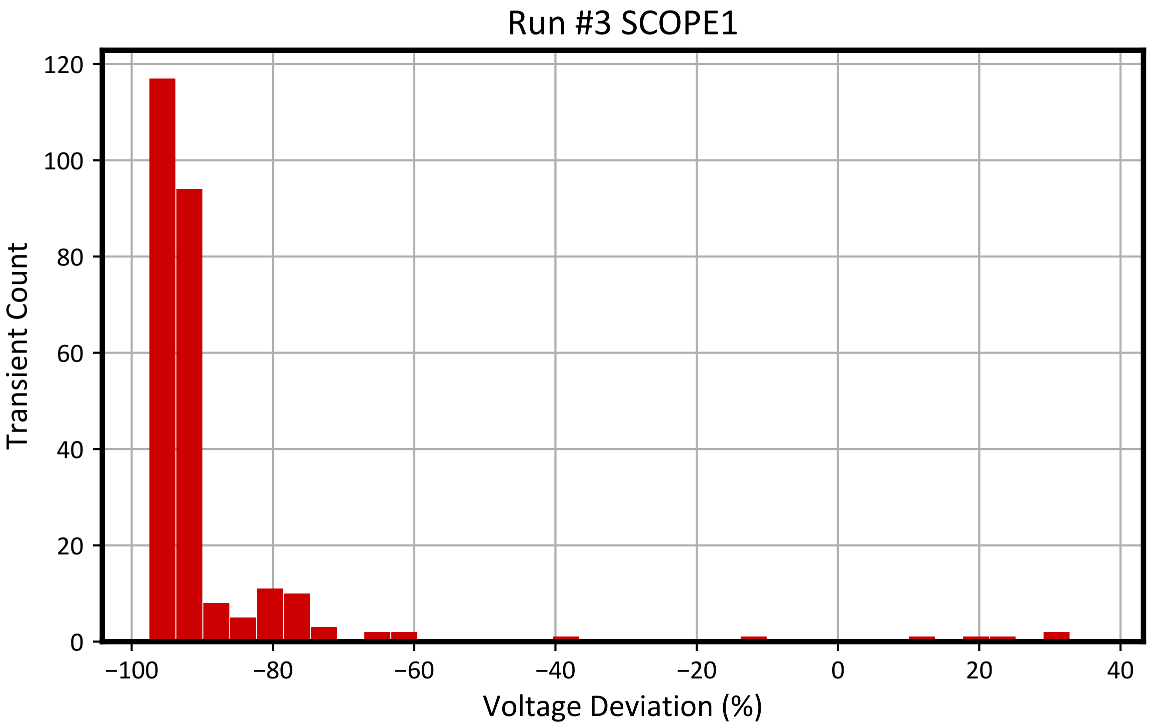

Figure 7-9. Run 3 (47.5MeV, 5.5V), Channel 1, Voltage Deviation Histogram

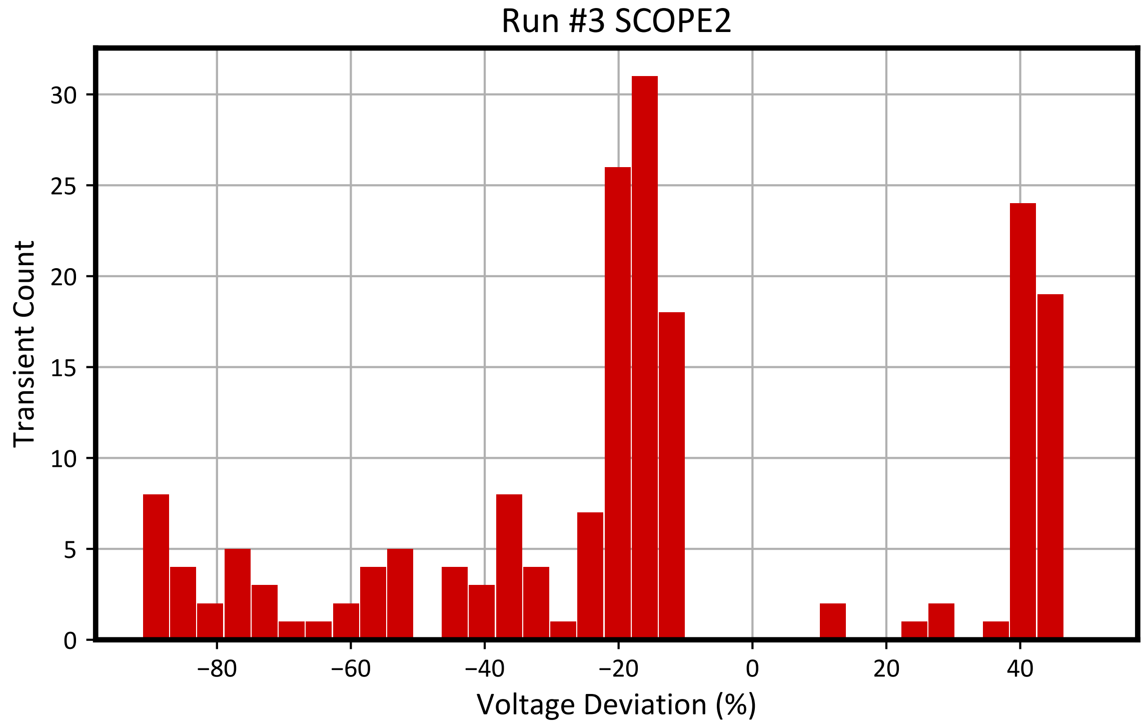

Figure 7-10. Run 3 (47.5MeV, 5.5V), Channel 2, Voltage Deviation Histogram

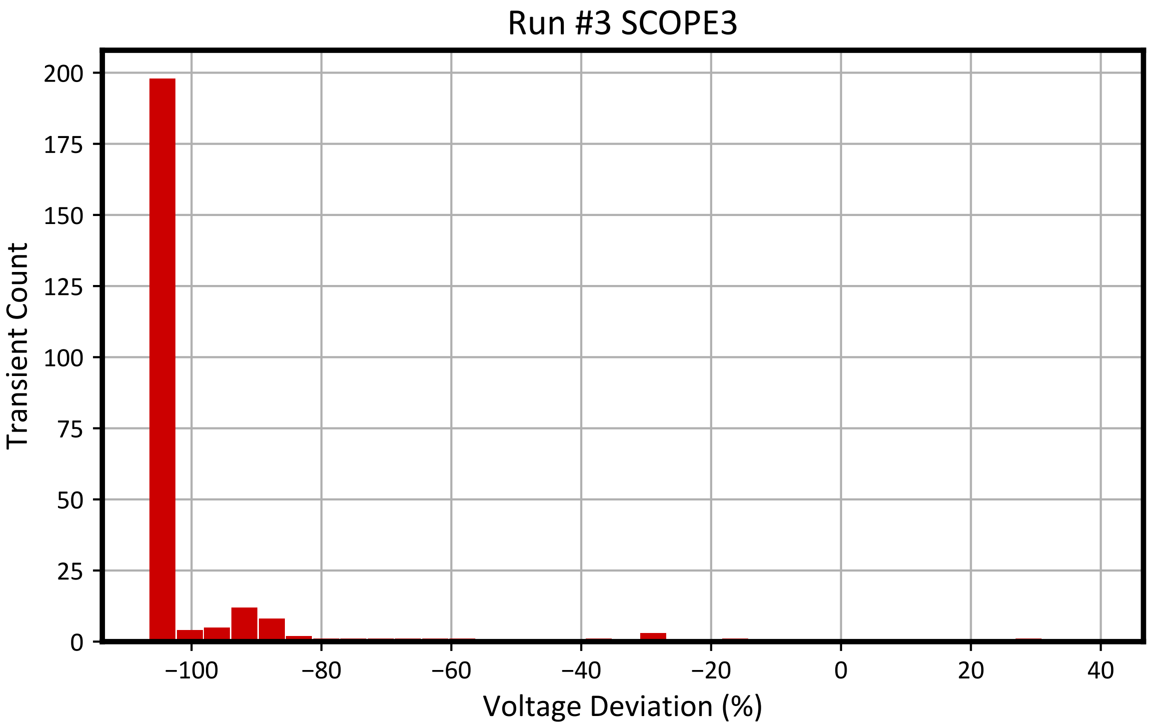

Figure 7-11. Run 3 (47.5MeV, 5.5V), Channel 3, Voltage Deviation Histogram

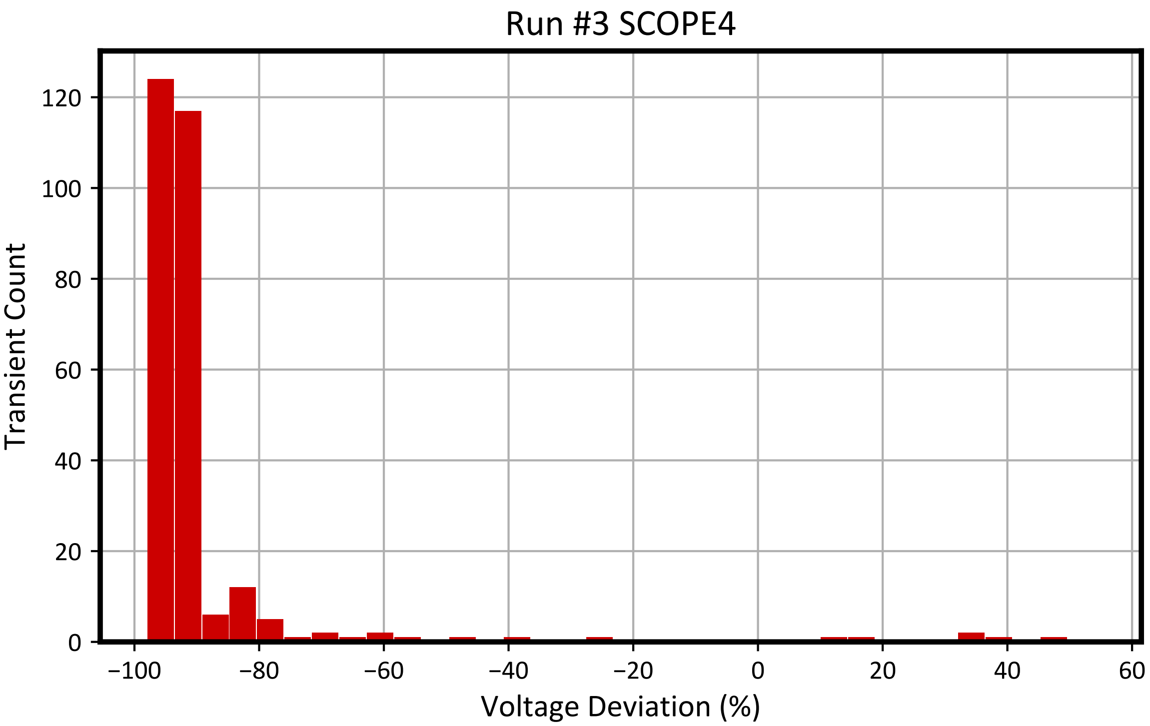

Figure 7-12. Run 3 (47.5MeV, 5.5V), Channel 4, Voltage Deviation Histogram

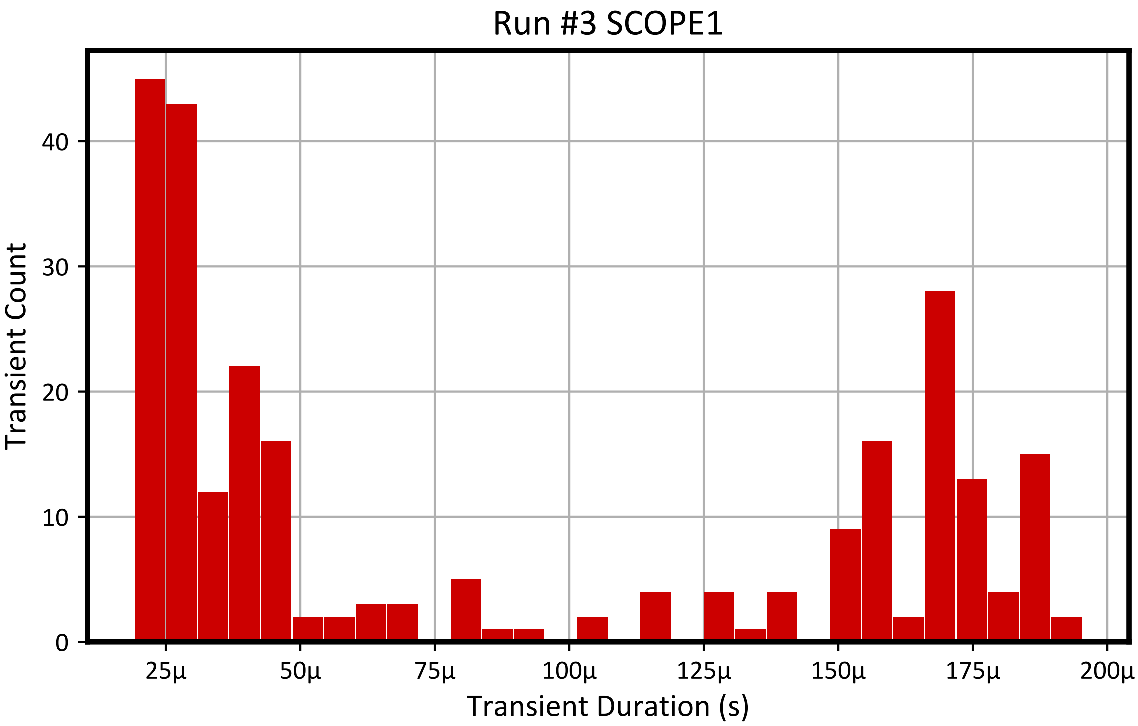

Figure 7-13. Run 3 (47.5MeV, 5.5V), Channel 1, Transient Duration Histogram

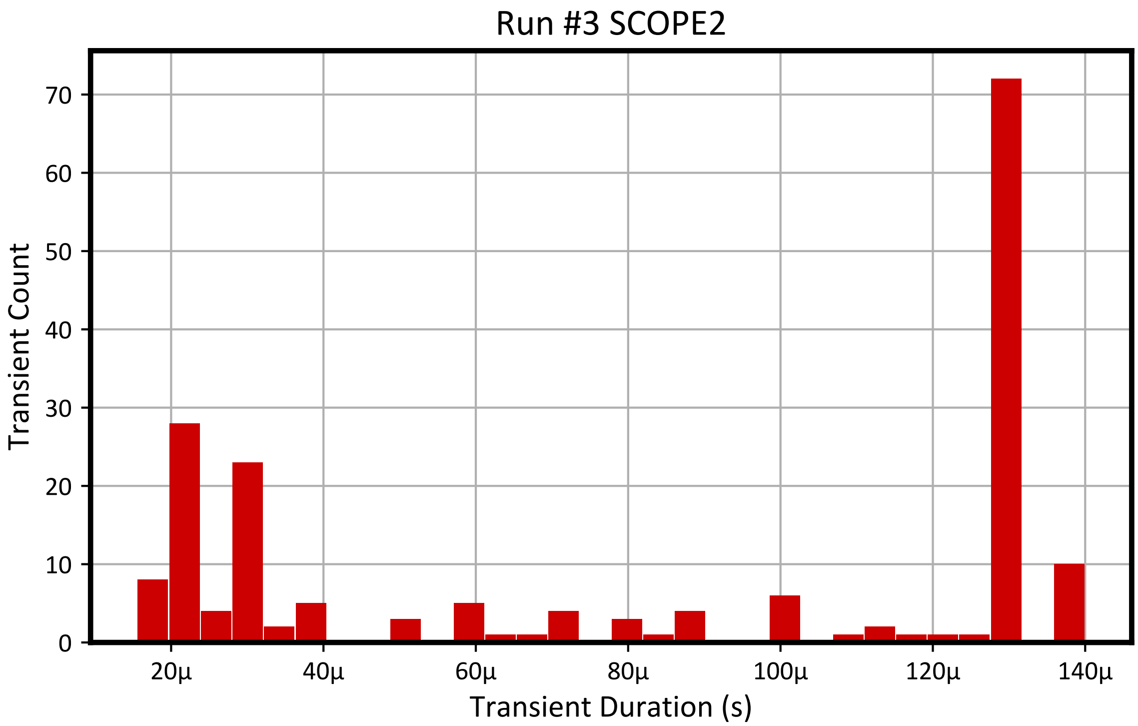

Figure 7-14. Run 3 (47.5MeV, 5.5V), Channel 2, Transient Duration Histogram

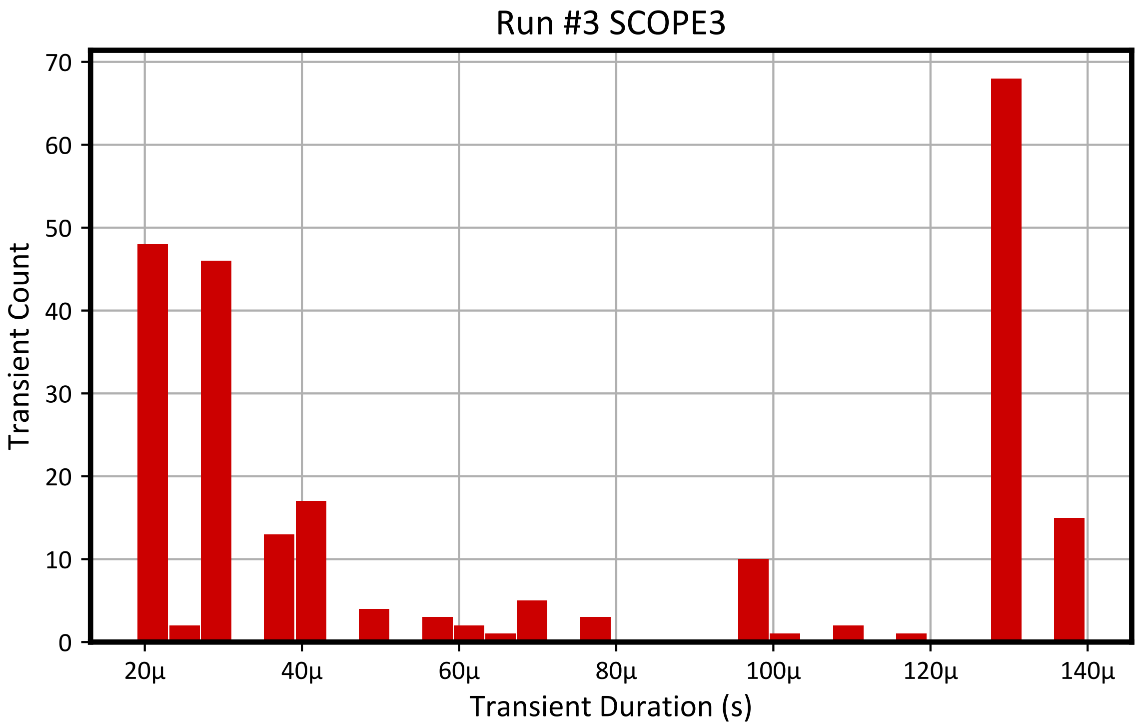

Figure 7-15. Run 3 (47.5MeV, 5.5V), Channel 3, Transient Duration Histogram

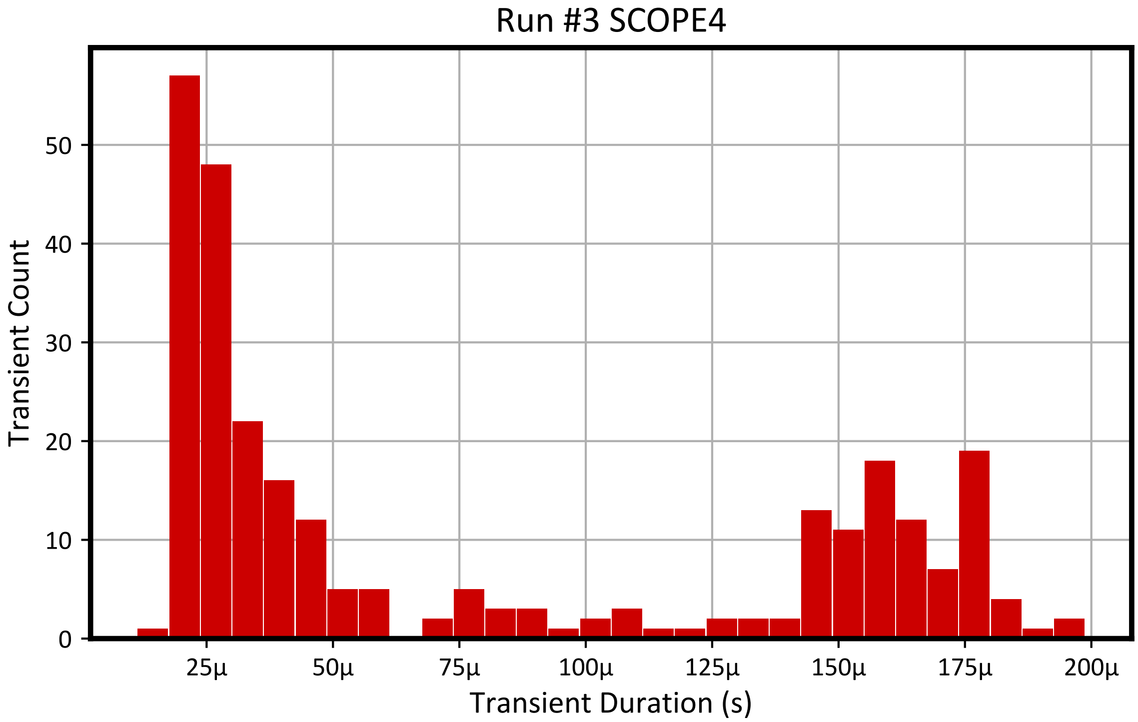

Figure 7-16. Run 3 (47.5MeV, 5.5V), Channel 4, Transient Duration Histogram

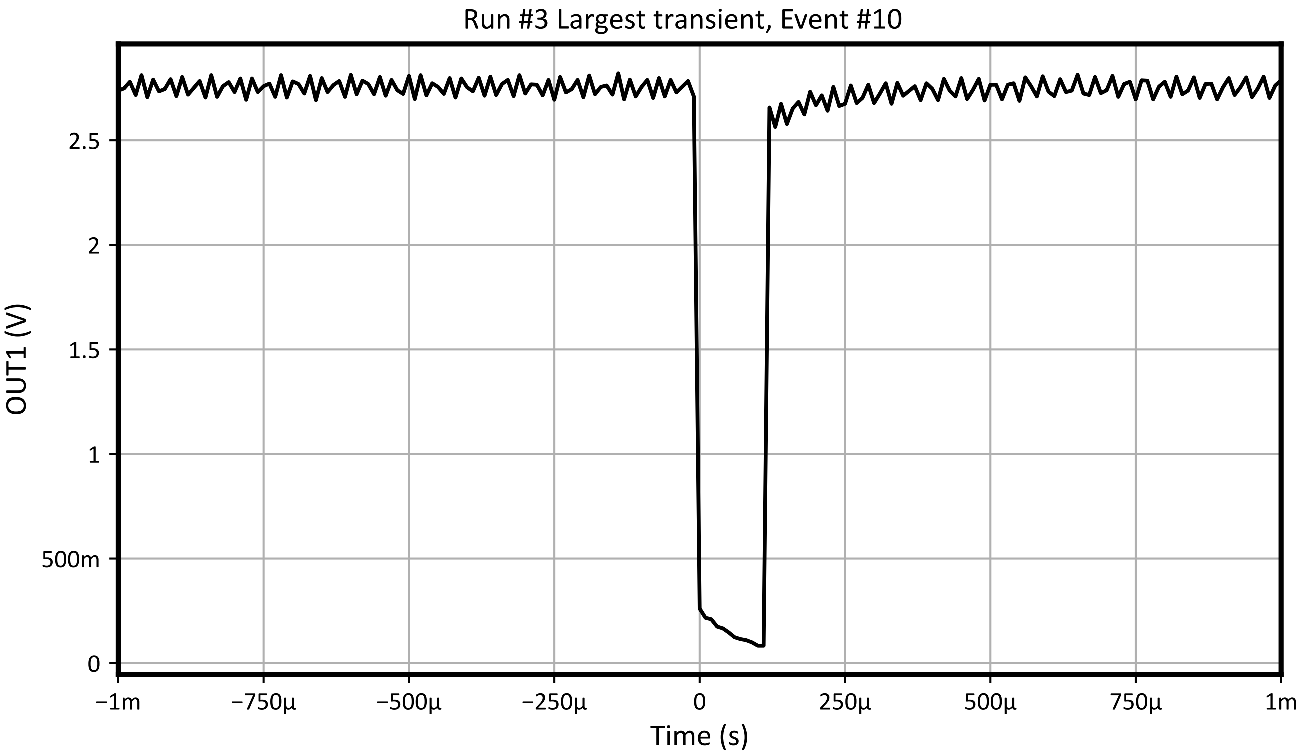

Figure 7-17. Run 3 (47.5MeV, 5.5V), Channel 1, Large Transient Example

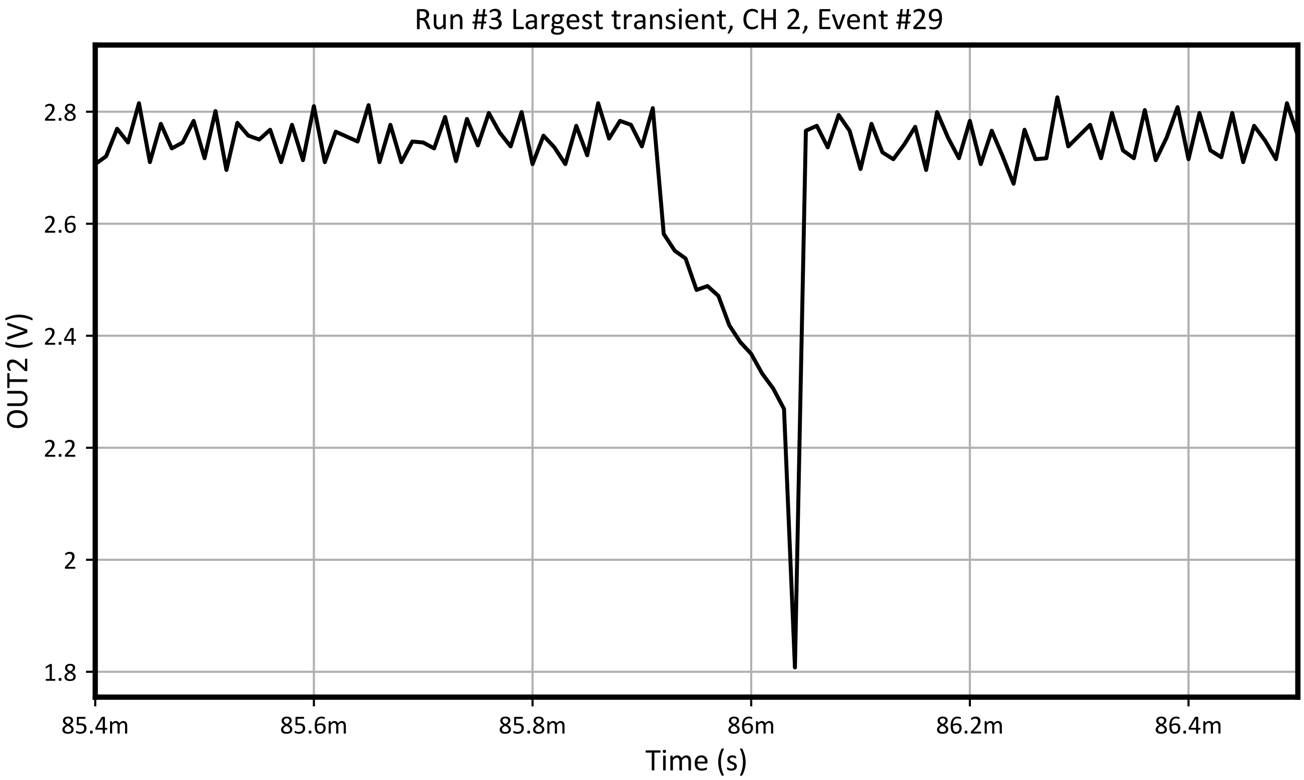

Figure 7-18. Run 3 (47.5MeV, 5.5V), Channel 2, Large Transient Example

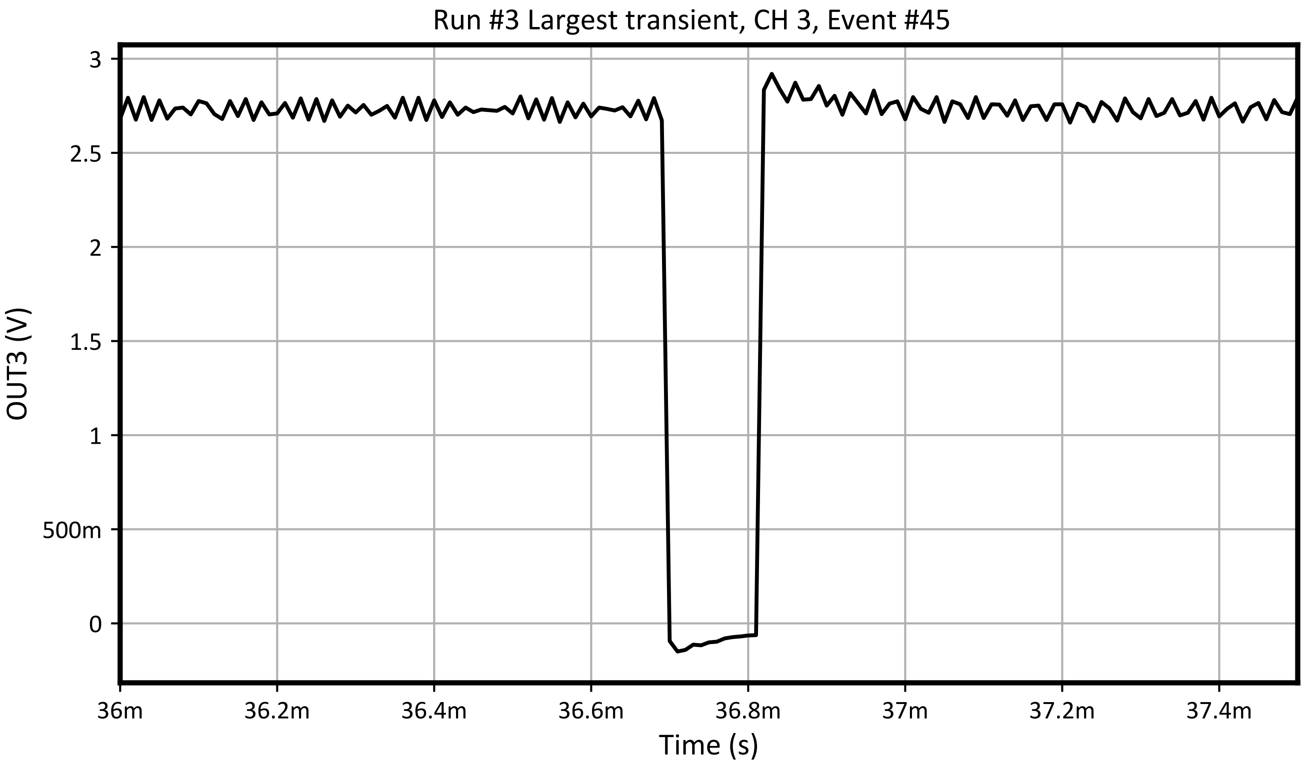

Figure 7-19. Run 3 (47.5MeV, 5.5V), Channel 3, Large Transient Example

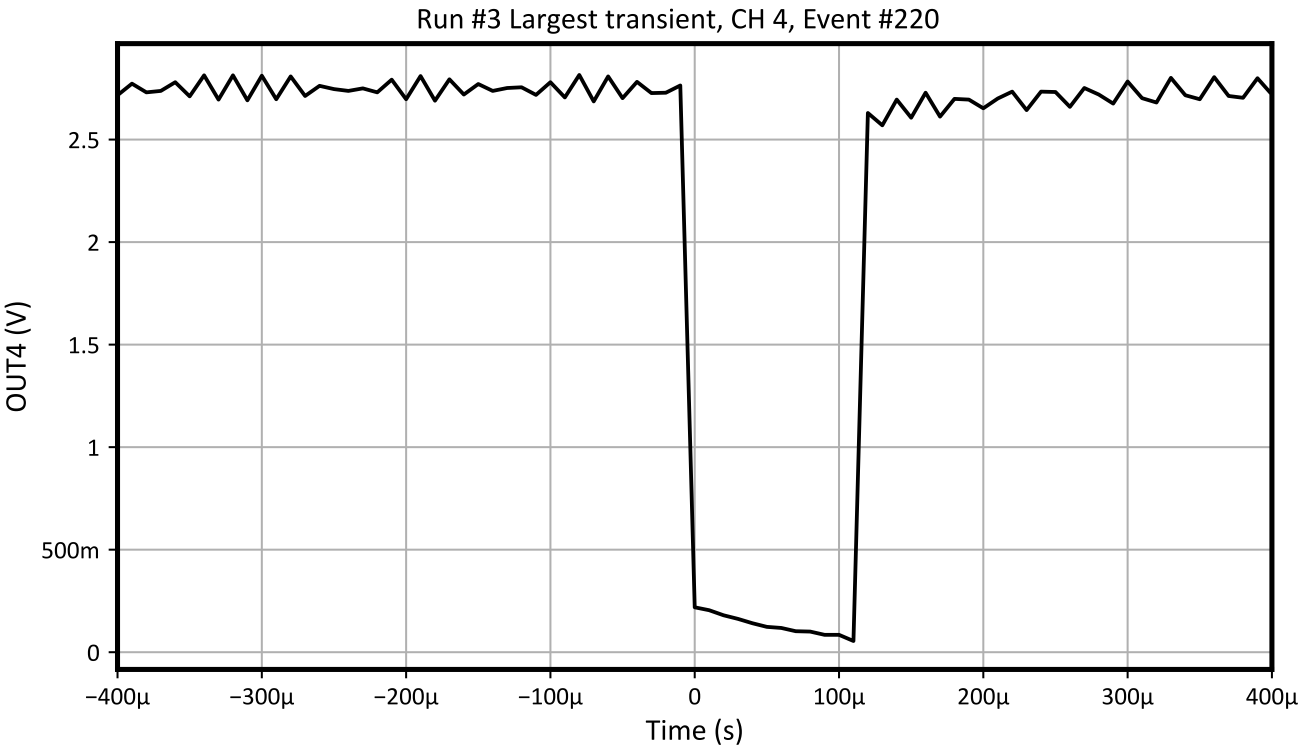

Figure 7-20. Run 3 (47.5MeV, 5.5V), Channel 4, Large Transient Example

Table 7-2. SEL Cross Section

Supply Voltage (V)	LET_{EFF} (MeV-cm^2/mg)	Events (All Channels)	Effective Fluence (ions/cm^2)	UB Cross-section
5.5	45.6	0	1.0E+07	3.69E-07

Table 7-3. SET Cross Section

Supply Voltage (V)	LET_{EFF} (MeV-cm^2/mg)	Events (All Channels)	Effective Fluence (ions/cm^2)	UB Cross-section
5.5	47.5	1620	1.0E+07	1.701E-04
	30.1	449	1.0E+07	4.925E-05
	19.9	399	1.0E+07	4.401E-05
	8.53	196	1.0E+07	2.254E-05
	2.76	6	1.0E+07	1.306E-06
	1.34	0	1.0E+07	3.689E-07
3.3	47.5	519	1.0E+07	5.656E-05
	30.1	525	1.0E+07	5.719E-05
	19.9	425	1.0E+07	4.674E-05
	8.53	218	1.0E+07	2.489E-05
	2.76	5	1.0E+07	1.167E-06
	1.34	0	1.0E+07	3.689E-07
2.5	47.5	632	1.0E+07	6.833E-05
	30.1	670	1.0E+07	7.227E-05
	19.9	574	1.0E+07	6.229E-05
	8.53	310	1.0E+07	3.465E-05
	2.76	10	1.0E+07	1.839E-06
	1.34	0	1.0E+07	3.689E-07

Table 7-4. Weibull Parameters

Parameters	2.5V	3.3V	5.5V
Cross-saturation (cm^2)	6.72E-05	5.26E-05	9.34E-04
Onset (MeV-cm^2/mg)	1.67	1.68	1.34
w	9.45	10.53	99.99
s	0.94	1.05	2.17

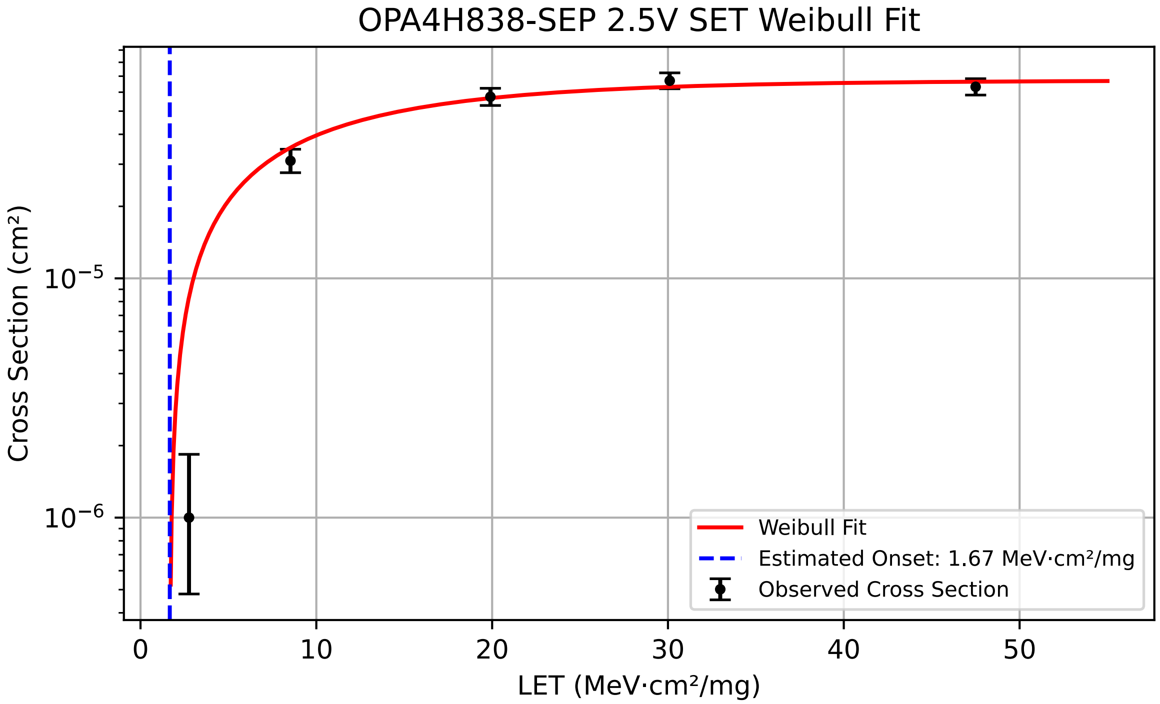

Figure 7-21. Weibull Fit for 2.5V Supply Voltage (All Channels)

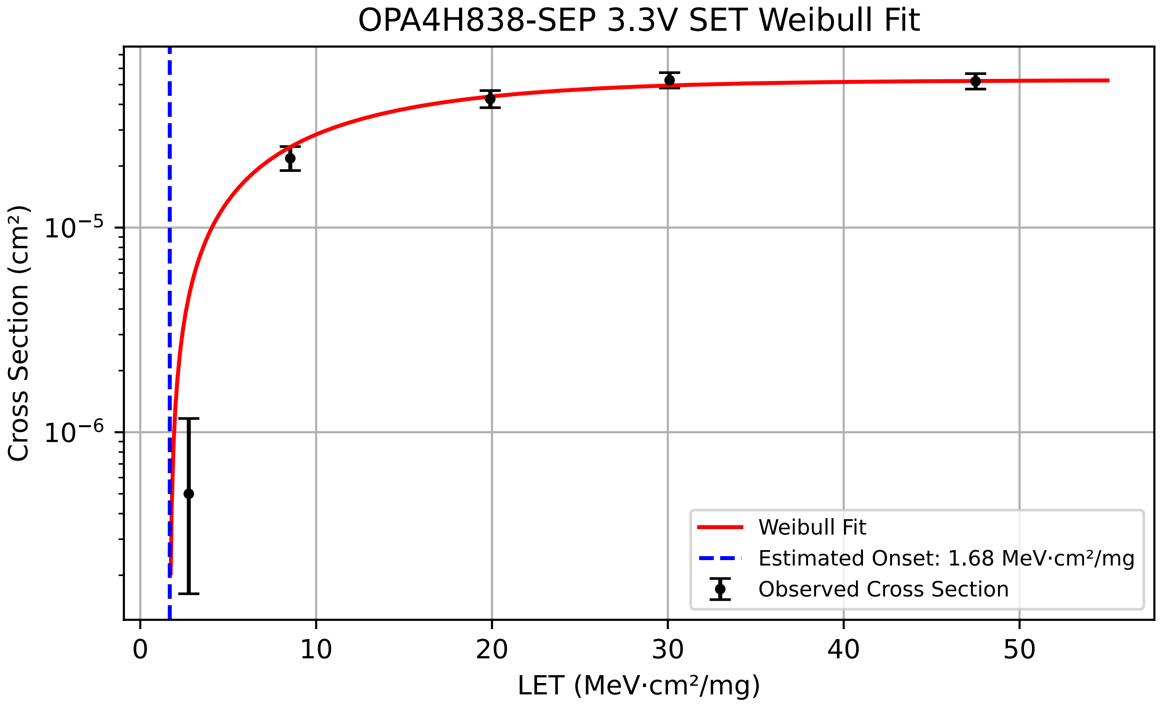

Figure 7-22. Weibull Fit for 3.3V Supply Voltage (All Channels)

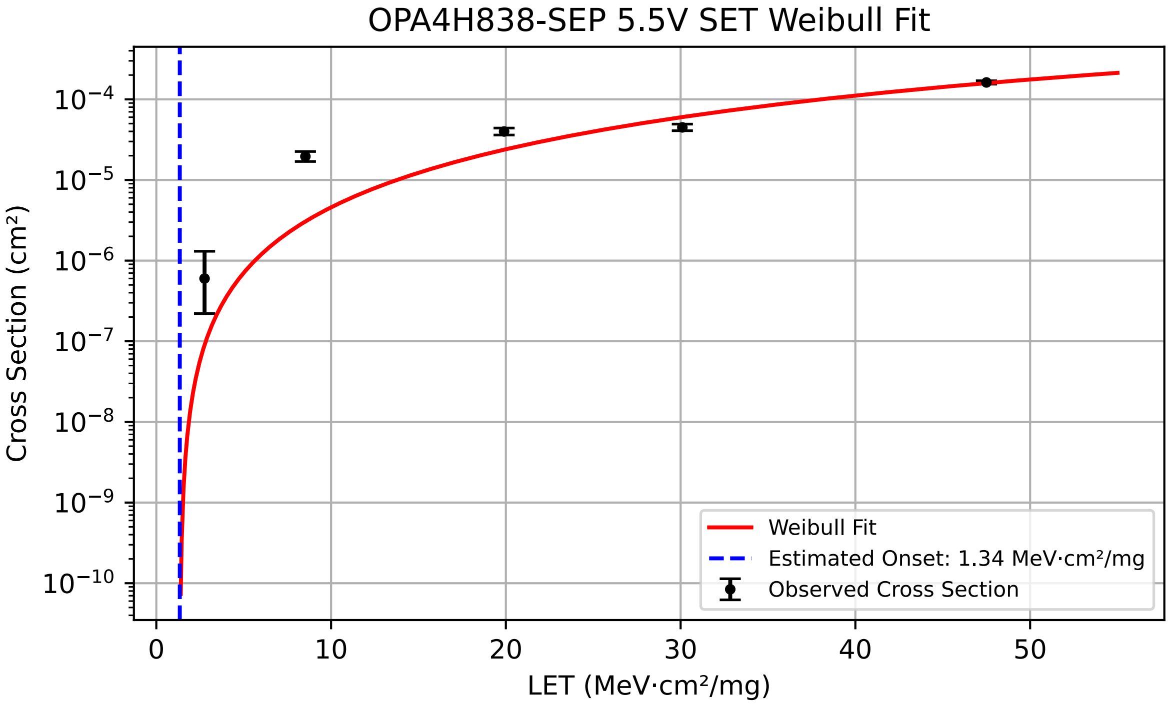

Figure 7-23. Weibull Fit for 5.5V Supply Voltage (All Channels)

8 Summary

The purpose of this study is to characterize the effect of heavy-ion irradiation on the single-event effect (SEE) performance of the OPA4H838-SEP ultra-low noise, fast-settling, zero-drift, zero-crossover Operational Amplifier. Heavy-ions with LET_{EFF} = 1.34 to 48 MeV×cm^2/mg are used for the SEE characterization campaign. Flux of 10^5 ions/cm^2 ·s and a fluence of 10^7 ions/cm^2 per run are for the characterization. The SEE results demonstrated that the OPA4H838-SEP is free of destructive SEL at LET_{EFF} = 45.6 MeV×cm^2/mg across the full electrical specifications. Transients at LET_{EFF} = 1.34 to 47.5 MeV×cm^2 /mg on V_{OUT} are presented and discussed.

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