Heavy-Ion Test Results of the Dual Rail-to-Rail Input and Output Precision C-Load Op Amp RH1498MW

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Executive Summary

This report details the heavy-ion test experiments performed on the RH1498MW at the Lawrence Berkeley National Labs (LBNL). The RH1498 is a dual, rail-to-rail input and output precision C-Load™ op amp with a 10MHz gain-bandwidth product and a 6V/µs slew rate. The wafer lots are processed to Linear Technology's in house Class S flow to yield circuits usable in stringent military and space applications. Heavy-ions induced SEE (Single Event Effect) experiments included Single Event Transient (SET), Single Event Upset (SEU) and Single Event Latchup (SEL) tests up to an LET of 117.5 MeV.cm^2/mg at elevated temperatures (to case temperatures of 100°C). Under heavy-ion irradiations, with various power supply and input biases, as well as load conditions at the op-amp outputs, the RH1498M showed sensitivities only to SETs. Beam tests confirmed the immunity of this part to SEL and SEU in all test conditions. The measured SET sensitive cross-section is about 8% of the total die's area, while the threshold LET was about 3 MeV.cm^2/mg.

The beam data correlated well with previous SET data published for this part [4]. The SET pulse widths were short in time (90% of them are shorter than 2us), and their amplitudes varied from +/-0.65V to +/-6V (90% of them are smaller than +/-3V and about 1% of them are higher than +/-5V), at LET of 58.78 MeV.cm^2/mg. Since these events were short in their pulse-widths (smaller than 1us for the high amplitude ones) and if well designed for, this circuit can be used as is, as the widest measured SET-PW is less than the typical op-amp's response time (6V/us). However, for accurate selection of the circuit peripheral parasitic, we would recommend that the designer simulates his design by injecting SETs at the circuit's inputs/outputs, as wide as the observed SETs in this report, as well as varying the bias during these injections. This could be accomplished by the LTSpice tool offered by Linear Technology, as most of the Linear LT parts spice models are offered [5]. That should provide guidance to the designer but the result should be correlated with laser and beam tests as most of the RH and LT parts differ in their process and sometimes in their design as well. The wrong selection of these parasitic can make things worse and widen the SET from nanoseconds to microseconds, making it harder on the following circuit to not propagate them.

1. Overview

This report details the heavy-ion test experiments performed on the RH1498MW at the Lawrence Berkeley National Labs (LBNL). The RH1498 is a dual, rail-to-rail input and output precision C-Load™ op amp with a 10MHz gain-bandwidth product and a 6V/µs slew rate. The RH1498 is designed to maximize input dynamic range by delivering precision performance over the full supply voltage. Using a patented technique, the input stages of the RH1498 are trimmed, one at the negative supply and the other at the positive supply. The resulting guaranteed common mode rejection is much better than other rail-to-rail input op amps. When used as a unity-gain buffer in front of single supply 12-bit A-to-D converters, the RH1498 is guaranteed to add less than 1LSB of error even in single 5V supply systems. With 110dB of supply rejection, the RH1498 maintains its performance over a supply range of 4.5V to 36V. The inputs can be driven beyond the supplies without damage or phase reversal of the output. These op amps remain stable while driving capacitive loads up to 10,000pF. The wafer lots are processed to Linear Technology's in house Class S flow to yield circuits usable in stringent military and space applications.

The device is qualified and available in 10-Lead flatpack (W10) hermetically sealed package. More details are given about this op-amp in [1, 2 and 3]. This is a 7um technology using exclusively bipolar transistors. The part's block diagram is shown in Fig. 1. The W package designation is given in Fig. 2.

Absolute Maximum Ratings (Note 1)

Total Supply Voltage (V + to V–)	36V
Input Current	10mA
Output Short-Circuit Duration (Note 2)	Continuous
Operating Temperature Range	– 55°C to 125°C
Specified Temperature Range	–55°C to 125°C
Junction Temperature	150°C
Storage Temperature Range	–65°C to 150°C
Lead Temperature (Soldering, 10 sec)	300°C

Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

Note 2: A heat sink may be required to keep the junction temperature below this absolute maximum rating when the output is shorted indefinitely.

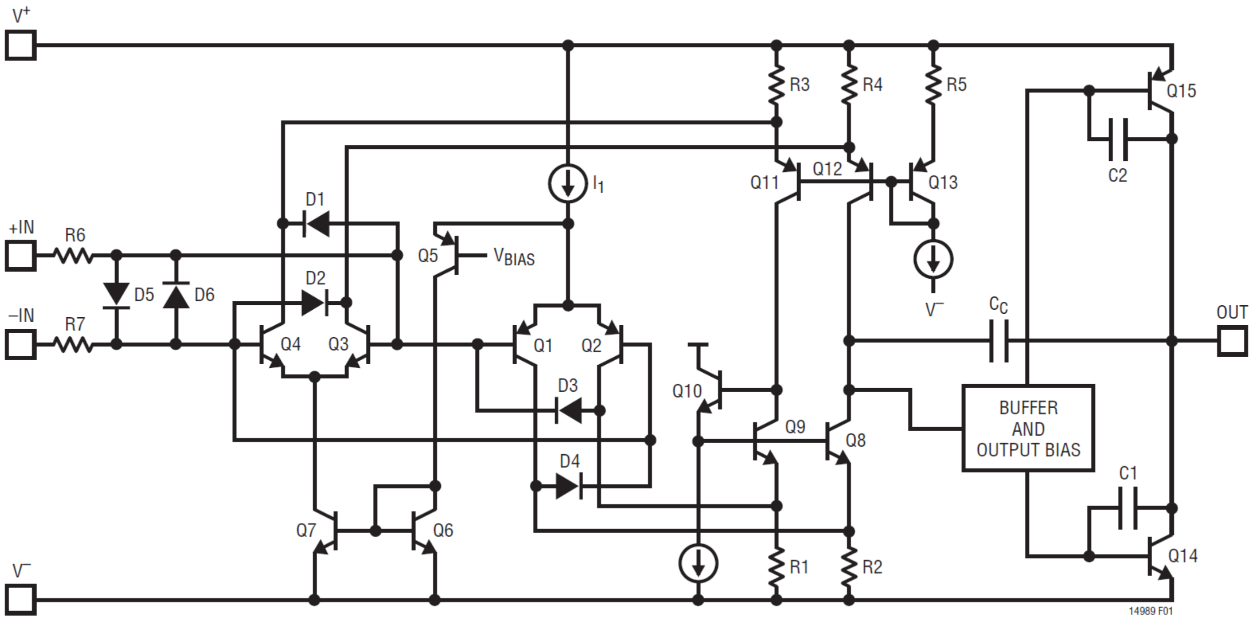


Fig. 1: Block Diagram of the RH1498M DIE

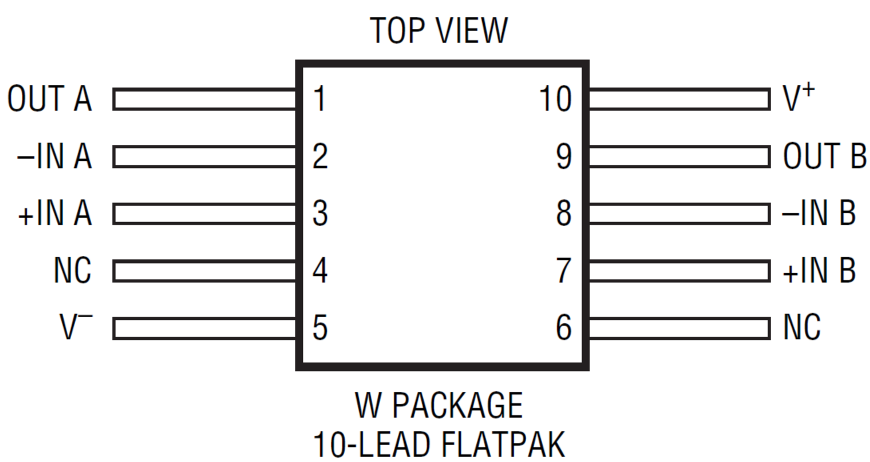


Fig. 2: RH1498M in W Package

Table 1 summarizes the parts’ features and the electrical test equipment.

Table 1: Test and Part's Information

Generic Part Number	RH1498MW
Package Marking	RH1498 Date Code
Manufacturer	Linear Technology
Quantity tested	2
Dice Dimension	2.972 X 2.083 $mil^2 \approx 6.19\ mm^2$
Part Function	Dual, rail-to-rail input and output precision C-Load™ op amp
Part Technology	CBIP700 (7um)
Package Style	Hermetically sealed flat-10
Test Equipment	Power supply, digital oscilloscope, multimeter, and computer
Temperature and Tests	SET, SEU and SEL @ Room Temp. and 100°C

2. Test Setup

Custom SEE boards were built for heavy-ion tests by the Linear Technology team, and discussion with The Aerospace Corporation, Boeing Corporation, and Orbital engineers. The RH1498MW parts were tested at LBNL on Dec. 2012 at two different temperatures (at room temperature as well as at 100°C). During the beam runs, we were monitoring the temperature of the adjacent sense transistor (2N3904) to the DUT but not the die temperature (junction temperature). Hence the test engineer needs to account for additional temperature difference between the dice and the sense transistor, which was not measured in vacuum. In-air, both of the case and the sense transistor temperatures were measured to be the same. The temperature difference between the junction of the die and the case is a function of the DUT power dissipation multiplied by the thermal resistance $R_{theta\text{-}JC}(\Theta_{JC})$. With no heating, the temperature of the adjacent temperature sense transistor (2N3904) to the DUT (or the DUT case) was measured on average at about 25°C. The junction temperature was not measured in vacuum; its calculation is provided in Eq.1. This value was correlated in-air with a thermocouple.

$$T_J = T_C + P_D * \Theta_{JC} \qquad (1)$$

Where: T_J is the junction temperature, T_C the case temperature, P_D the power dissipated in the die and Θ_{JC} the thermal resistance between the die and the case. Note: A relatively small amount of power is dissipated in other components on the board. That is not considered in this calculation.

The calculation of the dissipated power in the die is provided in Eq. 2:

$$P_D = Pin - Pout = |V_+ * I_+| + |V_- * I_-| - Pout \qquad (2)$$

Where:
1. V+ is the positive voltage supply
2. V- is the negative voltage supply
3. I+ is the positive current supply
4. I- is the negative current supply
5. Pin: Input Power Dissipation
6. Pout: Output Power Dissipation

Assuming that Pout =0 and in the case where:

T_c = 25°C; V_+= 15V; V-= -15V; Vin=+/-0.1V; I_+ = 9.1mA; I_- = 4.5mA; and Θ_{JC}= 40°C/W [6],

<u>P_D= 204mW and T_J≈33°C</u>

The SEE board contains:

- The DUT with open-top
- Two op-amps (one single RH1498 dice), the first (U1A) in single unity non-inverting configuration and the second (U1B) in single unity inverting configuration.
- The filtering RCs (12 Ohms, 0.1uF, and 0.01uF) for the voltage supplies (V- (-15V/-5V), V+ (+15V/+5V)) and the op-amp inputs IN_A, and IN_B.
- The unity gain resistor networks: 1) R1, R2, R5 and R6 for the non-inverting unity gain op-amp and 2) R7, R10, R12 and R20 for the inverting unity gain op-amp
- Ripple Capacitors to minimize these effects. Their values should be in the Pico Farads range.
- 1K resistor in series with the op-amp output combined with a 50 Ohms board termination for high load tests and without for low load tests. The monitored output value on the scope will be the op-amp output value divided by 20 and along with the parallel capacitor to the 1K resistor; it will mimic a transmission line to minimize the distortion of the SET-PW. The scope termination is set at 1MOhms.
- The 2N3904 bipolar transistor to sense the board's temperature, placed as close as possible to the DUT.

Fig. 3 shows the SEE test board schematics. The picture of this board is given in Fig. 4.

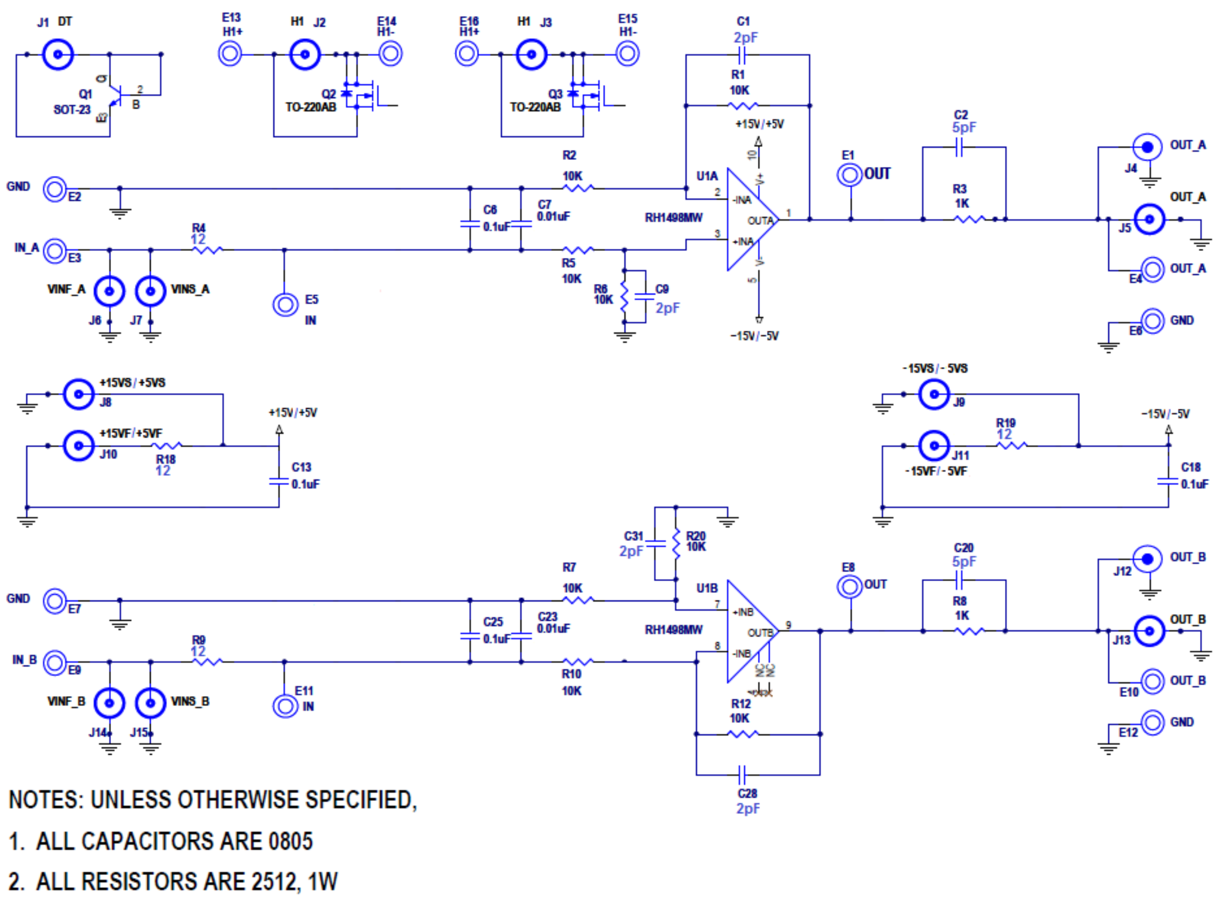


Fig. 3: Block Diagram of the RH1498MW SEE Test Board Intended with 5pF Ripple Capacitances (C2 and C20). In actual radiation SEE test boards, C2 and C20 are each of 0.5uF value instead of 5pF.

Due to wrong selection of the capacitance value from 5pF to 0.5uF (two 1uF in series), we won't be multiplying the detected SET amplitudes by 20. Indeed, as the SET initial rise/fall time is about 15 ns, the equivalent SET frequency is about 67 MHz, and the equivalent impedance of the ripple capacitance during the occurrence of an SET can then be calculated as:

$$R_{C2} = R_{C20} = \frac{1}{2\pi Cf} = \frac{1}{2\pi * 0.5 * 10^{-6} * 67 * 10^{6}} = 4.7\ mOhms$$

Consequently, the equivalent load resistance is (1 KOhms //4.7 mOhms) + 50 Ohms=50 Ohms and not 1050 Ohms as planned. Therefore, the measured SET amplitudes, in this condition, will not be multiplied by 20 but be kept as they are. For verification, and in this particular case (with 50 Ohms board termination, C2 and C20), we've run laser pulse fault injection at The Aerospace Corporation and measured the SET shapes (widths and amplitudes) at test points E1 and E8 which were both identical to the SET shapes at test points Out_A and Out_B, respectively.

In summary and as shown in Table 2, the SET tests were run in three conditions:

1. with 50 Ohms board termination, and the caps C2 and C20 of 0.5uF each,
2. without 50 Ohms board termination, and with the C2 and C20 caps of 0.5uF each,
3. with 50 Ohms board termination and without the C2 and C20 caps

Table 2: Run SET Tests and Laser Correlation Data

Test Case/ Runs with +/-15V power supply	50 Ohms Board Termination	Capacitors C2, C20 0.5uF each	Op-Amp Load without SET (Ohms)	Op-Amp Eq. Load During SET (Ohms)	SET at E1/E8 compared to at Out_A/Out_B	Laser Correlation Data at same energy and same location; Max. SET Amplitudes with same SET Shapes/ Max Load Currents during SET
1: 1-132	yes	yes	1050	50	same	+1V/-3V; 60mA
2: 133-134	no	yes	10^6	10^6	same	+3V/-6V; 6uA
3: 135-148	yes	no	1050	1050	20 X higher	+3V/-6V; 6mA

We believe that the SET amplitudes and widths will be smaller when the load resistance is smaller than 1KOhms, as the part will be current loaded and won't be able to reach higher SET amplitudes than -3V compared to the case when it is loaded with a resistance higher than 1KOhms. Indeed, the current flowing in this part during an SET will reach 60mA at max SET amplitude, in test case 1, which is much higher than what the part is spec'd for. <u>It is then advised to account for the load current during an SET that will increase/decrease the output voltage to not exceed the part's maximum load current.</u> All radiation test results will be shown and discussed in the radiation test results section.

In addition, to minimize the distortion of the measured SET-PW, the test setup was placed as close as possible to the vacuum chamber. It is connected with two 3 feet long BNC cables to two Agilent power supplies (PS) (N6705B) and to a LeCroy Oscilloscope (Wavepro 7300, 3 GHz) with extended monitor/cables to view the output signal (Vout). The first PS supplies the input voltages to the SEE test board and allows the automated logging and storage every 1 ms of the current input supplies (Iin), as well as the automation of power-cycles after the detection of a current spike on the input current that exceeds the current limit set by the user. The second PS is used for sensing the voltages of the input power supplies. This was done to avoid any interference from the power supplies that might cause widening of the transients upon the occurrence of an SET. The output pin (Vout) was connected to the scope with 3 feet BNC cable (vacuum chamber feed-through) and a scope probe of 11pF. For better accuracy, the equivalent capacitive load of the BNC cable and the scope probe should be calculated and accounted for, as it might affect the SET pulse width and shape. In this case, the cables' capacitive load was about 120pF.

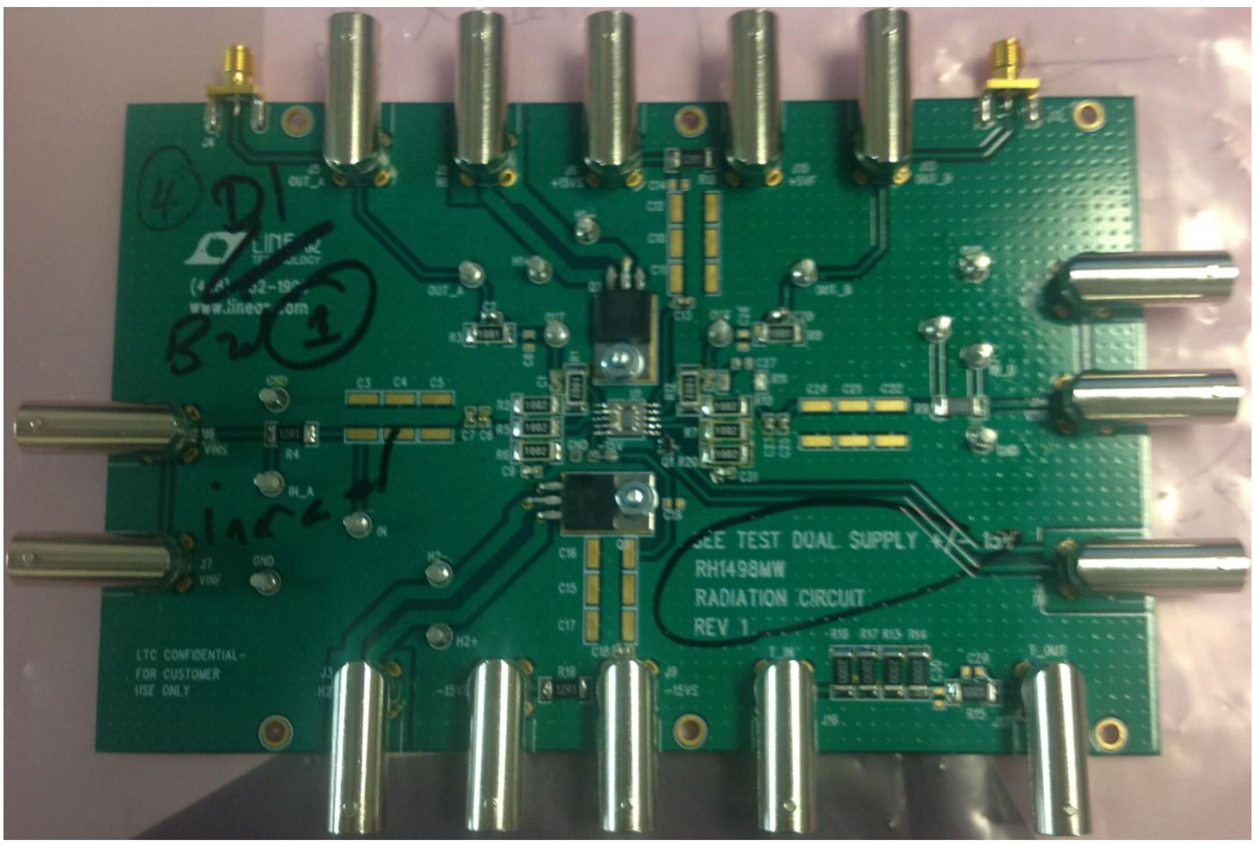


Fig. 4: Photograph of the first SEE Test Board

3. Heavy-Ion Beam Test Conditions

The RH1498MW DUTs were tested under various input bias conditions ranging from +/-0.1V, +/-2.5V, and +/-5V for the +/-5V supply voltages and +/-0.1V, +/-2.5V, +/-5V, and +/-7.5V for the +/-15V supply voltages. The selected beam energy is 10MeV/nucleon, which correlates with beam ions delivered at a rate of 7.7 MHz (eq. to a period of 130 ns). During these 130 ns, the ions are generated only within very short pulses that last for 10 ns, as shown in Fig. 5. At every pulse of 10 ns, N number of particles per square centimeter, depending on the flux, will be irradiating the DUT. The calculation of N is provided in Eq. 3:

$$N = \text{Flux} * 130\text{ns} \qquad (3)$$

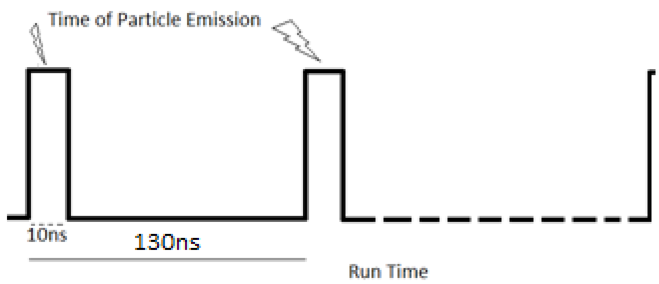


Fig. 5: Particle Emission during a Beam Run at Beam Energy of 10 MeV/nucleon; Emission Frequency = 7.7MHz

For instance if the flux equals 10^4 particles/cm^2/second, the probability (N) of having a particle emitted and striking within a defined square centimeter within a random 10ns active period and even during the entire period of 130 ns is 1.30×10^{-3}. Multiply that value by the die area to determine the probability of a particle striking the die; 1.30×10^{-3} particles/cm^2 * 2.477 10^{-2} cm^2 = 3.22×10^{-5}. We don't know exactly at what pulse this particle will be irradiating the DUT. The random nature of that emission will change the elapsed time between any two consecutive particles. The higher the beam's frequency or the flux; the higher is the likelihood to have more than one particle hitting the DUT in a very short time (within hundreds of nanoseconds). Indeed, the minimum time that is guaranteed by the facility to separate the occurrences of two particles can be as low as 130 ns but the probability of that happening is very low. To avoid overlapping of events, it is important then that the error-events last less than 130 ns or that the flux is much reduced.

Most importantly, in the case of these analog devices (power, signal conditioning, etc.), some of the DUT's transistors when hit by heavy-ions will cause wide SETs that might last for microseconds. To make sure that the error-rate calculation is accurate, the flux needs to be reduced until there is a consistency in the number of detected errors with the flux for a given ions' fluence. If that's not the case, the part is subject to multiple hits (that might cancel or widen the resulting SET). The test engineer needs to account for these additional effects. Also, if the original SET is widened at the DUT output, by the peripheral RC circuits or even the ones used to mitigate it, then the resulting event will dictate the maximum flux to be applied on the DUT.

For instance, because of the cabling between the SEE test board and the scope, that adds a minimum capacitive load on the output signal of about 120pF, the serial resistances on the op-amp inputs and the feedback path, the final measured SET-PW on the scope can be wider or smaller than the initial SET-PW originating from the DUT output. However, given the cabling requirements (feed-through) at LBNL for vacuum in-beam tests, this minimum capacitive/resistive/inductive load cannot be avoided. For such circuits, it is crucial then to reduce the length, the loading, as much as possible, to avoid reflection of the SET signal through these cables, the beam facility noise effects, etc.

Furthermore, the closer is the power supply and the scope to the test setup, the higher is the likelihood to reduce the noise effects propagating through the beam facility cables and power grids. Ideally, it is advised to have the entire test setup (the power supply along with the SET detection circuit fulfilling the scope function) placed in the vacuum to minimize these effects. For this particular op-amp, reducing the capacitive load at best is crucial since exceeding 10nF at its output will make the circuit unstable, as clearly mentioned in the RH1498 datasheet and shown in Fig. 6. For instance, with a capacitive load of 120 pF, an overshoot of 10% is expected on the output signal. Because of it, an output of 7.5V might overshoot at best with 750mV after an SET. This won’t be the case in actual space flight boards.

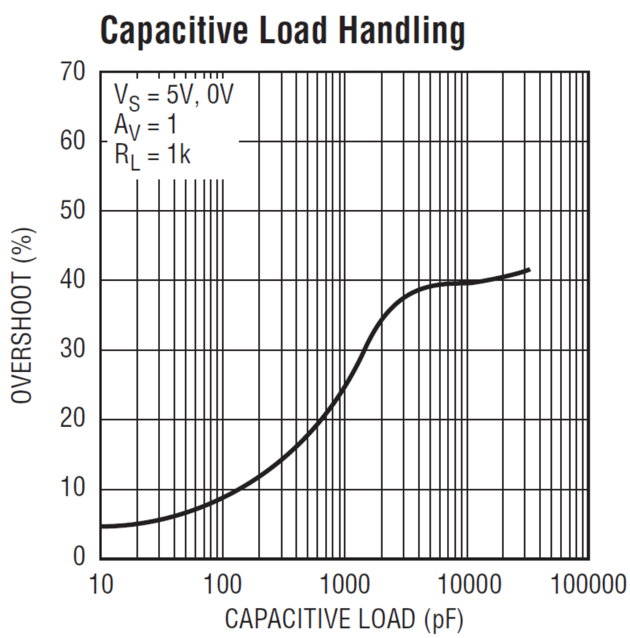


Fig. 6: Overshoot vs. Capacitive Load

Most importantly, based on previous laser tests, performed at The Aerospace Corporation, the RH1498MW SET cross-section is expected to be about 5E-3cm^2. Consequently, the beam flux must be set to lower values than 200p/sec/cm^2 to not cancel the previous SET. Therefore, the applied flux should be lowered for two main reasons: 1) avoid cancellation of previous SET effect and 2) avoid increase of the SET pulse width and amplitude when two events overlap. The run fluxes are reported in Table 5. Note that because of the high beam cost, we had exceeded a few times, the maximum flux limit, which led to lower SET cross-sections than the real sensitive cross-section of the part. This was clearly shown at high LETs (Fig. 23). Higher fluxes can lead also to higher SET amplitudes and widths as it is shown below in the load section.

4. Radiation Test Results

Heavy-ions SEE experiments included SET, SEU and SEL tests up to a Linear Energy Transfer (LET) of 117 MeV.cm^2/mg at elevated temperatures (to case temperatures of 100°C). In 148 runs, the RH1498 parts were irradiated under various input bias conditions, low and high loads of this op-amp, as well as two different supply biases +/-5V and +/-15V, as shown in Table 3. Table 5 shows the raw data for these runs. Neither SEU nor SEL nor destructive events have been observed during all these tests; all events were transients, with various amplitudes and pulse widths that depended on the LET and the load current. The SET cross-sections were mostly dependent on the input and power biases as well as the ions' LETs, but little on the load.

Table 3: Beam Test Conditions (Bias, Input, and Output Voltage and Load Currents)

Power Supply (V+/V-)	+/-5V	+/-15V
Op-Amp Input Bias (IN_A/ IN_B)	+/-5V, +/-2.5V, +/-0.1V	+/-7.5V, +/-5V, +/-2.5V, +/-0.1V
Op-Amp Output Voltage (Load Currents) (OUT_A/OUT_B) (OUT_A/OUT_B) without 50Ohms board termination	+/-5V(5uA), +/-2.5V(2.5uA), +/-0.1V(0.1uA)	+/-7.5V(7.5uA), +/-5V(5uA), +/-2.5V(2.5uA), +/-0.1V(0.1uA)
Op-Amp Output Voltage (Load Currents) (OUT_A/OUT_B) with 50 Ohms board termination for a total of 1.050KOhms op-amp load	+/-0.25V(5mA), +/-0.125V(2.5mA), +/-0.05V(100uA)	+/-0.375V(7.5mA), +/-0.25V(5mA), +/-0.125V(2.5mA), +/-0.05V(100uA)

Also, the SET-PW on the DUT output is the sum of the prompt effect from the injected SET and the DUT response time to it. Once the hit input transistor has trigged to the ion's deposited charge, the part will need approximately the circuit's slew rate time (typically about 6V/us, [2]) multiplied by the SET amplitude to recover from its effect (Fig. 7). The SET amplitude will vary with the injected charge (eq. to LET) and its diffusion in the hit transistor and adjacent transistors to it. The more transistor isolation there is (added usually for SEL mitigation) and resulting in less charge diffusion, the higher and sharper the prompt effect (SET amplitude) is and vice-versa. On the contrary, as the settling time increases with the transient amplitude; wider SETs can be expected. Also, as the slew-rate increases with the supply voltage (Fig. 8), it is expected that +/-15V power supply case will show wider SETs and higher SET cross-sections. In summary, the SET prompt effect, its diffusion and its propagation in the circuit at a given bias will shape the final propagated SET at the op-amp output, as it will be shown in the remainder of this report.

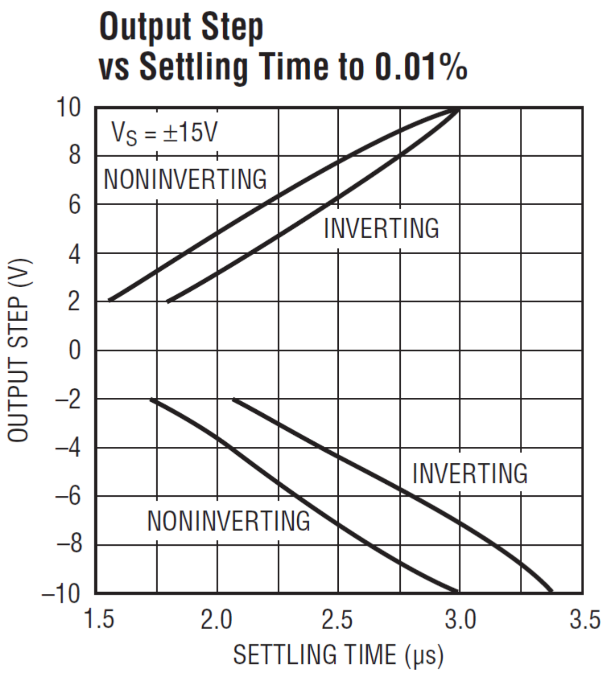


Fig. 7: Output Step vs. Settling Time

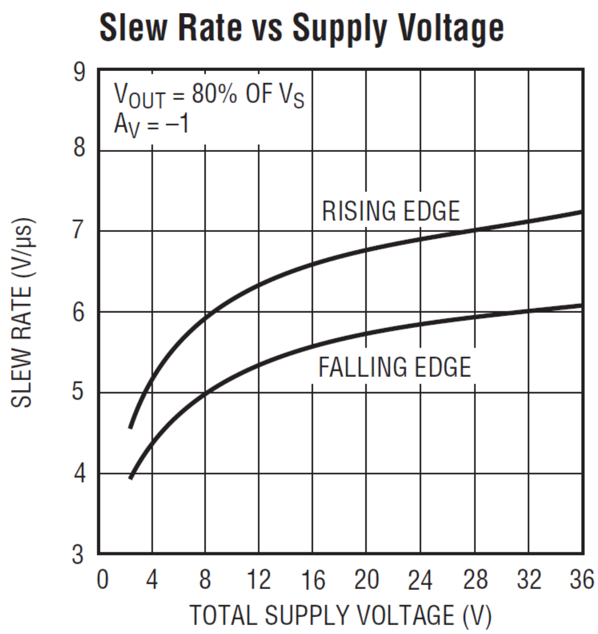


Fig. 8: Slew Rate vs. Total Supply Voltage

During the radiation runs, the SEE test procedure was the same for both power supply bias conditions (+/-15V, and +/-5V). For SET detection, the scope was set to trigger on positive and negative SETs as a result of a change in the output value (Out_A and Out_B in Fig. 3) exceeding +/-100 mV. This was mostly done to eliminate noise effects on small amplitude outputs (+/-0.1V, +/-0.125V, +/-0.25V, or +/-0.375V). The pulse widths were calculated based on these levels as well. Therefore, the reported SET-PW is always smaller than the SET base width (from the time it starts till it ends). All the waveforms were saved during the beam tests and are available to the reader per his/her request.

Ions' hits resulted in two SET-types: 1) SET affecting simultaneously both op-amp outputs (A and B) and 2) SET on a single op-amp output (A or B). Both SET-types can be positive or negative and we have categorized them as 1) dual events, as shown in Fig. 9 and 10, and 2) single events, as shown in Figs. 11, 12 and 13. At low load, some of the single ones although very short at their peak, had a positive overshoot of about 3V, as shown in Fig. 12 and that lasted in some cases for about 10us. Fig. 14 shows the maximum SET-PWs versus LET, which represent less than 1% of the SET population.

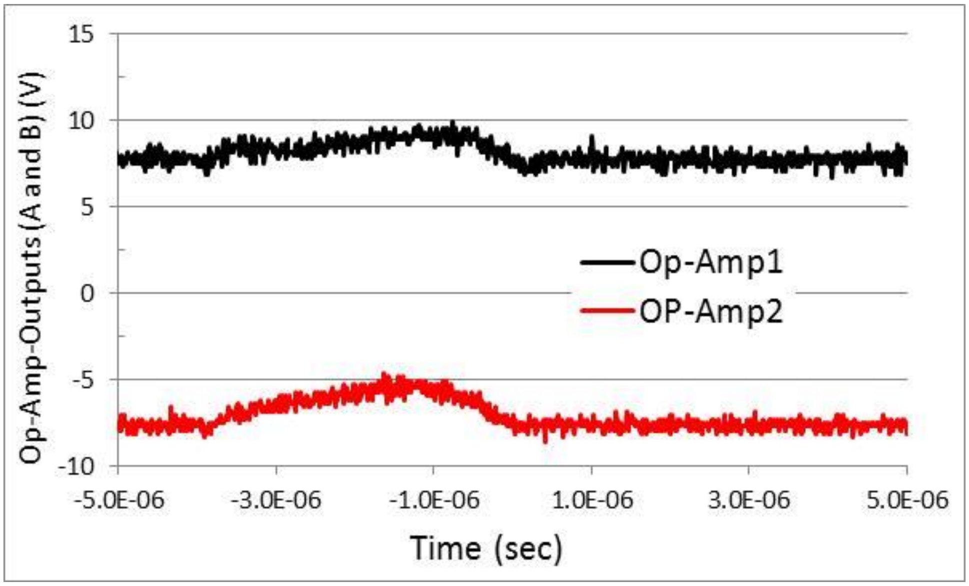


Fig. 9: A Dual Event SET at Low Load (without 50 Ohms board termination and with ripple capacitors C2 and C20 of 0.5uF each), Run#133: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg; SET-PW in this case is about 2.5us

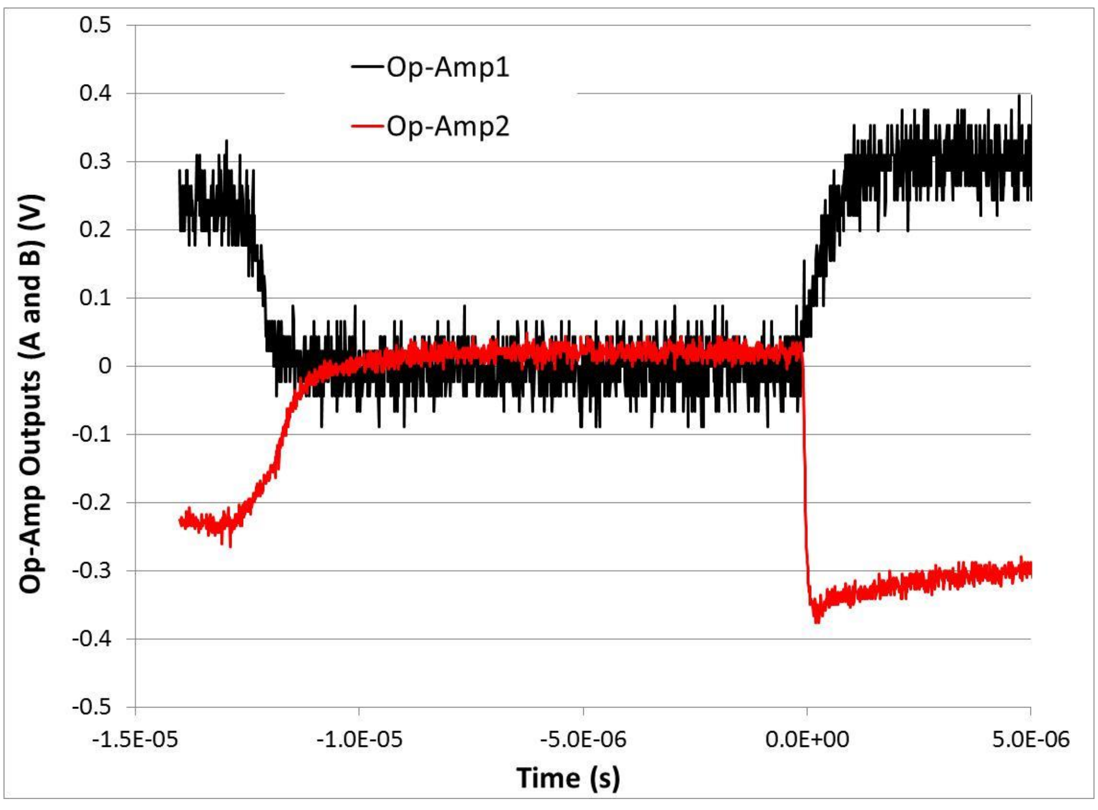


Fig. 10: A Dual Event SET at High Load (with 50 Ohms board termination and 0.5 uF C2 and C20 capacitances). Eq. Load during the SET is 50 Ohms instead of 1050 Ohms without irradiation. Run#31: Power Supply Bias: +/-15V, Input Supply Bias: +/-5V; Ion: Xe; LET=58.78MeV.cm^2/mg.

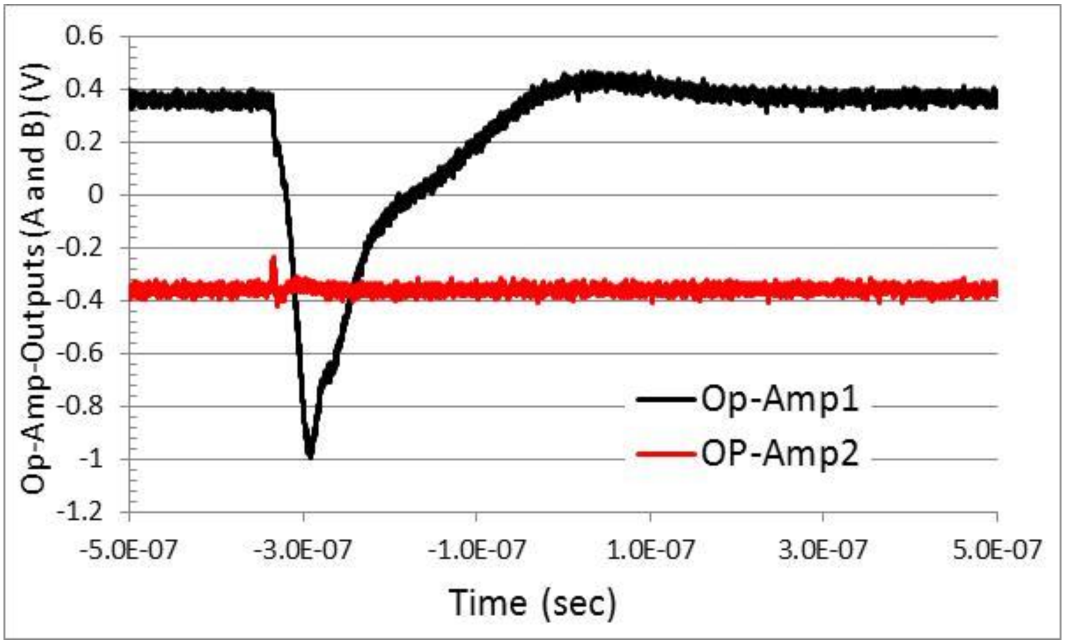


Fig. 11: A Single Event SET at High Load (with 50 Ohms board termination and 0.5 uF C2 and C20 capacitances). Eq. Load during the SET is 50 Ohms instead of 1050 Ohms without irradiation. Run#15: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg; SET-PW in this case is about 250ns, SET-Amplitude about -1.4V

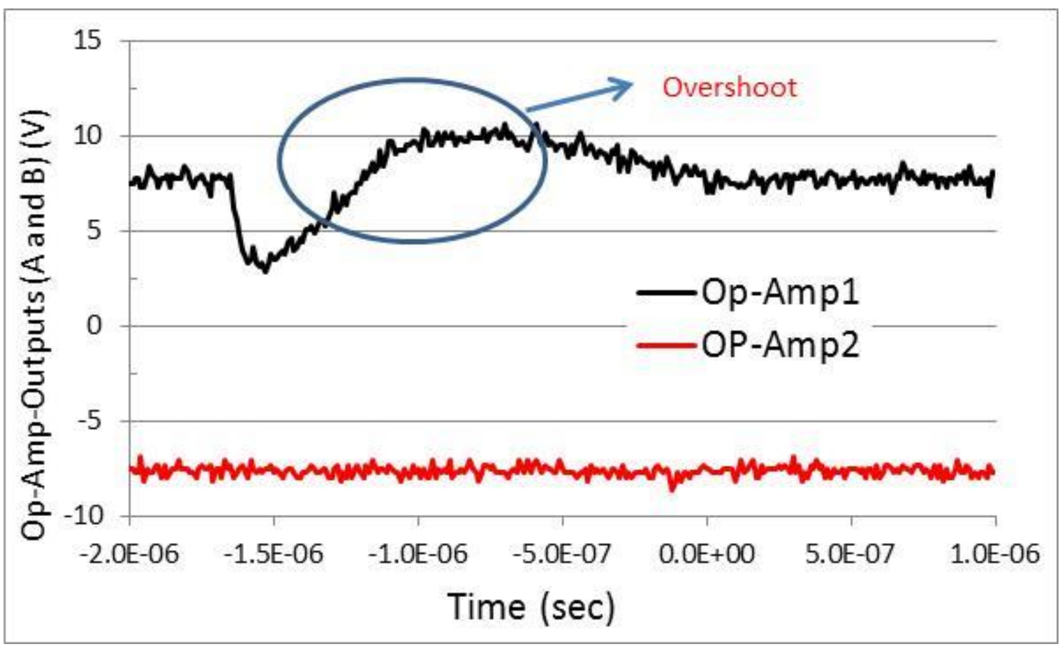


Fig. 12: A Single Event SET at Low Current Load (without 50 Ohms board termination and with 0.5 uF C2 and C20 capacitances; eq. load 1MOhms), with overshoot of about 2.5V, Run#133: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg; SET-PW in this case is about 0.5us with an overshoot that lasts for another 1us.

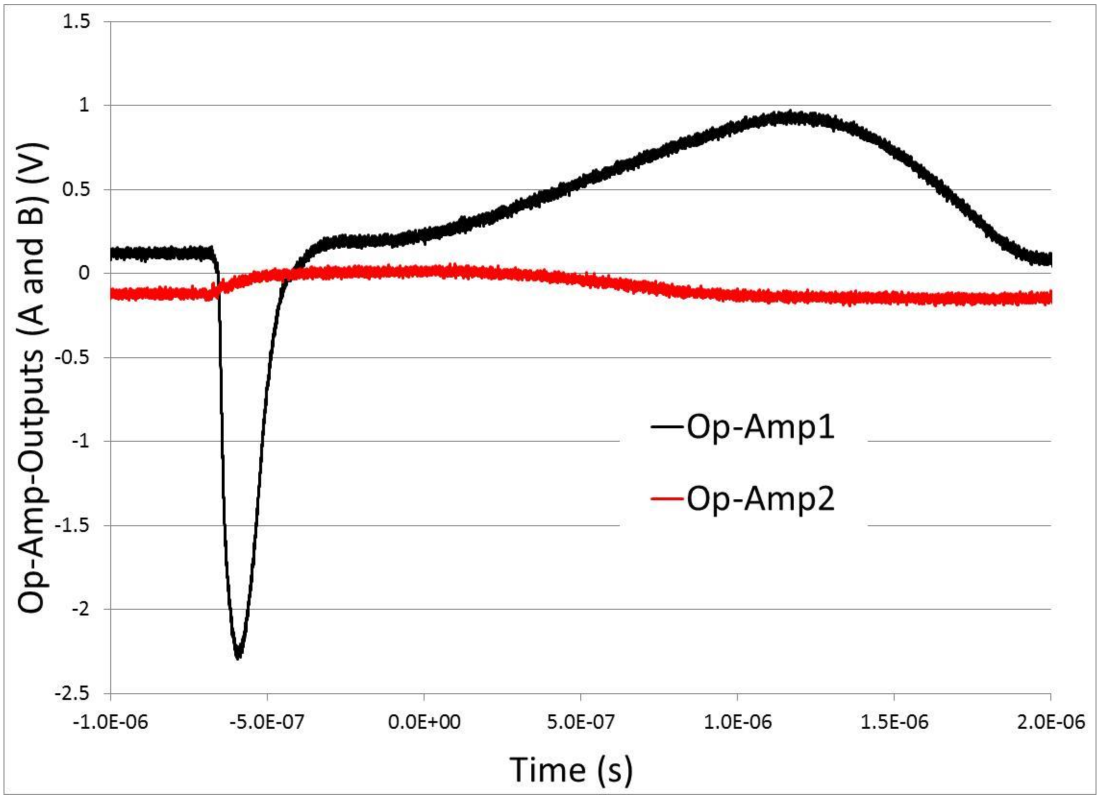


Fig. 13: A Single Event SET with overshoot of about 2.5V at High Current Load (with 50 Ohms board termination and 0.5 uF C2 and C20 capacitances). Eq. Load during the SET is 50 Ohms instead of 1050 Ohms without irradiation. Run#6: Power Supply Bias: +/-15V, Input Supply Bias: +/-2.5V; Ion: Xe; LET=58.78MeV.cm^2/mg; SET-PW in this case is about 0.4us with an overshoot that lasts for another 2us.

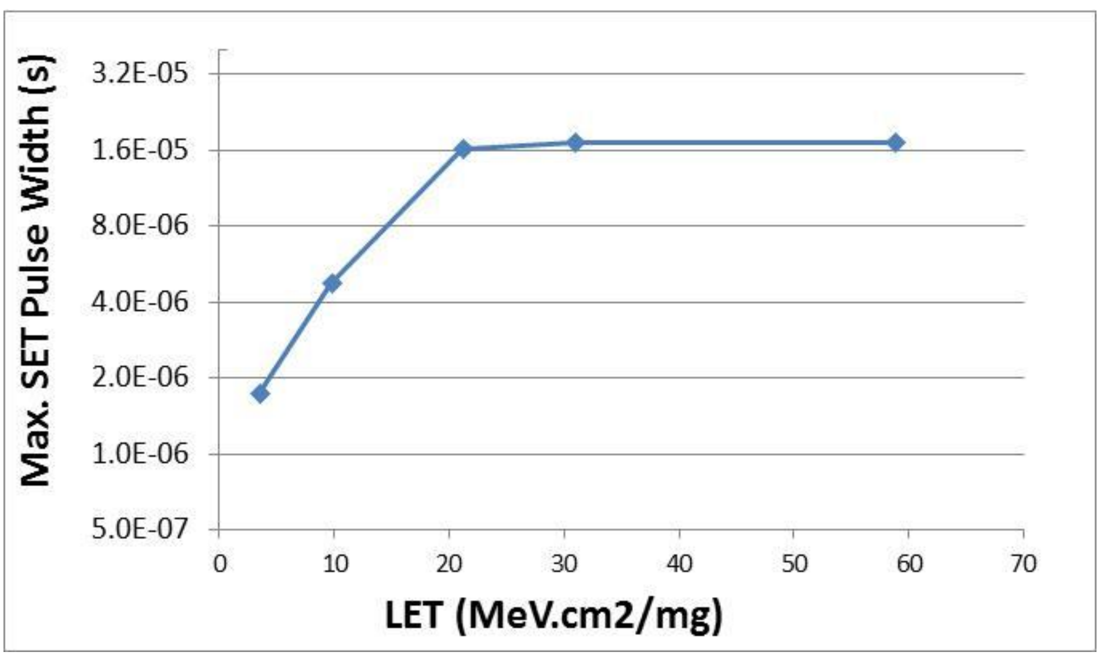


Fig. 14: Maximum SET Pulse Width vs. LET for all recorded SETs with low and high loads. **At Xe (LET=58.78MeV.cm2/mg), 90% of these SET pulse widths are smaller than 2us and 3V.**

1) Load Effects on the SET Pulse Widths and Amplitudes

Load effects have been tested by running the measurements with two different board terminations (with and without 50 Ohms board termination). The former mimic high current loads (higher than specified in datasheet if tested with C2 and C20 in parallel with the 1KOhms resistances) while the latter mimic low current load on this op-amp. The beam data showed that the SET maximum widths and mainly amplitudes varied with the load and the ion's LET. The higher the load resistance (higher than 1KOhms) or LET are; the higher the SET amplitudes and widths are. Indeed, per the LT1498 datasheet [2], and as shown in Fig. 15, higher current loads will lead to higher output saturation voltages and consequently to smaller transients if these output saturation voltages are attained.

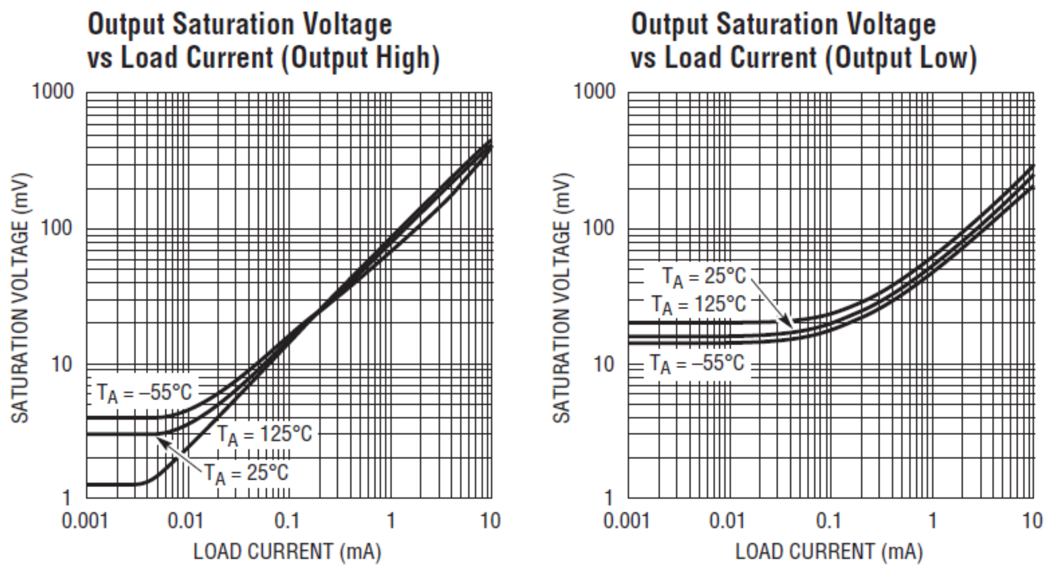


Fig. 15: Output Saturation Voltage vs. Load Current

At high resistive load (1 MOhms), and at an LET of 58.78 MeV.cm^2/mg (Xe ions), the maximum SET amplitude was about +/-6V and the maximum SET pulse width about 3.3us, as shown in Figs. 16, 17 and 18. However, with equivalent 50 Ohms load resistance and at the same LET, smaller SETs (amplitudes up to 2.5V and widths up to 5us) have been detected, as shown in Figs. 10, 19, 20 and 21. Figs. 18 and 19 show that in most cases, the SET-amplitude is inversely proportional to the SET pulse width, which will reduce the likelihood of their propagation to other circuits. At both loads, most of the SETs were short and small as shown in Figs. 16 to 24 and therefore may be ignored by design. Similar SET amplitudes and widths to the observed SETs were shown in [4]. In addition, as shown in Fig. 22 that compares SET amplitudes obtained at low and high resistive loads, the maximum SET amplitudes decrease if the op-amp output resistive load is lower than 1KOhms. For instance:

1. At minimum load current (with 1 MOhms output resistance), the cross-section of the widest (>4.5us) and the highest in amplitude (>5V) SETs are about two orders of magnitude less than the entire op-amp SET sensitive cross-section.
2. Also, about 95% of SETs are smaller than 4V in their amplitudes and 4us in their widths.
3. At high current load (with 50Ohms resistance at the op-amp output, C2 and C20), 90% of the SETs are smaller than 0.5V in their amplitudes and 2us in their widths.

Finally, Figs. 23 and 24 show that both of the SET amplitudes and widths increase with the flux.

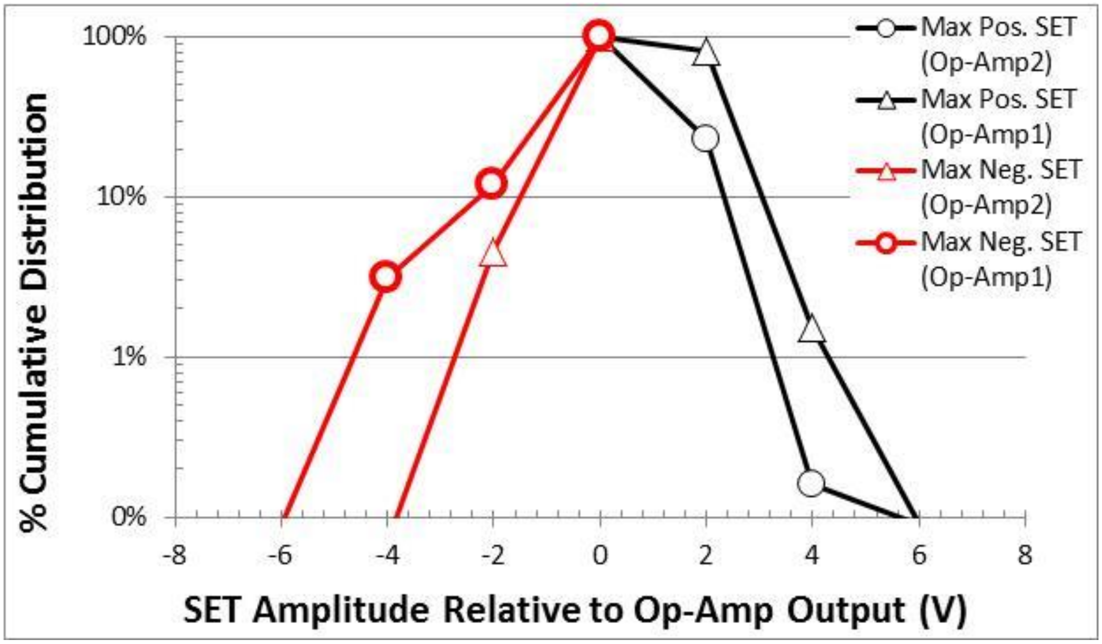


Fig. 16: % Cumulative Distribution vs. SET Amplitude at low load current (without 50Ohms board termination; 1MOhms scope termination), Runs#133-134: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg

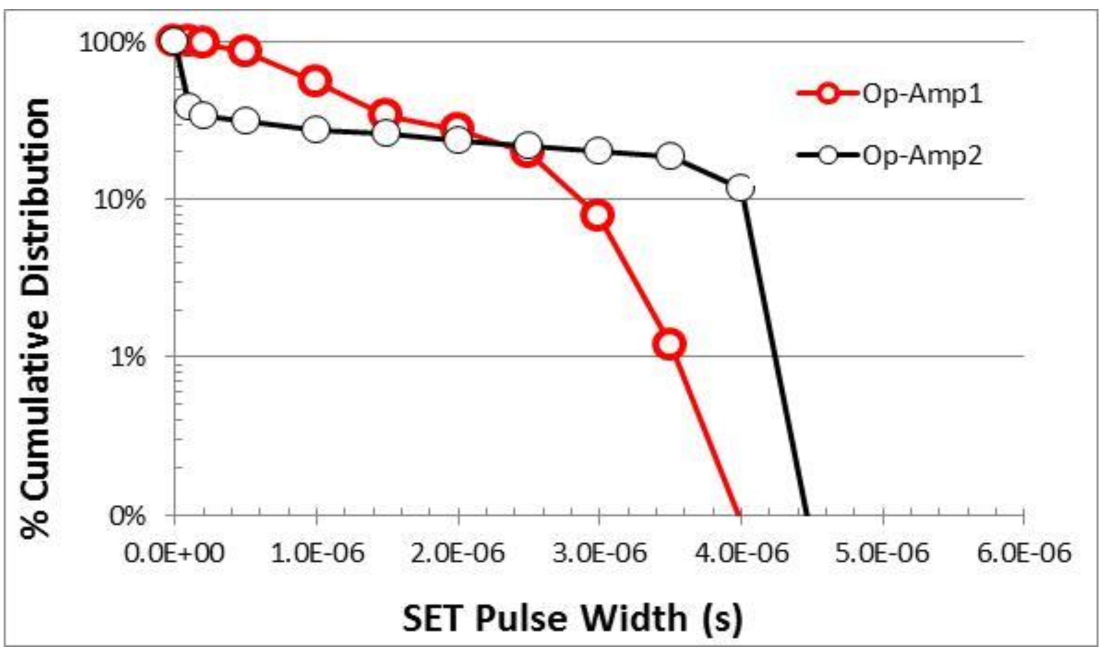


Fig. 17: % Cumulative Distribution vs. SET Pulse Width at Low Load Current (without 50Ohms board termination; 1MOhms scope termination), Runs#133-134: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg

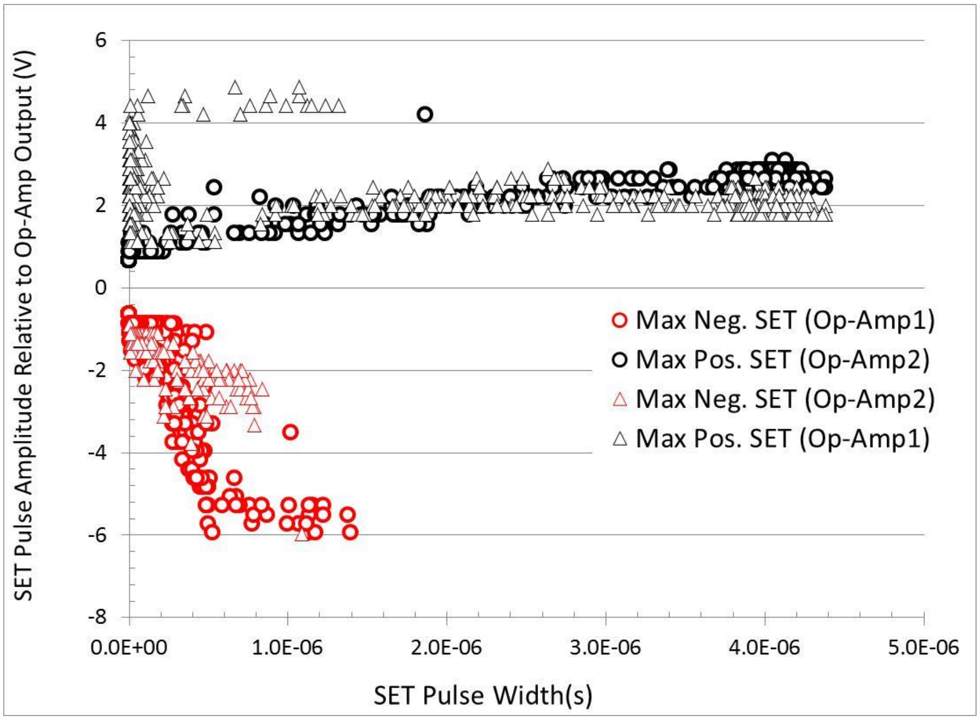


Fig. 18: SET Pulse Width vs. SET Pulse Amplitude at Low Load Current (without 50 Ohms board termination), Runs#133-134: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg

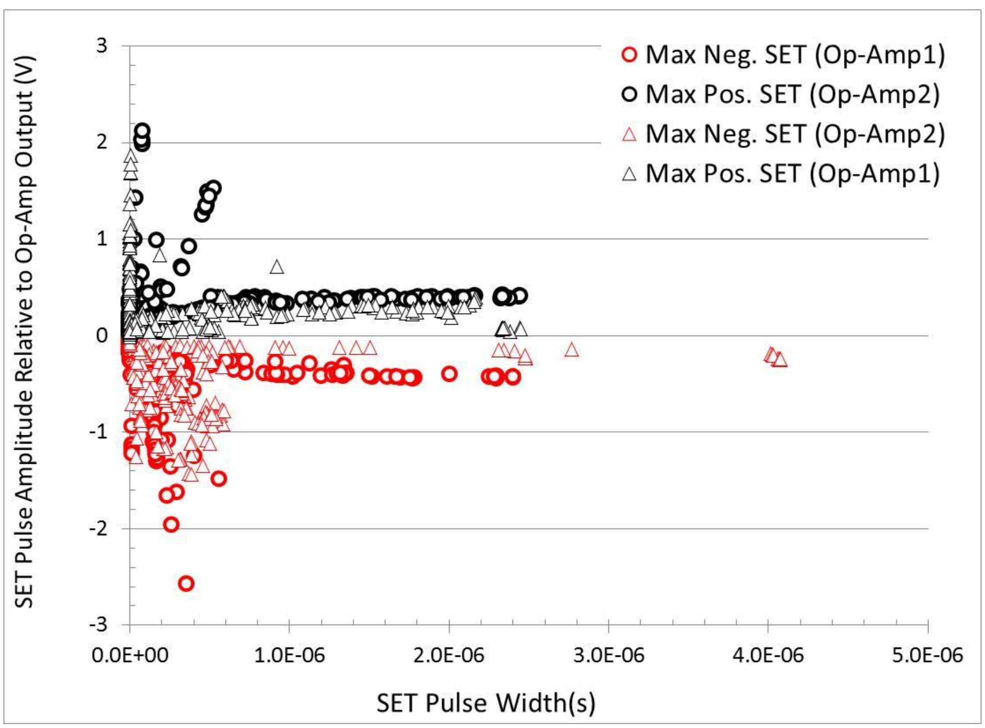


Fig. 19: SET Pulse Width vs. SET Pulse Amplitude at High Load Current (with 50Ohms board termination), Run#15-18: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg. Beam-induced small amplitude SETs might have been wider than 5us as the scope window duration time was smaller than the entire SET-PW. However, the SET-PWs for the high-amplitude SETs are accurate (shorter than 1us).

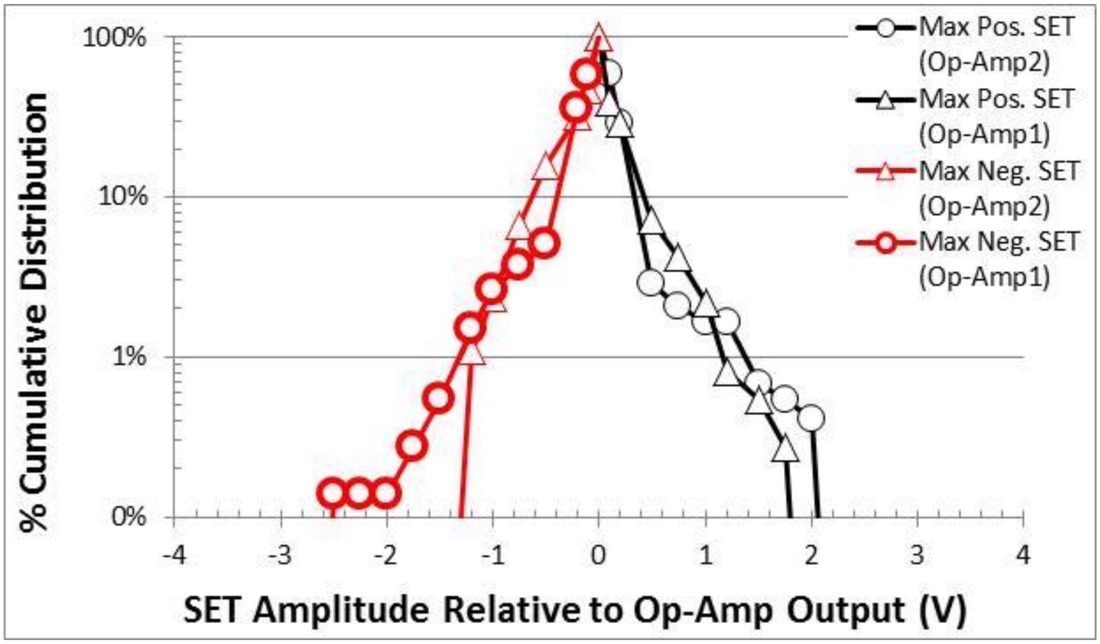


Fig. 20: % Cumulative Distribution vs. SET Pulse Amplitude at High Load Current (with 50 Ohms board termination), Run#15-18: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg

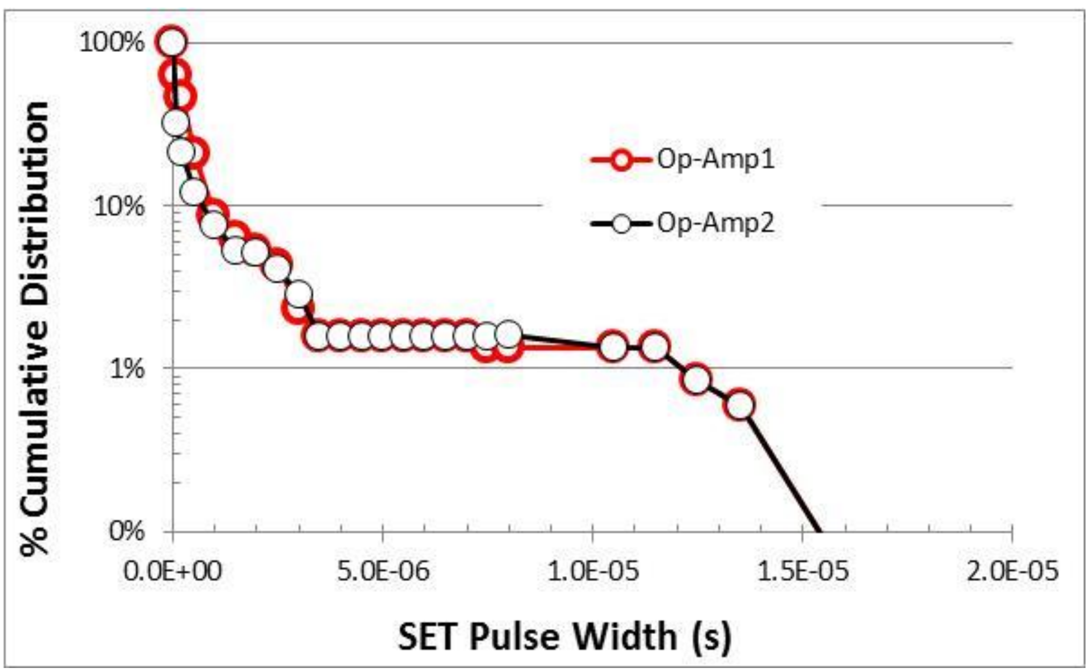


Fig. 21: % Cumulative Distribution vs. SET Pulse Width at High Load Current (with 50 Ohms board termination), Run#45-48: Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Kr; LET=30.8MeV.cm^2/mg

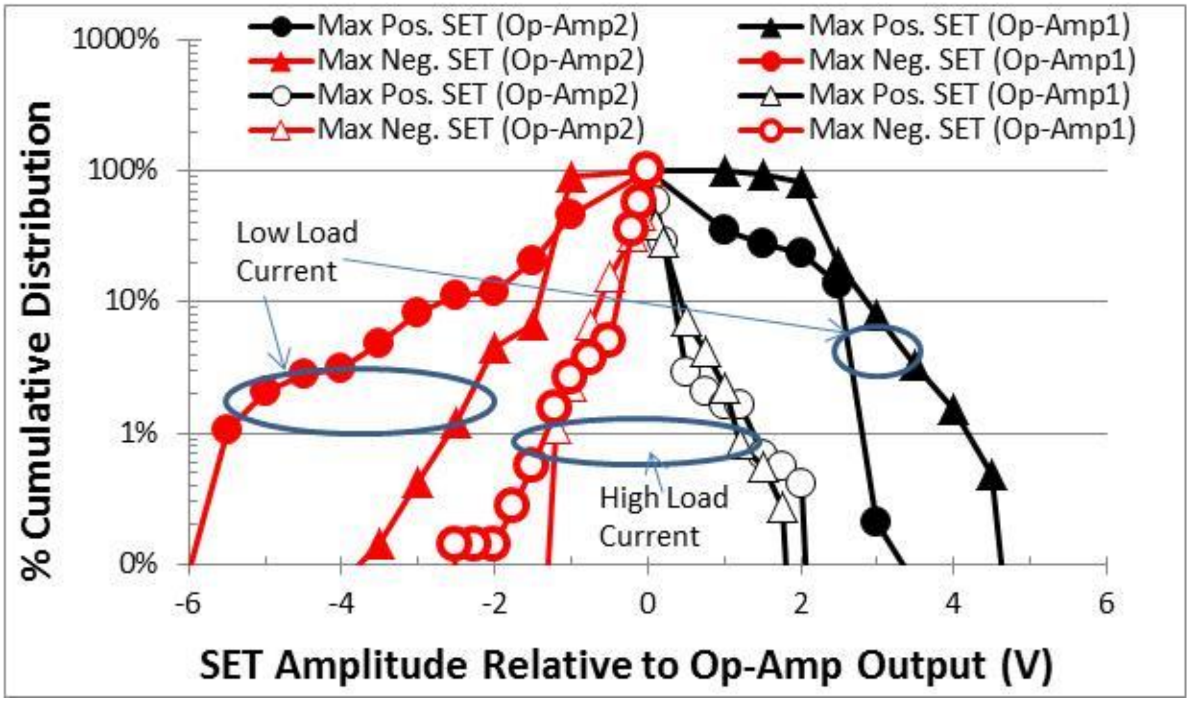


Fig. 22: % Cumulative Distribution vs. SET Pulse Amplitude and Output Load (7.5mA and 7.5uA), Run#133 (Min Load), Run#16 (High Load): Power Supply Bias: +/-15V, Input Supply Bias: +/-7.5V; Ion: Xe; LET=58.78MeV.cm^2/mg

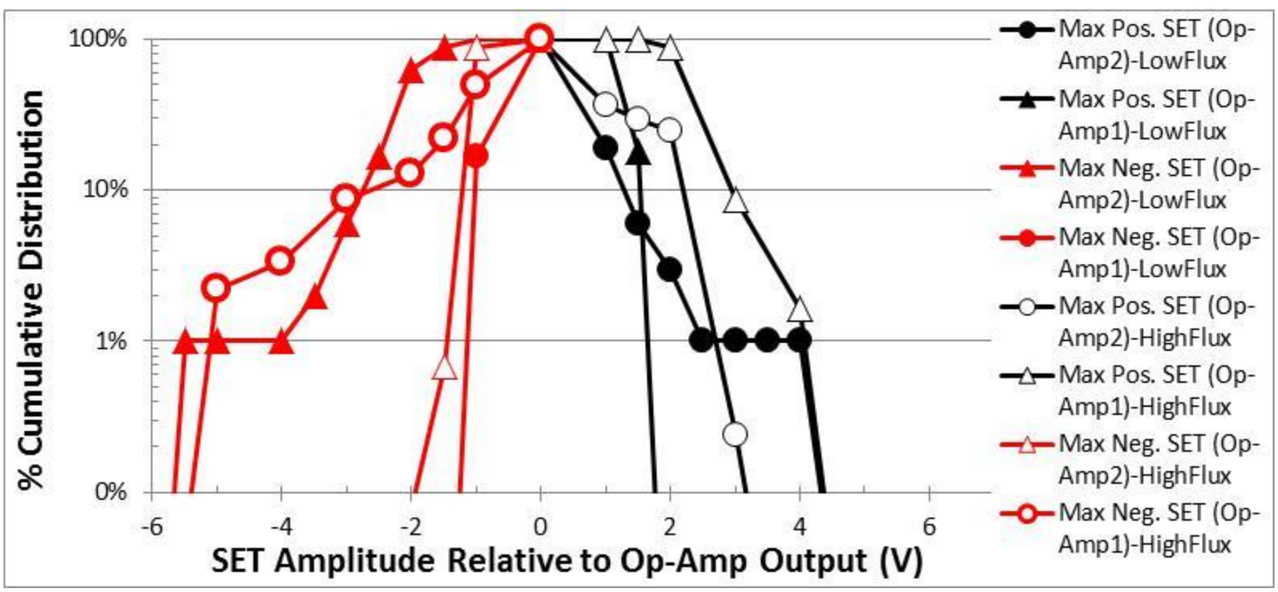


Fig. 23: % Cumulative Distribution vs. SET Pulse Width at high load current (without 50 Ohms board termination), Runs#133 (high Flux), 134 (low Flux): Power Supply Bias: +/-15V, Input Supply Bias: +/-0.1V; Ion: Xe; LET=58.78MeV.cm^2/mg

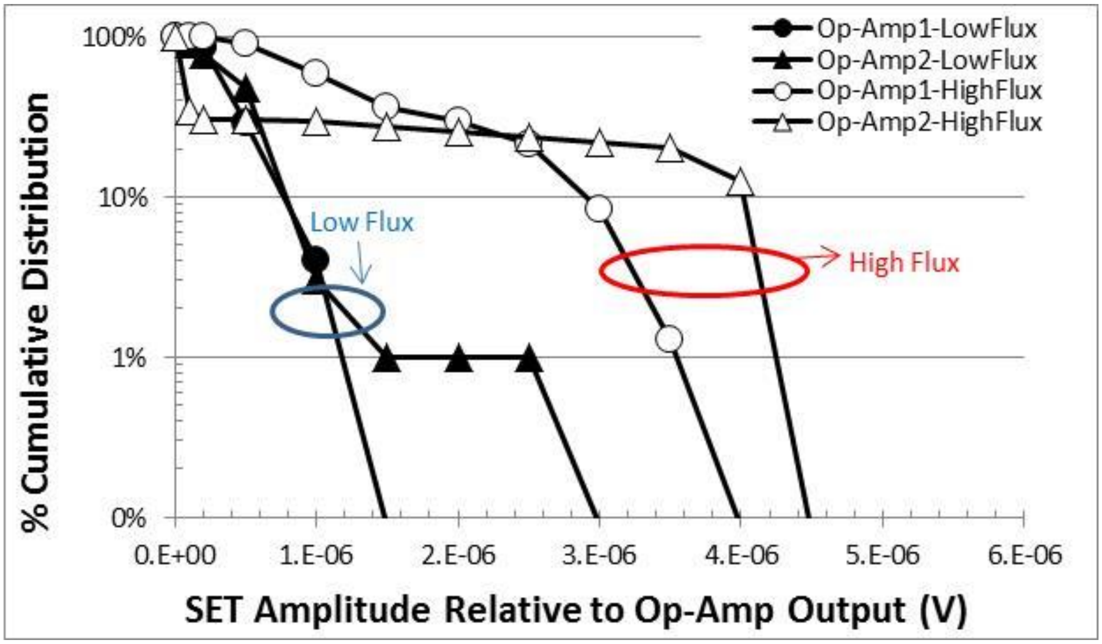


Fig. 24: % Cumulative Distribution vs. SET Pulse Width at the highest load (without 50 Ohms board termination), Runs#133 (high Flux), 134 (low Flux): Power Supply Bias: +/-15V, Input Supply Bias: +/-0.1V; Ion: Xe; LET=58.78MeV.cm^2/mg

2) Input Bias and Power Supply Effects

a. On the SET Pulse-Amplitudes

As shown in Figs. 25 to 26, the SET maximum amplitudes did not vary much with the different input biases (+/-7.5V, +/-5V, +/-2.5V, +/-0.1V), when powered at +/-15V but considerably when biased at +/-5V. The maximums positive and negative SET amplitudes, increased almost linearly with the LET, as shown in Figs. 25 and 26. The data show also that +/-5V for power supply and +/-5V for input bias seems to be the best case. For complete SET pulse widths and amplitudes dependences on the LETs and Bias conditions, see Appendix A.

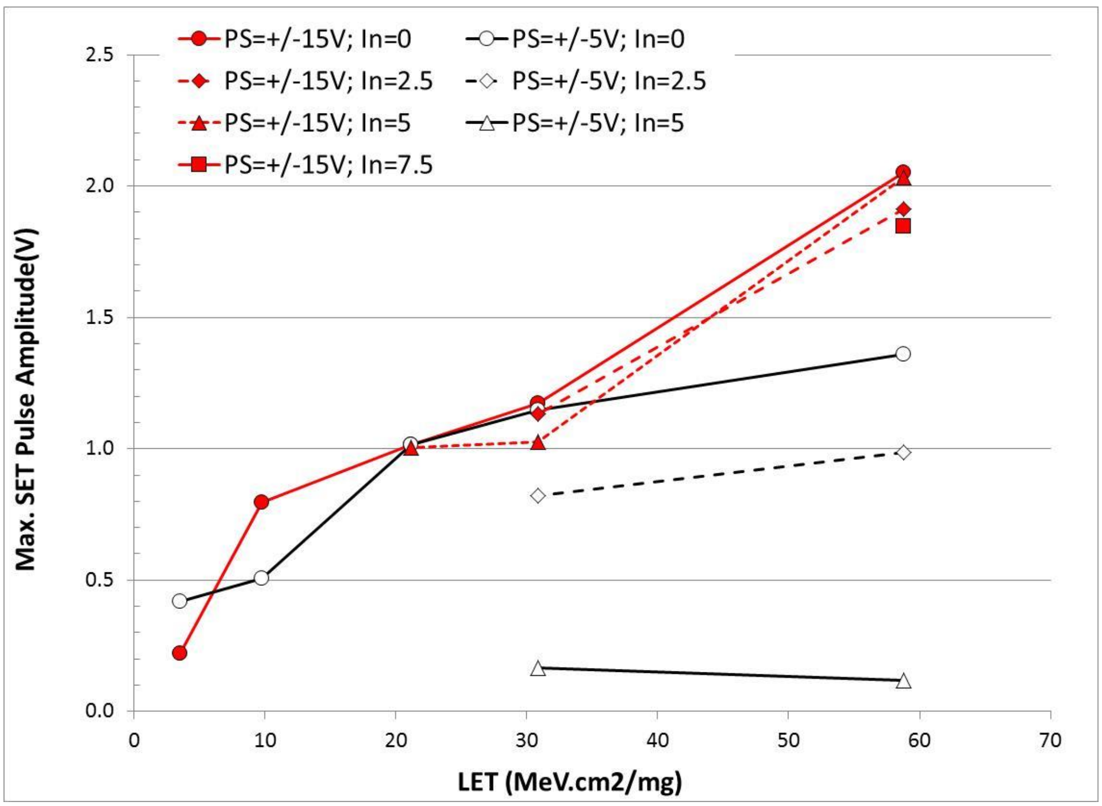


Fig. 25: Maximum Positive SET Pulse Amplitudes vs. LET and Bias for all recorded SETs, at high load.

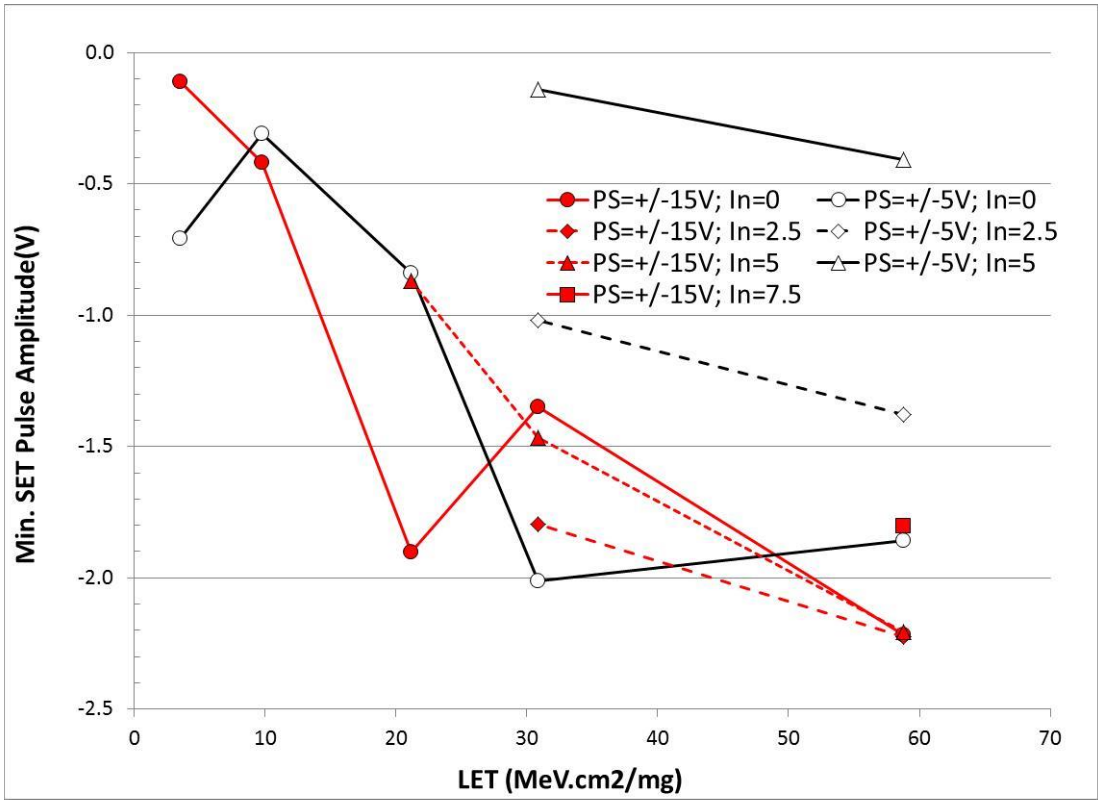


Fig. 26: Maximum Negative SET Pulse Amplitudes vs. LET and Bias for all recorded SETs, at high load.

b. On the SET Cross-Sections

The SET cross sections vary with the input biases. There is no clear correlation between the input biases and the resulting SET cross-sections. This was valid for both power supplies +/-15V and +/-5V, as shown in Figs. 27 and 28. Also, as mentioned above in page 12, the data showed that higher power supply results usually in higher SET cross-sections. On the other hand, some of the measured SET cross-sections with Xenon ions (58.78 MeV.cm^2/mg) were lower than with Krypton LETs. This can be explained by the high run fluxes where they exceeded the inverse of the SET cross-sections, to have at least one second between two consecutive SETs. With an automated tester that can capture faster these SETs, beam fluxes can be increased. As the expected saturation cross-sections are about 5E-3cm^2, the run fluxes must be lower than 200p/sec/cm^2 to avoid overlapping of two SETs within 1 second.

Both of Figs. 27 and 28 show the Weibull curves that customers can use to determine the RH1498MW orbital error rates in their space flight designs and Table 4 shows the Weibull parameters for their calculations, as provided in Eq. 4. Note that if SET pulse widths shorter than 1us can be ignored in their designs then the resulting orbital error-rates will be negligible as the threshold LET is higher than 30.86 MeV.cm^2/mg for the other events.

Table 4: Weibull Parameters Used for the RH1498MW SEE Cross-Sections (Single and Dual Events) and the Calculation of the Error Rates

L_0	W	S	σ_0 (Single Event)	σ_0 (Dual Event)
(MeV / mg-cm^2)	(MeV / mg-cm^2)		(cm^2)	(cm^2)
3	20	1.8	3.5E-3	3.5E-3

$$\sigma = \sigma_0 \left[1 - e^{-((L-L_0)/W)^S}\right] \qquad (4)$$

In summary, under heavy-ion irradiations, and at the various input bias conditions (Table 3), the RH1498MW showed sensitivities only to SETs. The measured underlying SET sensitive cross-section (all events added) is about 5E-3 cm^2 (8% of the physical die cross-section), while the threshold LET is about 3 MeV.cm^2/mg.

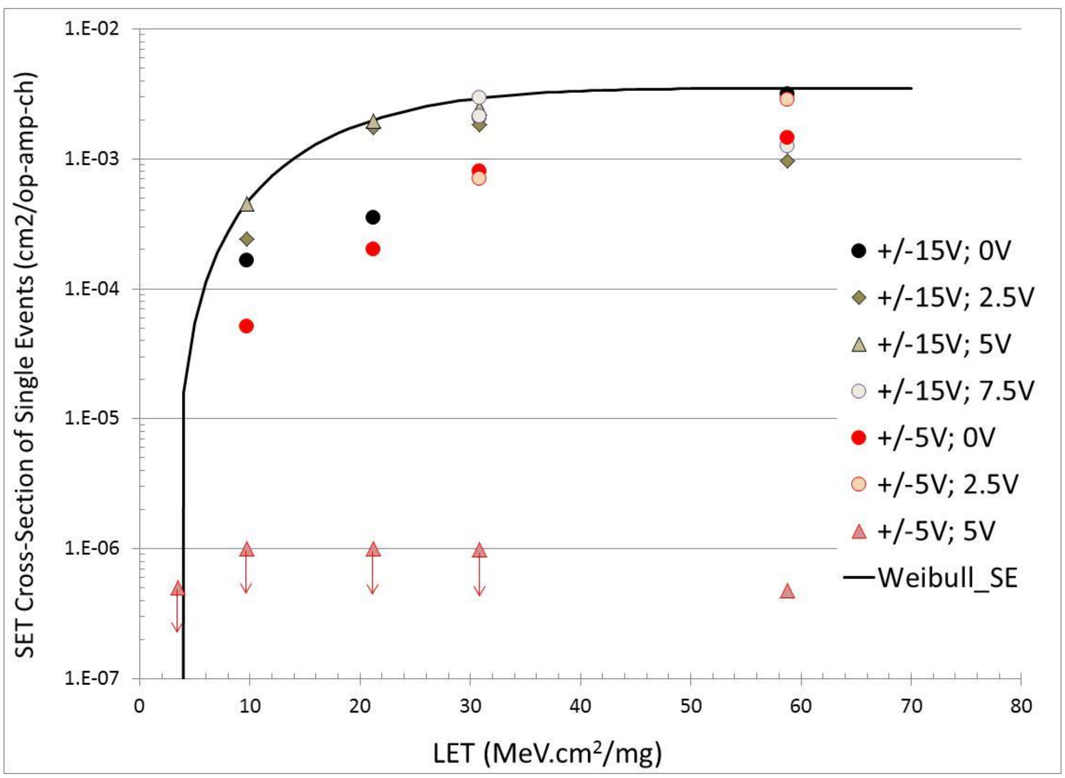


Fig. 27: Single Events Cross-Sections vs. LET with Power Supply Bias: +/-15V and +/-5V, Input Supply Bias: +/-7.5V, +/-5V, +/-2.5V, +/-0.1V; Minimum Load Current (without 50Ohms board termination)

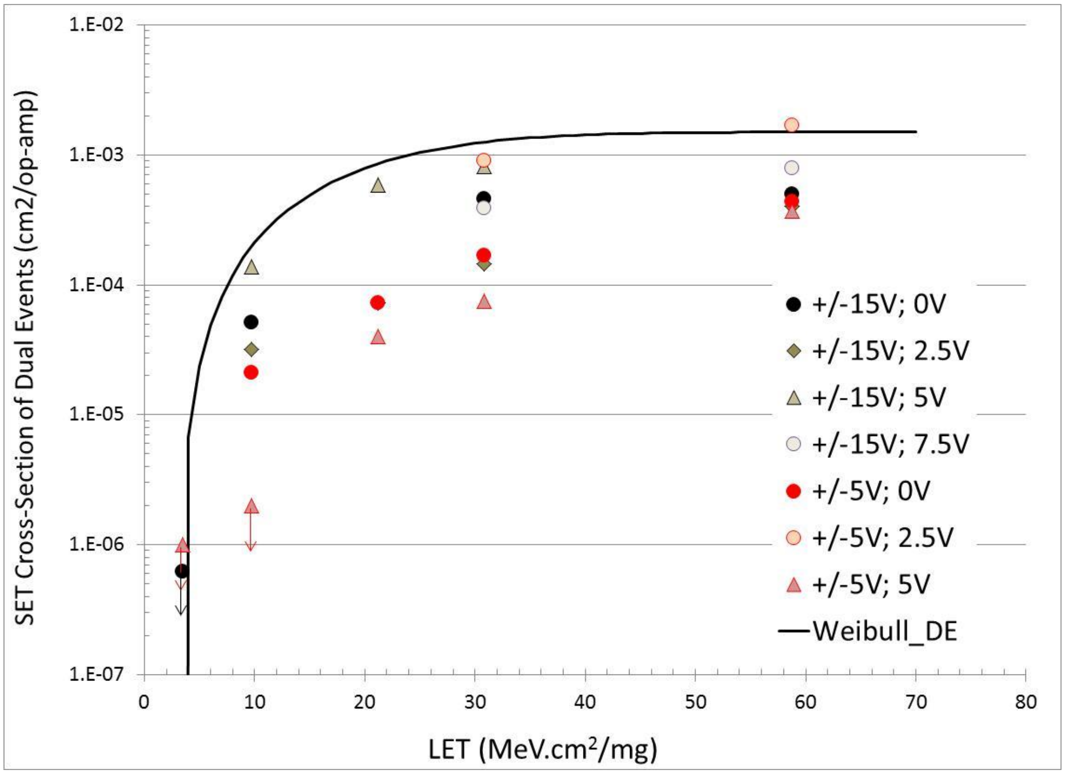


Fig. 28: Dual Events Cross-Sections vs. LET with Power Supply Bias: +/-15V and +/-5V, Input Supply Bias: +/-7.5V, +/-5V, +/-2.5V, +/-0.1V; Minimum Load Current (without 50Ohms board termination)

3) SEL Immunity at Hot (100°C) at +/-10% Nominal Power Supply (+/-16.5V)

At high temperature (100°C) at the DUT case, the test results (black circles in Fig. 32) showed immunity to SELs up to an LET of 117.5 MeV.cm^2/mg.

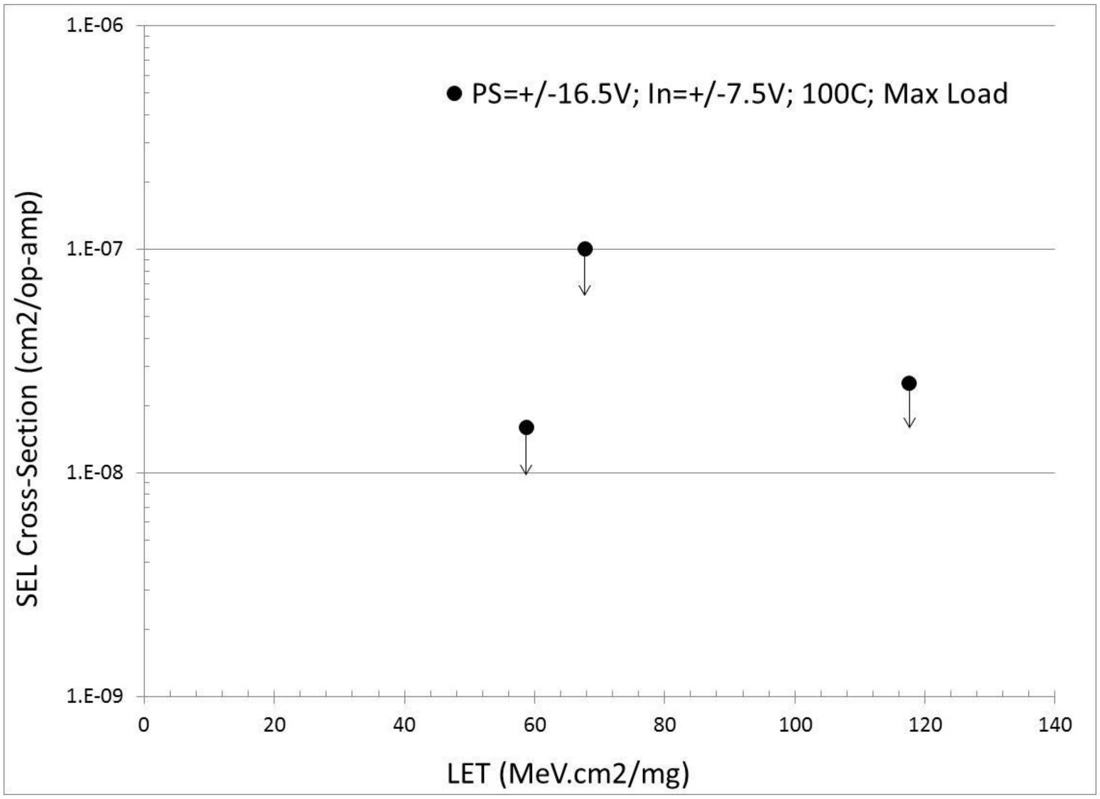


Fig. 29: Measured SEL Cross-Sections vs. LET, showing the RH1498MW immunity to SELs

Arrows pointing down are indication of no observed SETs up to that fluence at tested LET

Table 5: Raw Data for the Heavy-Ion Beam Runs

Run #	Tb (Vacuum)	PS	Vin (E5)	Vin (E11)	Trig Out	Trig. Ch.	Ion	Eff. Fluence	Average Flux	Maximum Flux	Tilt Angle	Eff. LET	TID (Run)	TID (Cum.)	#SET	SET Cross-Section	Observations
	C		(V)	(V)	(mV)			p/cm2	p/sec/cm2	p/sec/cm2	degrees	MeV.cm2/mg	rads(Si)	rads(Si)		cm2/circuit	
1	Room Temp	+/-15V	0.07	0.07	36	OutA	Xe 58.78	1.94E+05	1.47E+03	1.71E+03	0	58.78	1.82E+02	4.14E+03	189	9.74E-04	pos SET
2	//	+/-15V	0.07	0.07	36	OutA	Xe 58.78	1.78E+05	1.43E+03	1.82E+03	0	58.78	1.67E+02	4.20E+03	180	1.01E-03	pos SET
3	//	+/-15V	0.07	0.07	-36	OutA	Xe 58.78	3.04E+05	1.56E+03	1.96E+03	0	58.78	2.86E+02	1.14E+03	269	8.85E-04	neg SET
4	//	+/-15V	0.07	0.07	35	OutB	Xe 58.78	4.03E+05	1.51E+03	1.75E+03	0	58.78	3.79E+02	8.56E+02	361	8.96E-04	pos SET
5	//	+/-15V	0.07	0.07	-35	OutB	Xe 58.78	2.62E+05	1.52E+03	1.71E+03	0	58.78	2.46E+02	4.77E+02	225	8.59E-04	neg SET
6	//	+/-15V	2.50	2.50	200	OutA	Xe 58.78	2.45E+05	1.52E+03	1.73E+03	0	58.78	2.30E+02	2.30E+02	207	8.45E-04	pos SET
7	//	+/-15V	2.50	2.50	90	OutA	Xe 58.78	1.85E+05	1.53E+03	1.82E+03	0	58.78	1.74E+02	4.04E+02	207	1.12E-03	neg SET
8	//	+/-15V	2.50	2.50	-90	OutB	Xe 58.78	2.01E+05	1.28E+03	1.77E+03	0	58.78	1.89E+02	5.93E+02	204	1.01E-03	pos SET
9	//	+/-15V	2.50	2.50	-150	OutB	Xe 58.78	2.47E+05	1.13E+03	1.84E+03	0	58.78	2.32E+02	8.26E+02	179	7.25E-04	neg SET
10	//	+/-15V	5.00	5.00	275	OutA	Xe 58.78	3.56E+05	1.50E+03	1.77E+03	0	58.78	3.35E+02	1.16E+03	231	6.49E-04	pos SET
11	//	+/-15V	5.00	5.00	200	OutA	Xe 58.78	2.35E+05	1.14E+03	1.75E+03	0	58.78	2.21E+02	1.38E+03	192	8.17E-04	neg SET
12	//	+/-15V	5.00	5.00	-200	OutB	Xe 58.78	1.52E+05	1.52E+03	1.74E+03	0	58.78	1.43E+02	1.52E+03	156	1.03E-03	pos SET
13	//	+/-15V	5.00	5.00	-260	OutB	Xe 58.78	1.67E+05	1.51E+03	1.75E+03	0	58.78	1.57E+02	1.68E+03	177	1.06E-03	neg SET
14	//	+/-15V	5.00	5.00	275	OutA	Xe 58.78	7.74E+04	5.23E+02	6.82E+02	0	58.78	7.28E+01	1.75E+03	154	1.99E-03	pos SET
15	//	+/-15V	7.50	7.50	380	OutA	Xe 58.78	9.17E+04	5.72E+02	7.29E+02	0	58.78	8.62E+01	1.84E+03	191	2.08E-03	pos SET
16	//	+/-15V	7.50	7.50	370	OutA	Xe 58.78	1.41E+05	4.47E+02	6.95E+02	0	58.78	1.33E+02	1.97E+03	150	1.06E-03	neg SET
17	//	+/-15V	7.50	7.50	-330	OutB	Xe 58.78	9.90E+04	5.47E+02	6.78E+02	0	58.78	9.31E+01	2.07E+03	162	1.64E-03	pos SET
18	//	+/-15V	7.50	7.50	-380	OutB	Xe 58.78	1.18E+05	5.48E+02	6.81E+02	0	58.78	1.11E+02	2.18E+03	229	1.94E-03	neg SET
19	//	+/-5V	0.07	0.07	25	OutA	Xe 58.78	1.82E+05	5.57E+02	7.10E+02	0	58.78	1.71E+02	2.35E+03	253	1.39E-03	pos SET
20	//	+/-5V	0.07	0.07	10	OutA	Xe 58.78	1.05E+05	5.72E+02	6.98E+02	0	58.78	9.88E+01	2.45E+03	101	9.62E-04	neg SET
21	//	+/-5V	0.07	0.07	-10	OutB	Xe 58.78	1.08E+05	5.73E+02	7.16E+02	0	58.78	1.02E+02	2.55E+03	120	1.11E-03	pos SET
22	//	+/-5V	0.07	0.07	-20	OutB	Xe 58.78	1.22E+05	5.14E+02	6.91E+02	0	58.78	1.15E+02	2.66E+03	102	8.36E-04	neg SET
23	//	+/-5V	2.50	2.50	140	OutA	Xe 58.78	7.58E+04	5.55E+02	6.60E+02	0	58.78	7.13E+01	2.73E+03	103	1.36E-03	pos SET
24	//	+/-5V	2.50	2.50	90	OutA	Xe 58.78	1.54E+05	5.70E+02	6.84E+02	0	58.78	1.45E+02	2.88E+03	105	6.82E-04	neg SET
25	//	+/-5V	2.50	2.50	-100	OutB	Xe 58.78	6.36E+04	5.69E+02	6.66E+02	0	58.78	5.98E+01	2.94E+03	112	1.76E-03	pos SET
26	//	+/-5V	2.50	2.50	-145	OutB	Xe 58.78	7.54E+04	5.10E+02	6.89E+02	0	58.78	7.09E+01	3.01E+03	107	1.42E-03	neg SET

27	//	+/-5V	5.00	5.00	255	OutA	Xe 58.78	1.93E+05	4.76E+02	7.38E+02	0	58.78	1.82E+02	3.19E+03	103	5.34E-04	pos SET
28	//	+/-5V	5.00	5.00	200	OutA	Xe 58.78	1.15E+05	4.61E+02	7.00E+02	0	58.78	1.08E+02	3.30E+03	1	8.70E-06	neg SET
29	//	+/-5V	5.00	5.00	200	OutA	Xe 58.78	1.09E+06	2.60E+03	9.20E+03	0	58.78	1.03E+03	4.33E+03	20	1.83E-05	neg SET
30	//	+/-5V	5.00	5.00	-200	OutB	Xe 58.78	2.06E+06	8.78E+03	9.30E+03	0	58.78	1.94E+03	6.26E+03	76	3.69E-05	pos SET
31	//	+/-5V	5.00	5.00	-260	OutB	Xe 58.78	2.91E+05	4.02E+03	8.96E+03	0	58.78	2.74E+02	6.54E+03	322	1.11E-03	neg SET
32	//	+/-5V	0.07	0.07	30	OutA	Kr 30.86	9.43E+04	4.07E+02	3.67E+03	0	30.86	4.66E+01	6.58E+03	105	1.11E-03	pos SET
33	//	+/-15V	0.07	0.07	30	OutA	Kr 30.86	5.26E+04	4.04E+02	5.77E+02	0	30.86	2.60E+01	6.61E+03	99	1.88E-03	pos SET
34	//	+/-15V	0.07	0.07	10	OutA	Kr 30.86	9.42E+04	2.36E+02	3.33E+02	0	30.86	4.65E+01	6.66E+03	115	1.22E-03	neg SET
35	//	+/-15V	0.07	0.07	-10	OutB	Kr 30.86	7.34E+04	2.36E+02	3.15E+02	0	30.86	3.62E+01	6.69E+03	106	1.44E-03	pos SET
36	//	+/-15V	0.07	0.07	-25	OutB	Kr 30.86	6.18E+04	2.36E+02	3.14E+02	0	30.86	3.05E+01	6.72E+03	102	1.65E-03	neg SET
37	//	+/-15V	2.50	2.50	135	OutA	Kr 30.86	5.48E+04	2.28E+02	3.20E+02	0	30.86	2.71E+01	6.75E+03	111	2.03E-03	pos SET
38	//	+/-15V	2.50	2.50	90	OutA	Kr 30.86	7.87E+04	2.54E+02	3.36E+02	0	30.86	3.89E+01	6.79E+03	118	1.50E-03	neg SET
39	//	+/-15V	2.50	2.50	-90	OUtB	Kr 30.86	7.22E+04	2.07E+02	3.08E+02	0	30.86	3.56E+01	6.82E+03	162	2.24E-03	pos SET
40	//	+/-15V	2.50	2.50	-145	OUtB	Kr 30.86	7.78E+04	2.22E+02	3.06E+02	0	30.86	3.84E+01	6.86E+03	117	1.50E-03	neg SET
41	//	+/-15V	5.00	5.00	265	OutA	Kr 30.86	4.56E+04	7.87E+01	2.68E+02	0	30.86	2.25E+01	6.88E+03	109	2.39E-03	pos SET
42	//	+/-15V	5.00	5.00	210	OutA	Kr 30.86	5.74E+04	7.53E+01	1.32E+02	0	30.86	2.83E+01	6.91E+03	101	1.76E-03	neg SET
43	//	+/-15V	5.00	5.00	-210	OUtB	Kr 30.86	4.00E+04	7.47E+01	1.26E+02	0	30.86	1.98E+01	6.93E+03	100	2.50E-03	pos SET
44	//	+/-15V	5.00	5.00	-265	OUtB	Kr 30.86	7.64E+04	7.86E+01	1.30E+02	0	30.86	3.77E+01	6.97E+03	101	1.32E-03	neg SET
45	//	+/-15V	7.50	7.50	380	OutA	Kr 30.86	3.87E+04	8.05E+01	1.36E+02	0	30.86	1.91E+01	6.99E+03	100	2.58E-03	pos SET
46	//	+/-15V	7.50	7.50	330	OutA	Kr 30.86	7.18E+04	7.89E+01	1.38E+02	0	30.86	3.55E+01	7.02E+03	100	1.39E-03	neg SET
47	//	+/-15V	7.50	7.50	-330	OutB	Kr 30.86	5.79E+04	7.91E+01	1.31E+02	0	30.86	2.86E+01	7.05E+03	100	1.73E-03	pos SET
48	//	+/-15V	7.50	7.50	-380	OutB	Kr 30.86	5.95E+04	8.23E+01	1.39E+02	0	30.86	2.94E+01	7.08E+03	100	1.68E-03	neg SET
49	//	+/-15V	0.07	0.07	25	OutA	Kr 30.86	6.44E+04	8.32E+01	1.32E+02	0	30.86	3.18E+01	7.11E+03	100	1.55E-03	pos SET
50	//	+/-15V	0.07	0.07	10	OutA	Kr 30.86	1.10E+05	8.58E+01	1.39E+02	0	30.86	5.43E+01	7.17E+03	85	7.73E-04	neg SET
51	//	+/-5V	0.07	0.07	10	OutA	Kr 30.86	2.70E+05	3.36E+02	5.47E+02	0	30.86	1.33E+02	7.30E+03	124	4.59E-04	neg SET
52	//	+/-5V	0.07	0.07	-25	OutA	Kr 30.86	1.26E+05	4.27E+02	5.41E+02	0	30.86	6.22E+01	7.36E+03	111	8.81E-04	neg SET
53	//	+/-5V	0.07	0.07	10	OutB	Kr 30.86	1.61E+05	4.08E+02	5.50E+02	0	30.86	7.95E+01	7.44E+03	103	6.40E-04	pos SET
54	//	+/-5V	0.07	0.07	-25	OutB	Kr 30.86	9.58E+04	2.28E+02	4.88E+02	0	30.86	4.73E+01	7.49E+03	108	1.13E-03	neg SET
55	//	+/-5V	2.50	2.50	135	OutA	Kr 30.86	9.20E+04	2.21E+02	2.88E+02	0	30.86	4.54E+01	7.54E+03	106	1.15E-03	pos SET
56	//	+/-5V	2.50	2.50	90	OutA	Kr 30.86	9.67E+04	2.19E+02	2.97E+02	0	30.86	4.77E+01	7.58E+03	105	1.09E-03	neg SET

57	//	+/-5V	2.50	2.50	-90	OutB	Kr 30.86	2.05E+05	2.20E+02	3.17E+02	0	30.86	1.01E+02	7.69E+03	102	4.98E-04	pos SET
58	//	+/-5V	2.50	2.50	-145	OutB	Kr 30.86	1.13E+05	2.19E+02	2.96E+02	0	30.86	5.58E+01	7.74E+03	141	1.25E-03	neg SET
59	//	+/-5V	5.00	5.00	265	OutA	Kr 30.86	5.21E+05	4.47E+02	2.28E+03	0	30.86	2.57E+02	8.00E+03	110	2.11E-04	pos SET
60	//	+/-5V	5.00	5.00	210	OutA	Kr 30.86	5.00E+05	5.28E+02	1.31E+03	0	30.86	2.47E+02	8.25E+03	0	2.00E-06	neg SET
61	//	+/-5V	5.00	5.00	-210	OutB	Kr 30.86	5.00E+05	2.08E+03	4.02E+03	0	30.86	2.47E+02	8.49E+03	0	2.00E-06	pos SET
62	//	+/-5V	5.00	5.00	-265	OutB	Kr 30.86	5.00E+05	3.74E+03	4.03E+03	0	30.86	2.47E+02	8.74E+03	28	5.60E-05	neg SET
64	//	+/-15V	0.07	0.07	25	OutA	Cu 21.17	7.84E+04	2.85E+02	1.39E+03	0	21.17	2.66E+01	8.77E+03	102	1.30E-03	pos SET
65	//	+/-15V	0.07	0.07	10	OutA	Cu 21.17	1.52E+05	3.24E+02	4.37E+02	0	21.17	5.15E+01	8.82E+03	64	4.21E-04	neg SET
67	//	+/-15V	0.07	0.07	-10	OutB	Cu 21.17	6.61E+04	4.52E+02	8.98E+02	0	21.17	2.24E+01	8.84E+03	52	7.87E-04	pos SET
68	//	+/-15V	0.07	0.07	-25	OutB	Cu 21.17	6.20E+04	3.23E+02	8.60E+02	0	21.17	2.10E+01	8.86E+03	53	8.55E-04	neg SET
69	//	+/-15V	2.50	2.50	135	OutA	Cu 21.17	4.13E+04	2.88E+02	3.79E+02	0	21.17	1.40E+01	8.87E+03	55	1.33E-03	pos SET
70	//	+/-15V	2.50	2.50	90	OutA	Cu 21.17	4.27E+04	2.97E+02	3.91E+02	0	21.17	1.45E+01	8.89E+03	58	1.36E-03	neg SET
71	//	+/-15V	2.50	2.50	-90	OutB	Cu 21.17	5.70E+04	2.67E+02	3.71E+02	0	21.17	1.93E+01	8.91E+03	56	9.82E-04	pos SET
72	//	+/-15V	2.50	2.50	-145	OutB	Cu 21.17	5.01E+05	1.26E+03	6.81E+03	0	21.17	1.70E+02	9.08E+03	48	9.58E-05	neg SET
73	//	+/-15V	5.00	5.00	265	OutA	Cu 21.17	5.81E+04	2.59E+02	1.80E+03	0	21.17	1.97E+01	9.10E+03	103	1.77E-03	pos SET
74	//	+/-15V	5.00	5.00	210	OutA	Cu 21.17	3.41E+04	1.44E+02	2.11E+02	0	21.17	1.16E+01	9.11E+03	51	1.50E-03	neg SET
75	//	+/-15V	5.00	5.00	-210	OutB	Cu 21.17	3.44E+04	1.48E+02	2.05E+02	0	21.17	1.17E+01	9.12E+03	44	1.28E-03	pos SET
76	//	+/-15V	5.00	5.00	-265	OutB	Cu 21.17	2.12E+04	1.48E+02	2.17E+02	0	21.17	7.18E+00	9.13E+03	43	2.03E-03	neg SET
77	//	+/-5V	0.07	0.07	25	OutA	Cu 21.17	1.12E+05	1.49E+02	2.19E+02	0	21.17	3.79E+01	9.17E+03	71	6.34E-04	pos SET
78	//	+/-5V	0.07	0.07	10	OutA	Cu 21.17	6.48E+04	1.52E+02	2.23E+02	0	21.17	2.19E+01	9.19E+03	33	5.09E-04	neg SET
79	//	+/-5V	0.07	0.07	-10	OutB	Cu 21.17	3.14E+05	6.99E+02	1.64E+03	0	21.17	1.06E+02	9.29E+03	43	1.37E-04	pos SET
80	//	+/-5V	0.07	0.07	-25	OutB	Cu 21.17	9.61E+04	9.30E+02	1.52E+03	0	21.17	3.26E+01	9.33E+03	54	5.62E-04	neg SET
81	//	+/-5V	5.00	5.00	265	OutA	Cu 21.17	5.02E+05	1.32E+03	4.24E+03	0	21.17	1.70E+02	9.50E+03	42	8.37E-05	pos SET
82	//	+/-5V	5.00	5.00	210	OutA	Cu 21.17	5.02E+05	2.43E+03	2.76E+03	0	21.17	1.70E+02	9.67E+03	0	1.99E-06	neg SET
83	//	+/-5V	5.00	5.00	-210	OutB	Cu 21.17	1.00E+06	3.90E+03	4.37E+03	0	21.17	3.39E+02	1.00E+04	0	1.00E-06	pos SET
84	//	+/-5V	5.00	5.00	-265	OutB	Cu 21.17	1.00E+06	2.55E+03	4.33E+03	0	21.17	3.39E+02	1.03E+04	29	2.90E-05	neg SET
85	//	+/-15V	0.07	0.07	10	OutA	Ar 9.74	8.71E+05	6.29E+03	8.06E+03	0	9.74	1.36E+02	1.05E+04	63	7.23E-05	neg SET
86	//	+/-15V	0.07	0.07	10	OutA	Ar 9.74	1.38E+05	5.61E+02	1.83E+03	0	9.74	2.15E+01	1.05E+04	27	1.96E-04	neg SET
87	//	+/-15V	0.07	0.07	25	OutA	Ar 9.74	2.08E+05	6.17E+02	8.21E+02	0	9.74	3.24E+01	1.05E+04	32	1.54E-04	pos SET
88	//	+/-15V	0.07	0.07	-10	OutB	Ar 9.74	5.00E+05	3.64E+03	9.70E+03	0	9.74	7.79E+01	1.06E+04	13	2.60E-05	pos SET

89	//	+/-15V	0.07	0.07	-25	OutB	Ar 9.74	3.84E+05	7.65E+03	9.64E+03	0	9.74	5.98E+01	1.07E+04	50	1.30E-04	neg SET
90	//	+/-15V	2.50	2.50	135	OutA	Ar 9.74	5.00E+05	3.01E+03	3.30E+03	0	9.74	7.79E+01	1.08E+04	69	1.38E-04	pos SET
91	//	+/-15V	2.50	2.50	90	OutA	Ar 9.74	4.94E+05	2.96E+03	3.23E+03	0	9.74	7.70E+01	1.08E+04	120	2.43E-04	neg SET
92	//	+/-15V	2.50	2.50	-90	OutB	Ar 9.74	4.64E+05	2.89E+03	3.16E+03	0	9.74	7.23E+01	1.09E+04	61	1.31E-04	pos SET
93	//	+/-15V	2.50	2.50	-135	OutB	Ar 9.74	3.35E+05	2.87E+03	3.31E+03	0	9.74	5.22E+01	1.10E+04	69	2.06E-04	neg SET
94	//	+/-15V	5.00	5.00	265	OutA	Ar 9.74	1.00E+05	6.01E+02	3.11E+03	0	9.74	1.56E+01	1.10E+04	60	6.00E-04	pos SET
95	//	+/-15V	5.00	5.00	210	OutA	Ar 9.74	2.10E+05	7.39E+02	1.09E+03	0	9.74	3.27E+01	1.10E+04	89	4.24E-04	neg SET
96	//	+/-15V	5.00	5.00	-210	OutB	Ar 9.74	3.45E+05	9.12E+02	1.07E+03	0	9.74	5.38E+01	1.11E+04	68	1.97E-04	pos SET
97	//	+/-15V	5.00	5.00	-265	OutB	Ar 9.74	1.27E+05	8.98E+02	1.04E+03	0	9.74	1.98E+01	1.11E+04	74	5.83E-04	neg SET
98	//	+/-5V	0.07	0.07	25	OutA	Ar 9.74	5.00E+05	9.35E+02	2.73E+03	0	9.74	7.79E+01	1.12E+04	43	8.60E-05	pos SET
99	//	+/-5V	0.07	0.07	10	OutA	Ar 9.74	5.00E+05	2.46E+03	2.71E+03	0	9.74	7.79E+01	1.12E+04	21	4.20E-05	neg SET
100	//	+/-5V	0.07	0.07	-10	OutB	Ar 9.74	5.00E+05	6.64E+03	1.63E+04	0	9.74	7.79E+01	1.13E+04	15	3.00E-05	pos SET
101	//	+/-5V	0.07	0.07	-25	OutB	Ar 9.74	4.27E+05	1.16E+03	1.18E+04	0	9.74	6.65E+01	1.14E+04	51	1.19E-04	neg SET
102	//	+/-5V	5.00	5.00	265	OutA	Ar 9.74	5.00E+05	1.53E+03	7.77E+03	0	9.74	7.79E+01	1.15E+04	17	3.40E-05	pos SET
103	//	+/-5V	5.00	5.00	210	OutA	Ar 9.74	5.00E+05	3.11E+03	7.85E+03	0	9.74	7.79E+01	1.15E+04	0	2.00E-06	neg SET
104	//	+/-5V	5.00	5.00	-210	OutB	Ar 9.74	5.00E+05	7.47E+03	7.81E+03	0	9.74	7.79E+01	1.16E+04	0	2.00E-06	pos SET
105	//	+/-5V	5.00	5.00	-265	OutB	Ar 9.74	5.00E+05	7.44E+03	7.74E+03	0	9.74	7.79E+01	1.17E+04	1	2.00E-06	neg SET
106	//	+/-15V	0.07	0.07	10	OutA	Ne 3.49	1.60E+06	6.40E+03	6.62E+04	0	3.49	8.93E+01	1.21E+04	1	6.25E-07	neg SET
107	//	+/-15V	0.07	0.07	25	OutA	Ne 3.49	1.71E+06	4.20E+04	6.60E+04	0	3.49	9.55E+01	1.19E+04	2	1.17E-06	pos SET
108	//	+/-15V	0.07	0.07	-10	OutB	Ne 3.49	1.00E+06	3.41E+04	3.63E+04	0	3.49	5.58E+01	1.19E+04	0	1.00E-06	pos SET
109	//	+/-15V	0.07	0.07	-25	OutB	Ne 3.49	1.00E+06	2.57E+04	3.61E+04	0	3.49	5.58E+01	1.20E+04	14	1.40E-05	neg SET
110	//	+/-15V	5.00	5.00	210	OutA	Ne 3.49	1.00E+06	9.87E+03	1.04E+04	0	3.49	5.58E+01	1.20E+04	29	2.90E-05	neg SET
111	//	+/-15V	5.00	5.00	265	OutA	Ne 3.49	1.00E+06	9.82E+03	1.02E+04	0	3.49	5.58E+01	1.21E+04	25	2.50E-05	pos SET
112	//	+/-15V	5.00	5.00	-210	OutB	Ne 3.49	1.00E+06	9.82E+03	1.02E+04	0	3.49	5.58E+01	1.21E+04	1	1.00E-06	pos SET
113	//	+/-15V	5.00	5.00	-265	OutB	Ne 3.49	1.00E+06	9.76E+03	1.02E+04	0	3.49	5.58E+01	1.22E+04	33	3.30E-05	neg SET
114	//	+/-5V	0.07	0.07	25	OutA	Ne 3.49	1.00E+06	9.72E+03	1.01E+04	0	3.49	5.58E+01	1.23E+04	0	1.00E-06	pos SET
115	//	+/-5V	0.07	0.07	10	OutA	Ne 3.49	1.00E+06	9.57E+03	1.02E+04	0	3.49	5.58E+01	1.23E+04	1	1.00E-06	neg SET
116	//	+/-5V	0.07	0.07	-10	OutB	Ne 3.49	1.00E+06	9.55E+03	1.01E+04	0	3.49	5.58E+01	1.24E+04	0	1.00E-06	pos SET
117	//	+/-5V	0.07	0.07	-25	OutB	Ne 3.49	1.00E+06	9.43E+03	9.97E+03	0	3.49	5.58E+01	1.24E+04	2	2.00E-06	neg SET
118	//	+/-5V	5.00	5.00	265	OutA	Ne 3.49	1.00E+06	9.43E+03	9.86E+03	0	3.49	5.58E+01	1.25E+04	0	1.00E-06	pos SET

119	//	+/-5V	5.00	5.00	210	OutA	Ne 3.49	1.00E+06	9.37E+03	9.84E+03	0	3.49	5.58E+01	1.25E+04	0	1.00E-06	neg SET
120	//	+/-5V	5.00	5.00	-10	OutB	Ne 3.49	1.00E+06	9.41E+03	9.88E+03	0	3.49	5.58E+01	1.26E+04	0	1.00E-06	pos SET
121	//	+/-5V	5.00	5.00	-25	OutB	Ne 3.49	1.00E+06	9.43E+03	9.86E+03	0	3.49	5.58E+01	1.27E+04	0	1.00E-06	pos SET
122	//	+/-5V	5.00	5.00	-265	OutB	Ne 3.49	1.00E+06	9.46E+03	9.96E+03	0	3.49	5.58E+01	1.27E+04	0	1.00E-06	neg SET
123	//	+/-15V	0.07	0.07	25	OutA	Xe 58.78	3.89E+04	9.44E+01	3.76E+02	0	58.78	3.66E+01	1.27E+04	101	2.60E-03	pos SET
124	//	+/-15V	0.07	0.07	10	OutA	Xe 58.78	8.49E+04	1.10E+02	2.56E+02	0	58.78	7.98E+01	1.28E+04	102	1.20E-03	neg SET
125	//	+/-15V	0.07	0.07	-10	OutB	Xe 58.78	5.50E+04	1.82E+02	2.42E+02	0	58.78	5.17E+01	1.29E+04	74	1.35E-03	pos SET
126	//	+/-15V	0.07	0.07	-25	OutB	Xe 58.78	5.56E+04	1.87E+02	2.65E+02	0	58.78	5.23E+01	1.29E+04	104	1.87E-03	neg SET
127	100	+/-16.5V	7.50	7.50	-380	OutB	Xe 58.78	1.24E+06			0	58.78	1.17E+03	1.39E+04	466	3.76E-04	neg SET
128	//	+/-16.5V	7.50	7.50	-380	OutB	Xe 58.78	1.00E+07			0	58.78	9.40E+03	2.33E+04	3572	3.57E-04	neg SET
129	//	+/-16.5V	7.50	7.50	-380	OutB	Xe 58.78	1.00E+07	3.11E+04	4.15E+04	30	67.87	1.09E+04	3.41E+04	4107	4.11E-04	
130	//	+/-16.5V	7.50	7.50	-380	OutB	Xe 58.78	1.00E+07	3.62E+04	4.09E+04	60	117.56	1.88E+04	5.29E+04	5963	5.96E-04	
131	//	+/-16.5V	-7.50	-7.50	-380	OutA	Xe 58.78	1.00E+07	3.69E+04	4.21E+04	60	117.56	1.88E+04	7.17E+04	6013	6.01E-04	
132	//	+/-16.5V	-7.50	-7.50	-380	OutA	Xe 58.78	1.00E+07	3.31E+04	4.15E+04	0	58.78	9.40E+03	8.12E+04	3251	3.25E-04	
133	//	+/-15V	7.50	7.50	7.4	OutA	Xe 58.78	1.00E+07	3.67E+04	4.17E+04	0	58.78	9.40E+03	9.06E+04	1323	1.32E-04	
134	//	+/-15V	7.50	7.50	-8.05	OutB	Xe 58.78	1.05E+05	2.63E+02	7.95E+02	0	58.78	9.88E+01	9.07E+04	100	9.52E-04	neg SET
135	//	+/-16.5V	7.50	7.50	-380	OutB	Xe 58.78	1.00E+07	3.08E+04	3.55E+04	0	58.78	9.40E+03	1.00E+05	1944	1.94E-04	neg SET
136	//	+/-16.5V	7.50	7.50	-380	All	Xe 58.78	2.00E+05	2.52E+02	7.04E+02	0	58.78	1.88E+02	1.00E+05	79	3.95E-04	neg SET
137	//	+/-16.5V	7.50	7.50	-380	OutB	Xe 58.78	2.00E+05	6.79E+02	1.83E+03	0	58.78	1.88E+02	1.00E+05	60	3.00E-04	neg SET
138	//	+/-16.5V	0.07	0.07	25	OutB	Xe 58.78	2.00E+05	1.63E+03	1.96E+03	0	58.78	1.88E+02	1.01E+05	40	2.00E-04	pos SET
139	//	+/-16.5V	0.07	0.07	10	OutB	Xe 58.78	2.00E+05	1.09E+03	2.02E+03	0	58.78	1.88E+02	1.01E+05	40	2.00E-04	neg SET
141	//	+/-16.5V	0.07	0.07	10	all	Xe 58.78	2.00E+05	1.62E+03	1.94E+03	0	58.78	1.88E+02	1.01E+05	20	1.00E-04	neg SET
142	//	+/-16.5V	7.50	7.50	-380	All	Xe 58.78	1.00E+07	2.97E+04	3.40E+04	-60	117.56	1.88E+04	1.20E+05	1556	1.56E-04	neg SET
144	//	+/-16.5V	7.50	7.50	-380	All	Xe 58.78	1.00E+07	2.94E+04	3.47E+04	-60	117.56	1.88E+04	1.39E+05	4401	4.40E-04	neg SET
145	30	+/-16.5V	7.50	7.50	-380	All	Xe 58.78	1.00E+07	2.99E+04	3.51E+04	0	58.78	9.40E+03	1.48E+05	2334	2.33E-04	neg SET
146	30	+/-16.5V	7.50	7.50	-380	All	Xe 58.78	1.00E+07	3.04E+04	3.48E+04	0	58.78	9.40E+03	1.57E+05	2154	2.15E-04	neg SET
147	30	+/-16.5V	7.50	7.50	-380	All	Xe 58.78	2.15E+05	5.32E+02	6.94E+02	0	58.78	2.02E+02	1.58E+05	104	4.84E-04	neg SET
148	30	+/-16.5V	7.50	7.50	-380	All	Xe 58.78	9.58E+04	7.95E+01	1.51E+02	0	58.78	9.01E+01	1.58E+05	43	4.49E-04	neg SET

*Tb is the temperature sensed by the transistor on the board (as shown in Fig. 5)

3ft BNC cable (120pF)	Energy Cocktail	10MeV/nucleon

References:

[1] RH1498M DataSheet: http://cds.linear.com/docs/en/datasheet/rh1498mfe.pdf

[2] LT1498 Datasheet: http://www.linear.com/product/LT1498

[3] RH1498M Spec.: http://cds.linear.com/docs/en/spec-notice/RH1498_DIE_CAN_SAM_05-08-5208_DICE_SPEC_REV__F.pdf

[4] J. Forney, and S. Buchner, Single Event Transient Testing of RH1499 Test Report, June 2006.

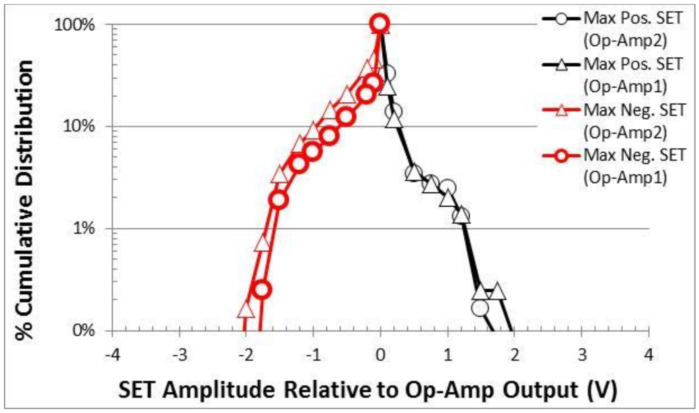
[6] LTSpice: http://www.linear.com/designtools/software/#LTspice

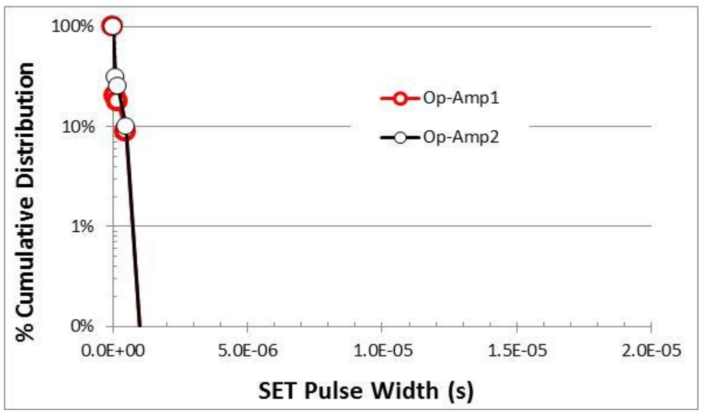
Appendix A.: SET Distributions in Pulse Widths and Amplitudes per Bias Conditions

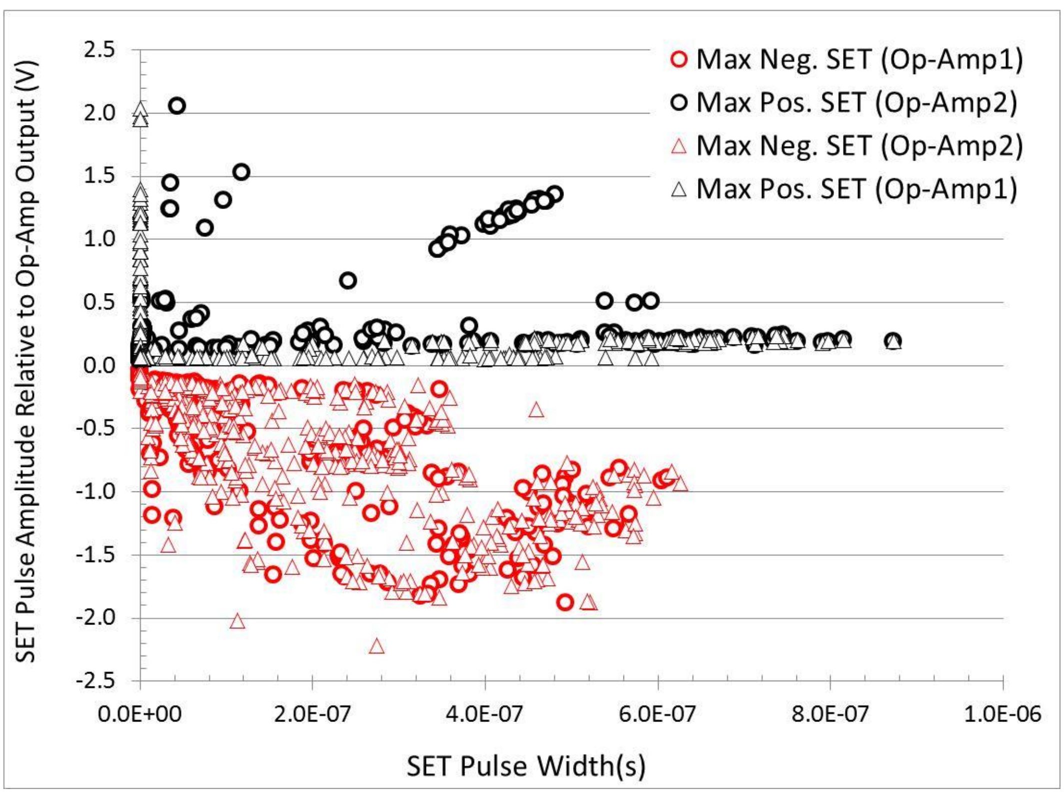
1. V supply=+/-15V; V input=+/-0.1V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 1-5)
2. V supply=+/-15V; V input=+/-0.1V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 32-36)
3. V supply=+/-15V; V input=+/-0.1V; Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 65-68)
4. V supply=+/-15V; V input=+/-0.1V; Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 85-89)
5. V supply=+/-15V; V input=+/-0.1V; Neon Ions; LET=3.49 MeV.cm^2/mg (Runs 106-109)
6. V supply=+/-15V; V input=+/-2.5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 6-9)
7. V supply=+/-15V; V input=+/-2.5V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 37-40)
8. V supply=+/-15V; V input=+/-2.5V; Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 69-72)
9. V supply=+/-15V; V input=+/-2.5V; Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 90-93)
10. V supply=+/-15V; V input=+/-5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 10-14)
11. V supply=+/-15V; V input=+/-5V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 41-44)
12. V supply=+/-15V; V input=+/-5V; Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 73-76)
13. V supply=+/-15V; V input=+/-5V; Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 94-97)
14. V supply=+/-15V; V input=+/-5V; Neon Ions; LET=3.49 MeV.cm^2/mg (Runs 110-113)
15. V supply=+/-15V; V input=+/-7.5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 15-18)
16. V supply=+/-15V; V input=+/-7.5V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 45-48)
17. V supply=+/-5V; V input=+/-0.1V. Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 19-22)
18. V supply=+/-5V; V input=+/-0.1V. Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 49-54)
19. V supply=+/-5V; V input=+/-0.1V. Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 77-80)
20. V supply=+/-5V; V input=+/-0.1V. Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 98-101)
21. V supply=+/-5V; V input=+/-0.1V; Neon Ions; LET=3.49 MeV.cm^2/mg (Runs 114-117); **No errors**
22. V supply=+/-5V; V input=+/-2.5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 23-26)
23. V supply=+/-5V; V input=+/-2.5V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 55-58)
24. V supply=+/-5V; V input=+/-5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 27-31)
25. V supply=+/-5V; V input=+/-5V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 59-63)
26. V supply=+/-5V; V input=+/-5V; Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 81-84)
27. V supply=+/-5V; V input=+/-5V; Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 102-105)
28. V supply=+/-5V; V input=+/-5V; Neon Ions; LET=3.49 MeV.cm^2/mg; **No Errors**
29. V supply=+/-16.5V; V input=+/-7.5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 135)

Note: From Run 1 to 30, beam-induced small amplitude SETs might have been wider than 5us as the scope window duration time was smaller than the entire SET-PW. However, the SET-PWs for the high-amplitude SETs are accurate (shorter than 1us).

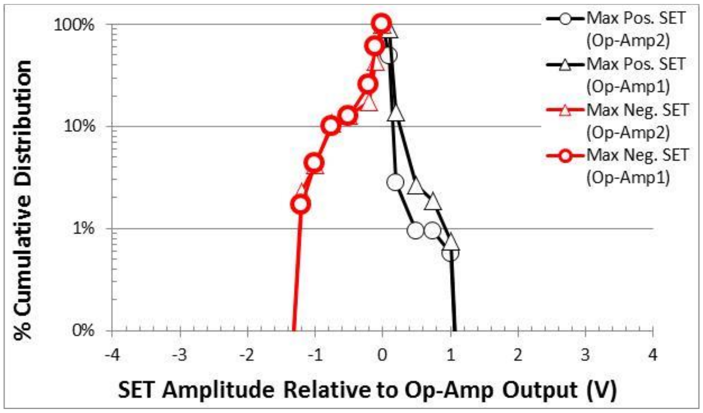
1. V supply=+/-15V; V input=+/-0.1V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 1-5)

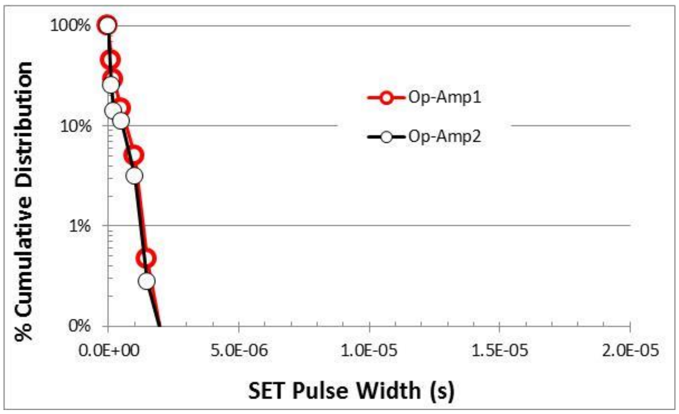


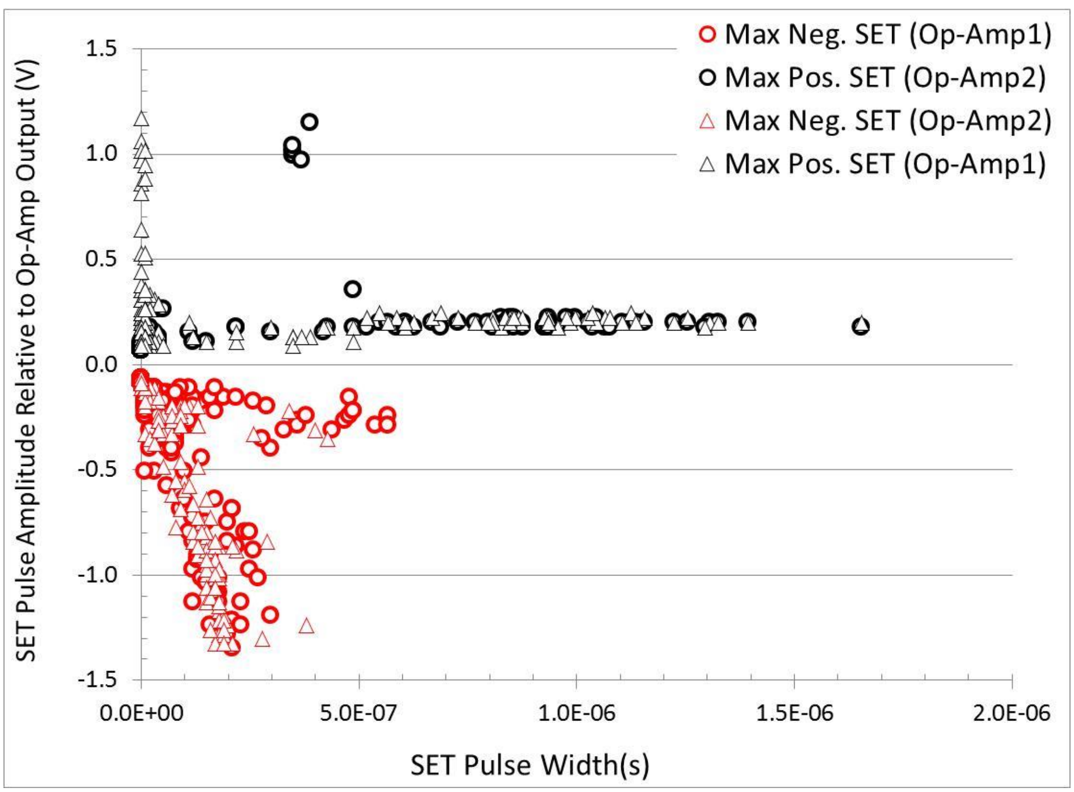




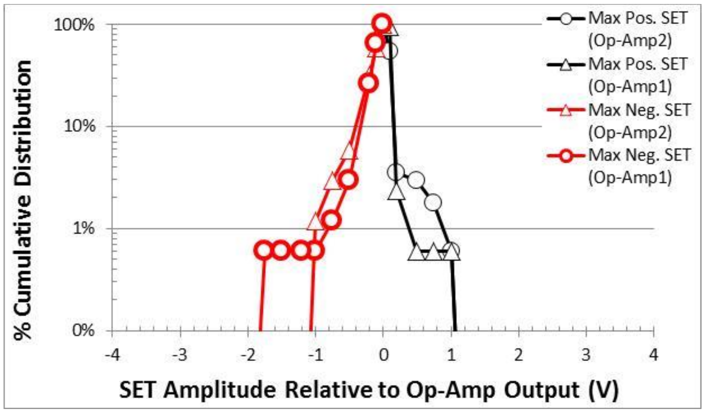
2. V supply=+/-15V; V input=+/-0.1V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 32-36)

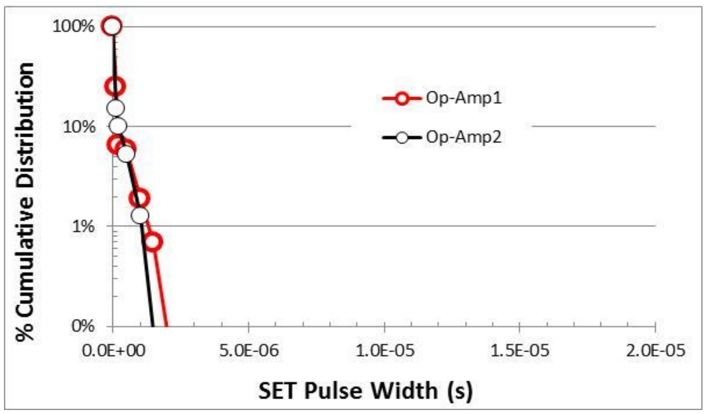


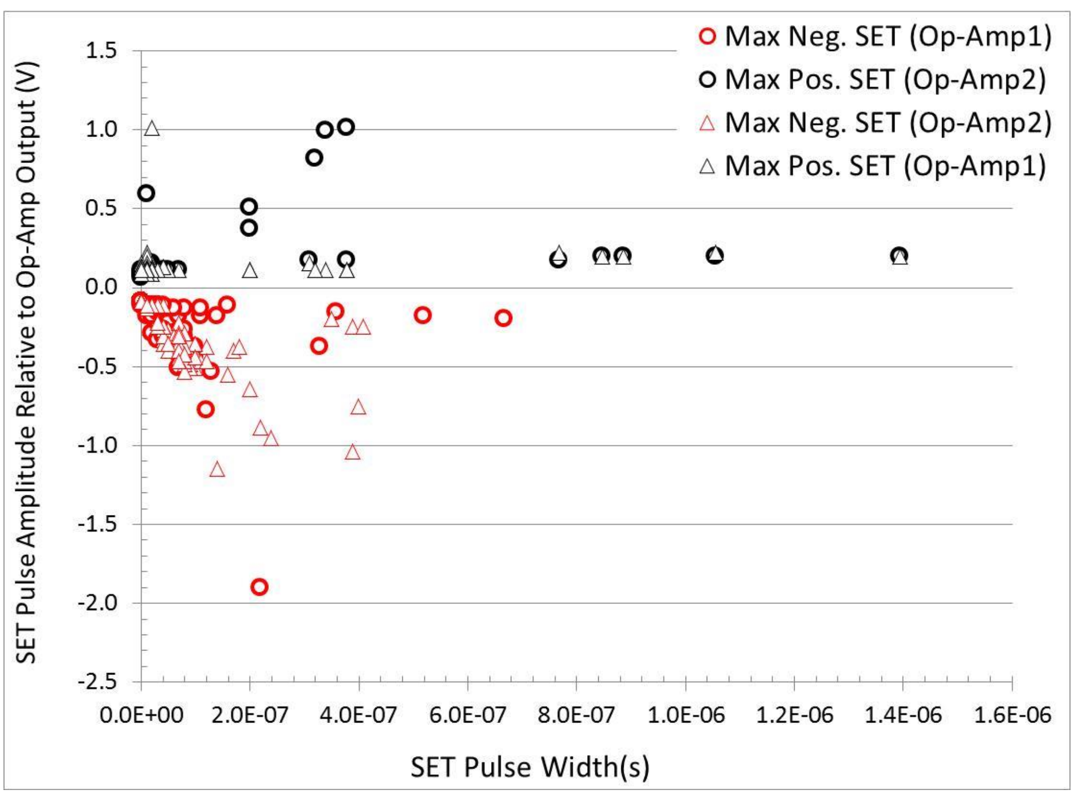




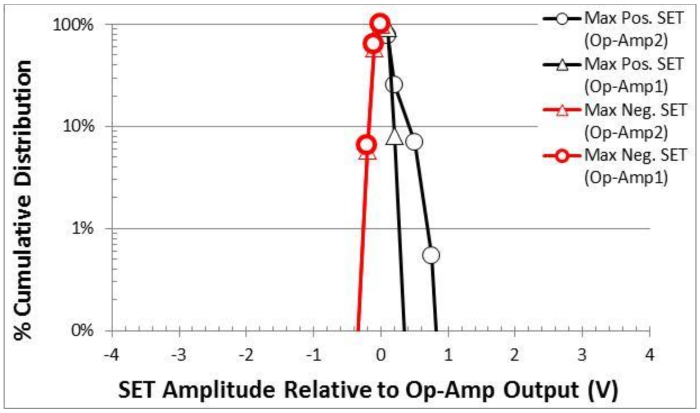
3. V supply=+/-15V; V input=+/-0.1V; Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 65-68)

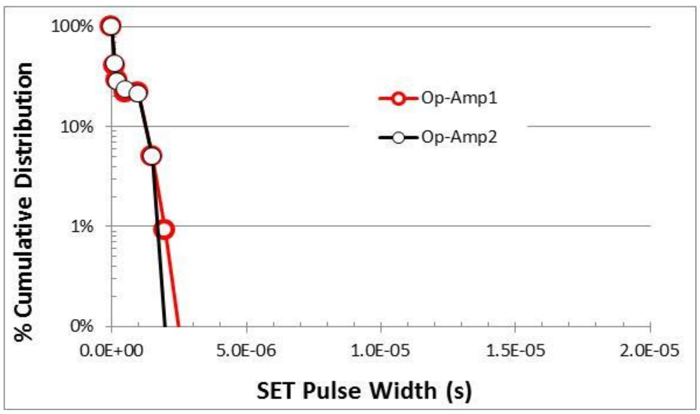


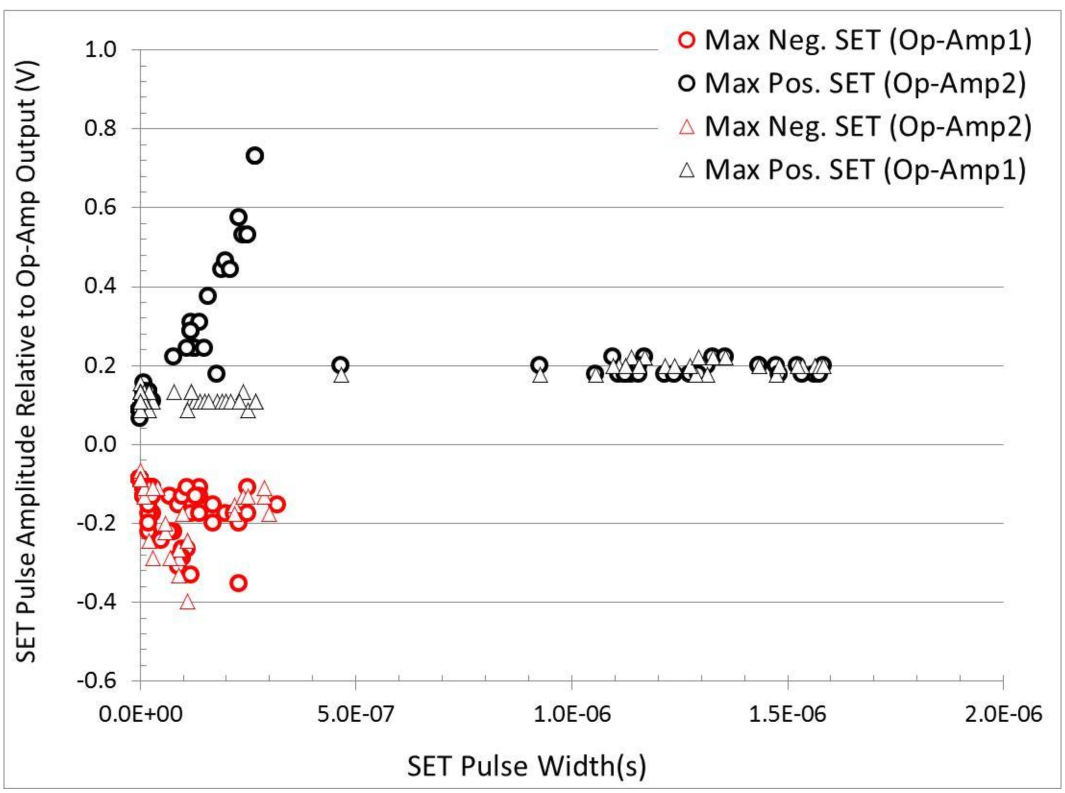




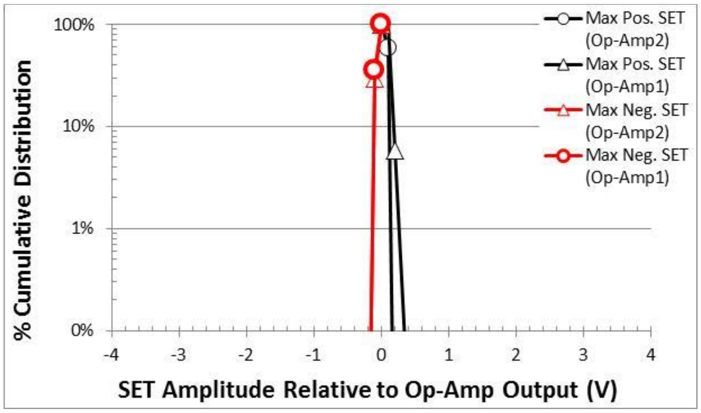
4. V supply=+/-15V; V input=+/-0.1V; Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 85-89)

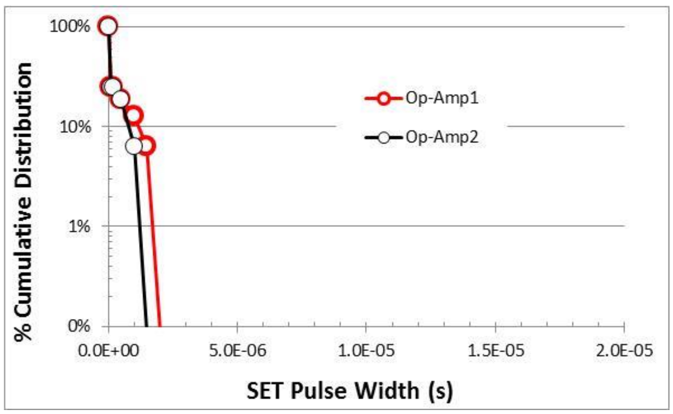


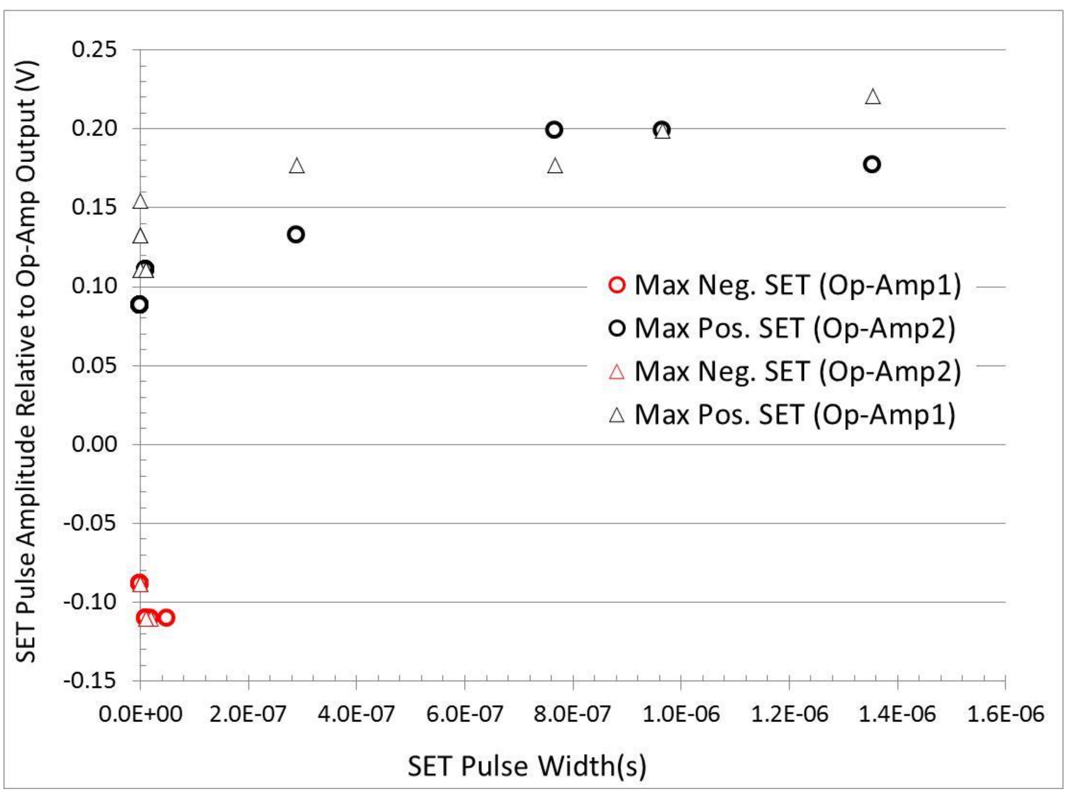




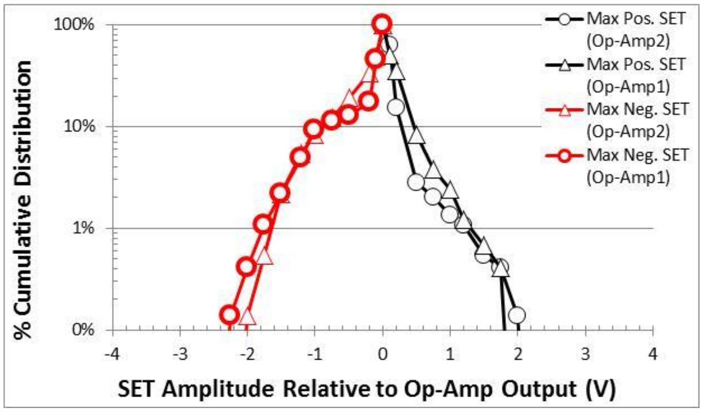
5. V supply=+/-15V; V input=+/-0.1V; Neon Ions; LET=3.49 MeV.cm^2/mg (Runs 106-109)

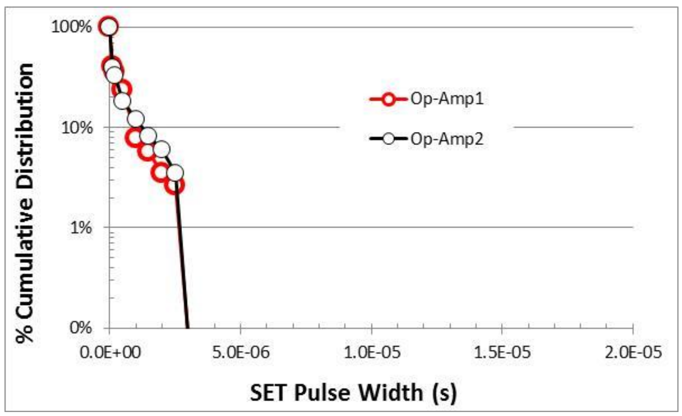


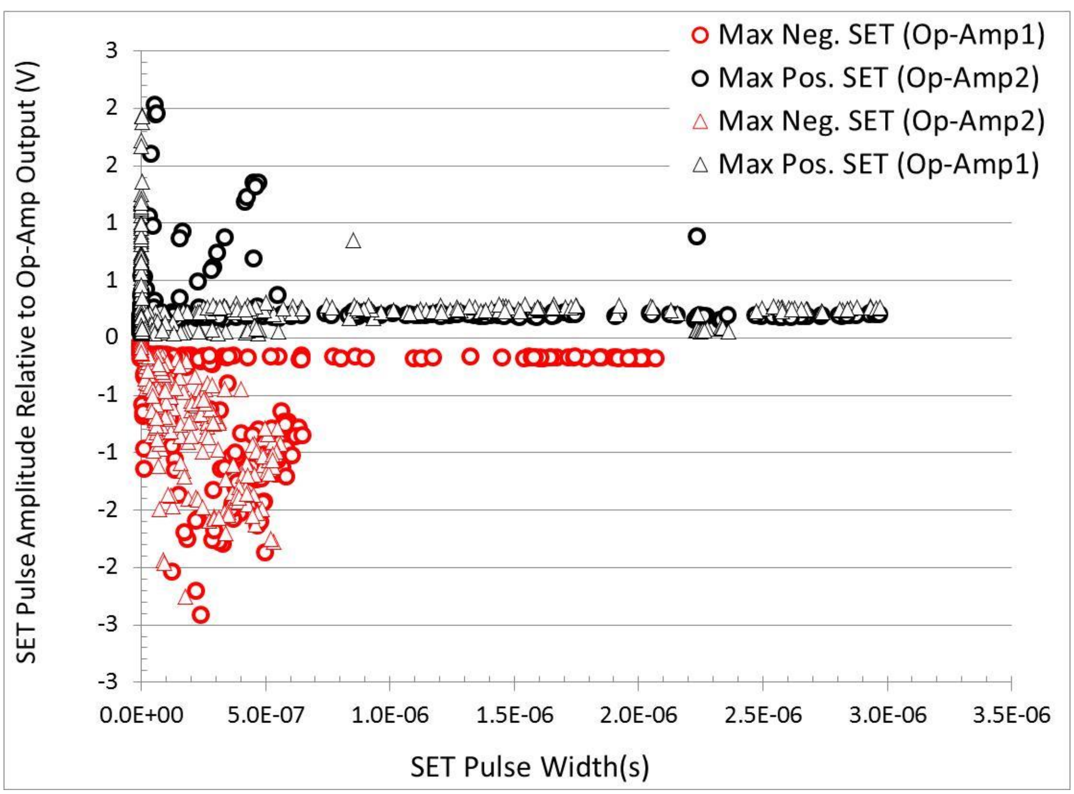




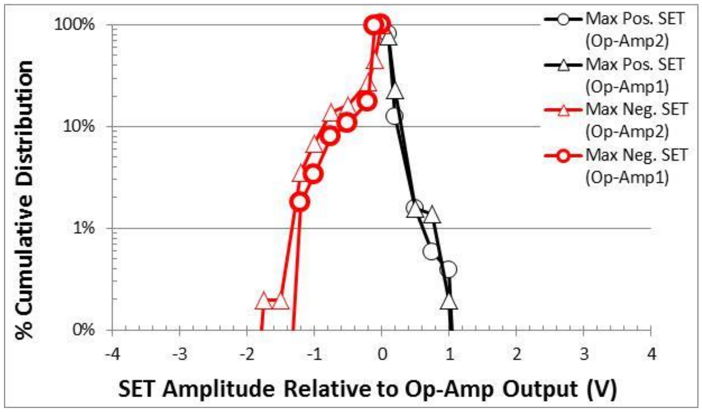
6. V supply=+/-15V; V input=+/-2.5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 6-9)

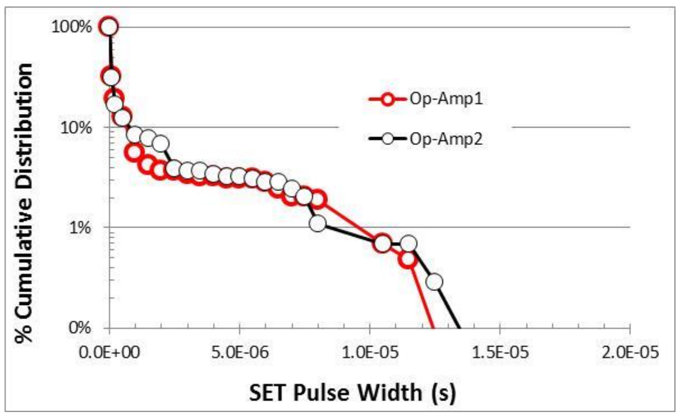


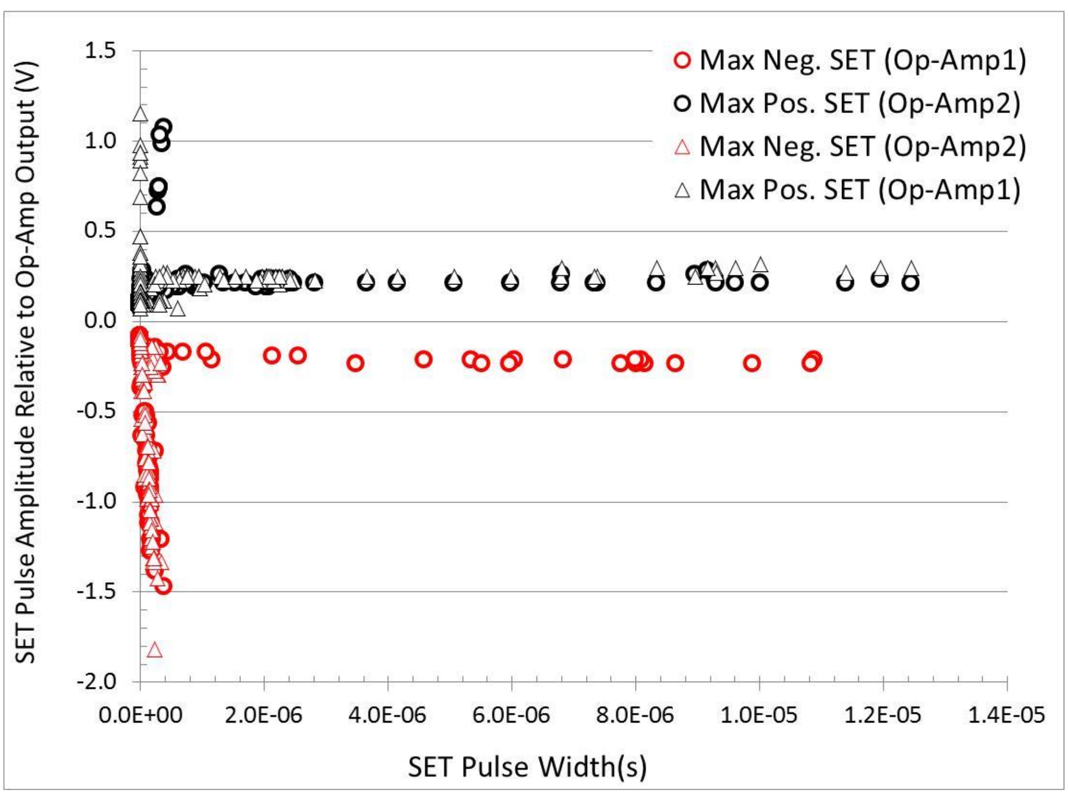




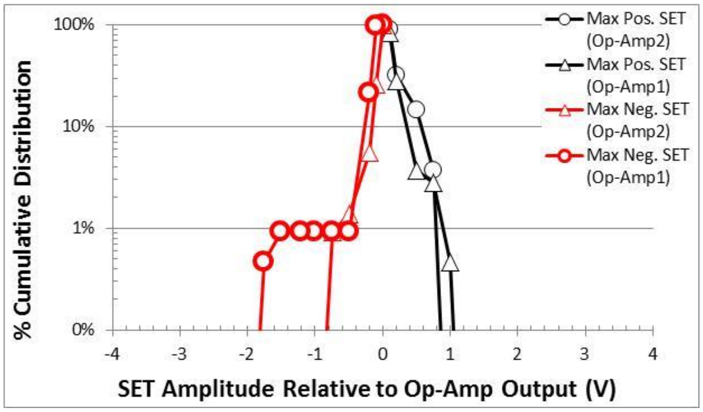
7. V supply=+/-15V; V input=+/-2.5V; Krypton Ions; LET=30.86 $MeV.cm^2/mg$ (Runs 37-40)

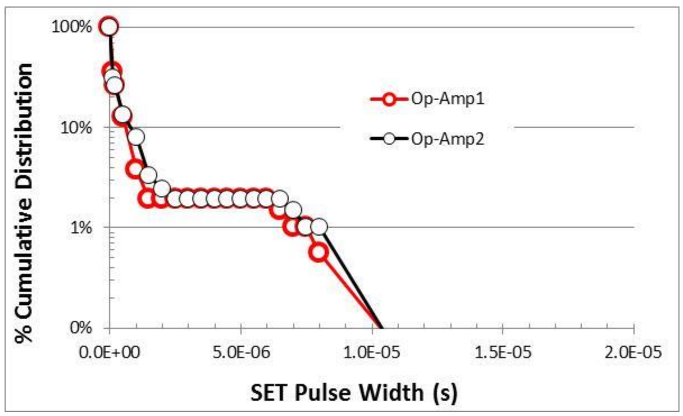


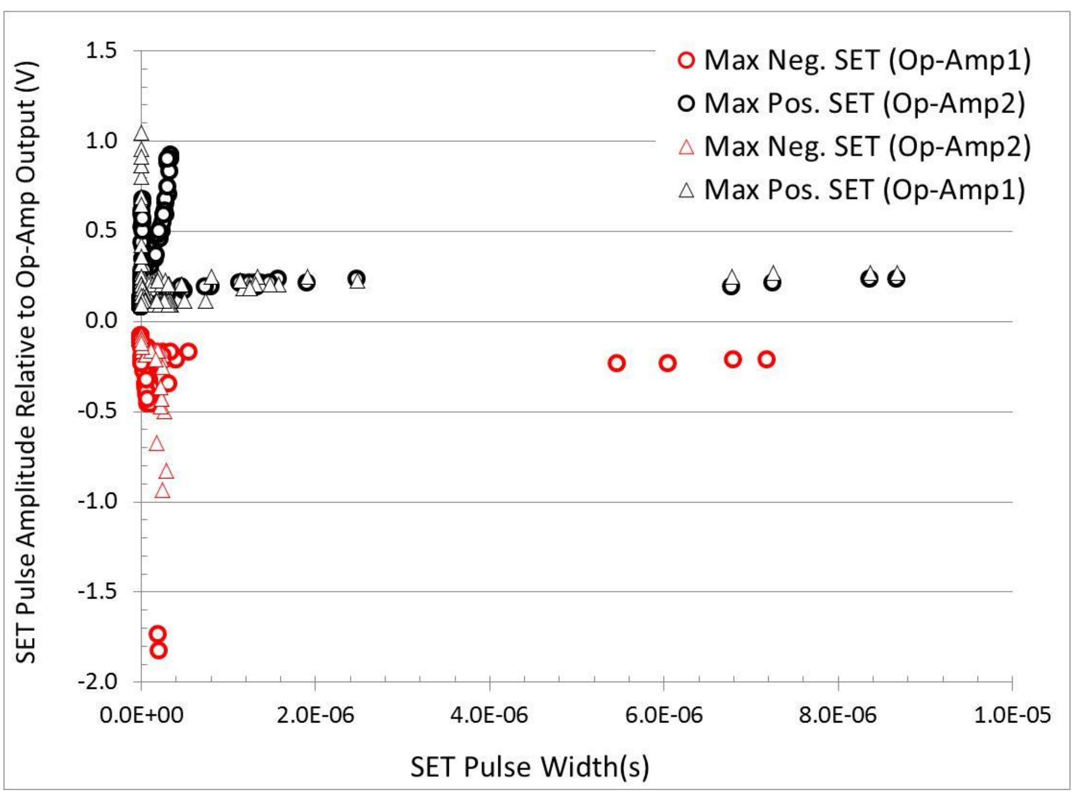




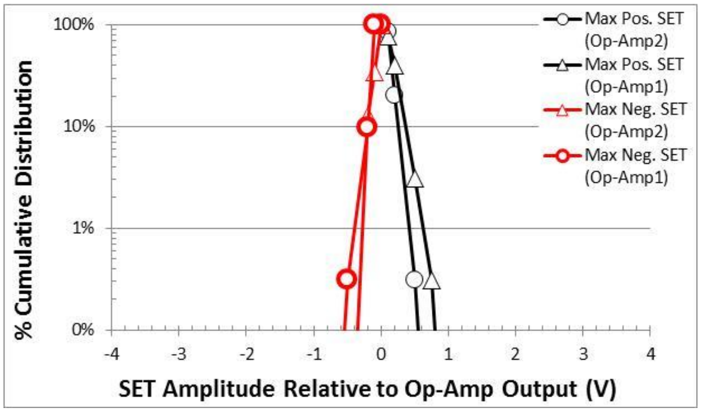
8. V supply=+/-15V; V input=+/-2.5V; Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 69-72)

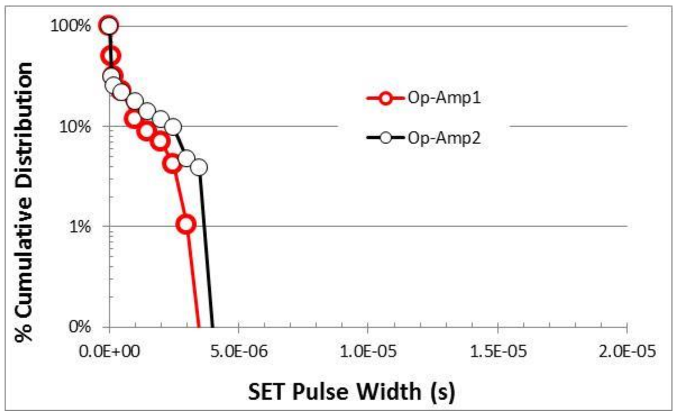


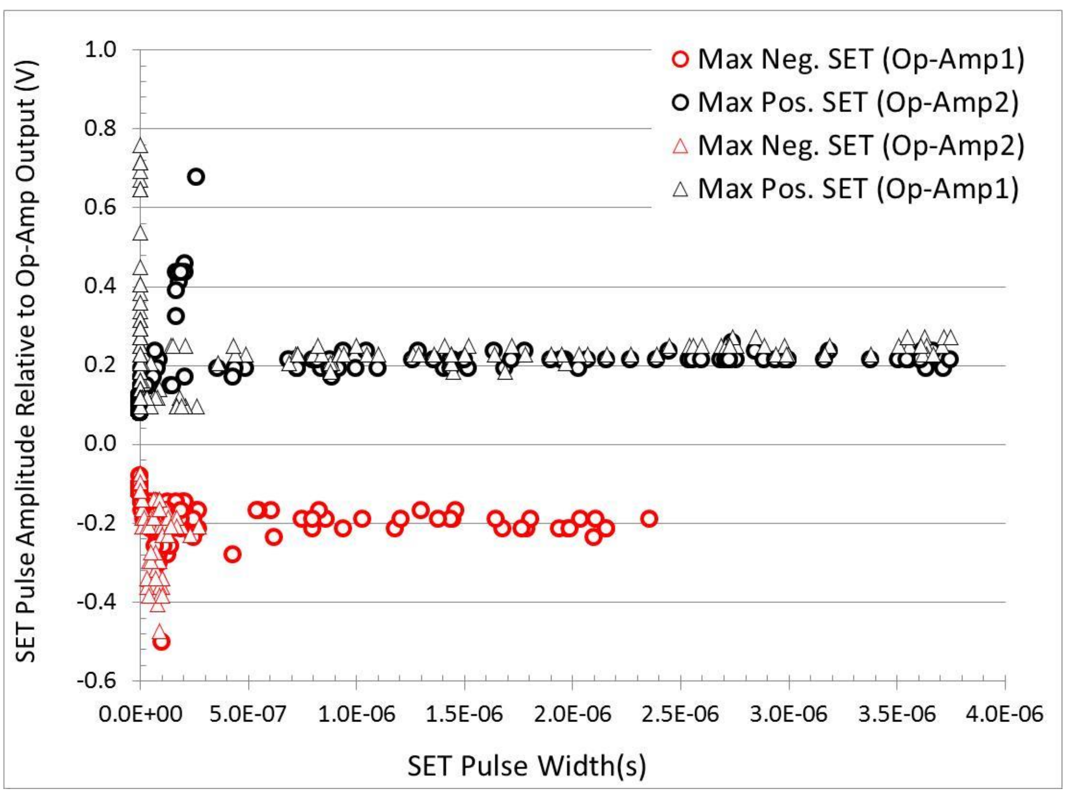




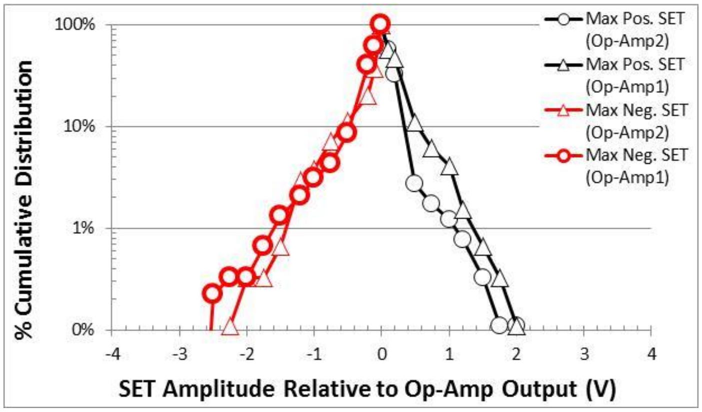
9. V supply=+/-15V; V input=+/-2.5V; Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 90-93)

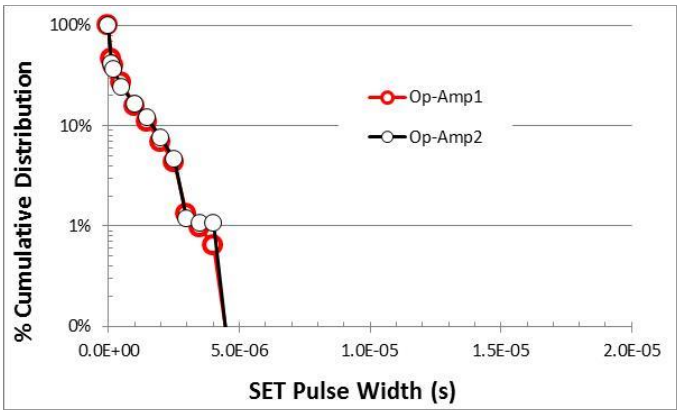


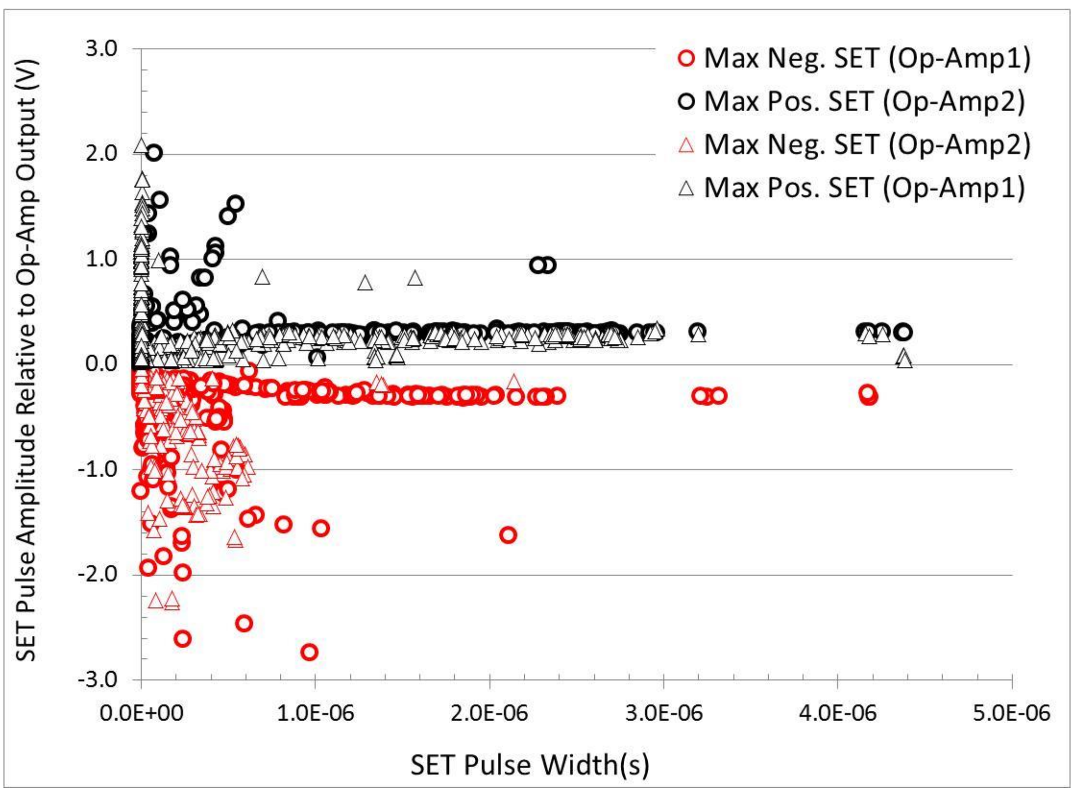




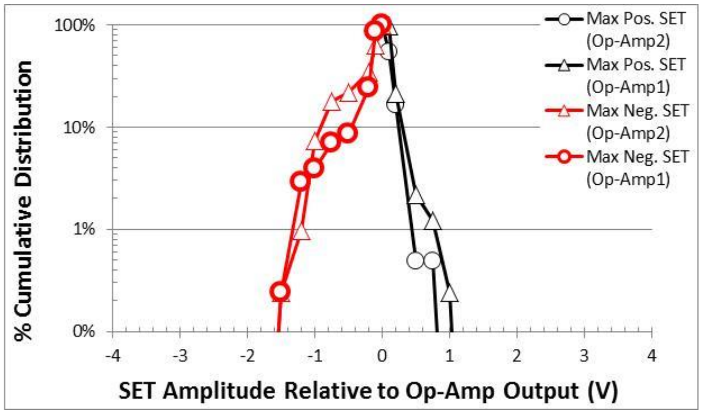
10. V supply=+/-15V; V input=+/-5V; Xenon Ions; LET=58.78 $MeV.cm^2/mg$ (Runs 10-14)

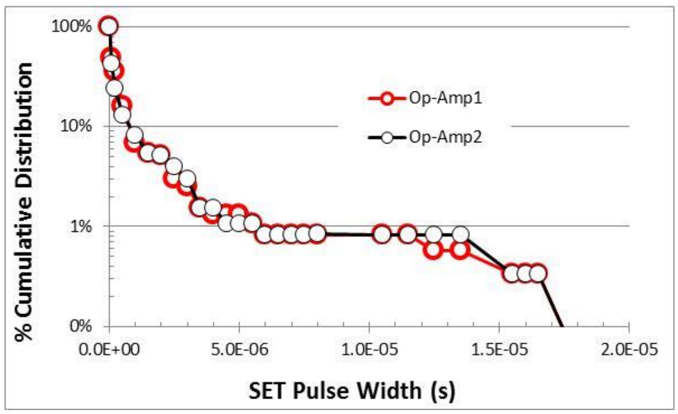


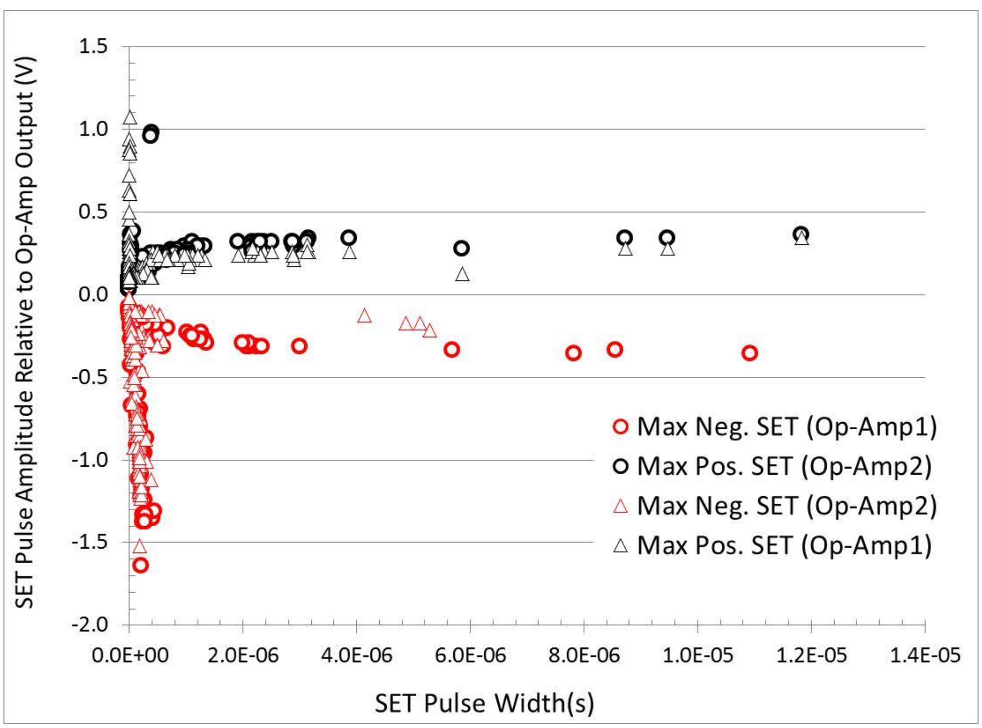




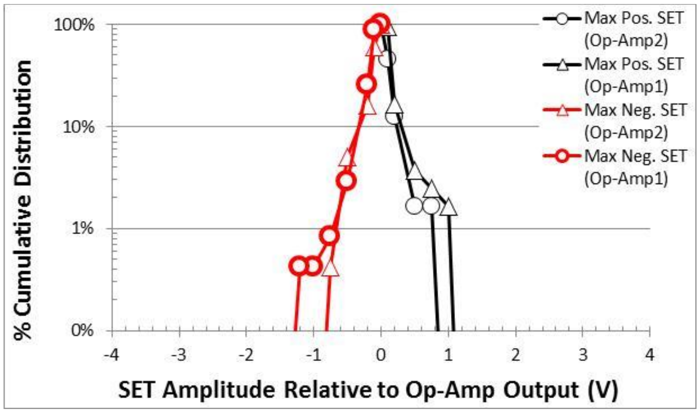
11. V supply=+/-15V; V input=+/-5V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 41-44)

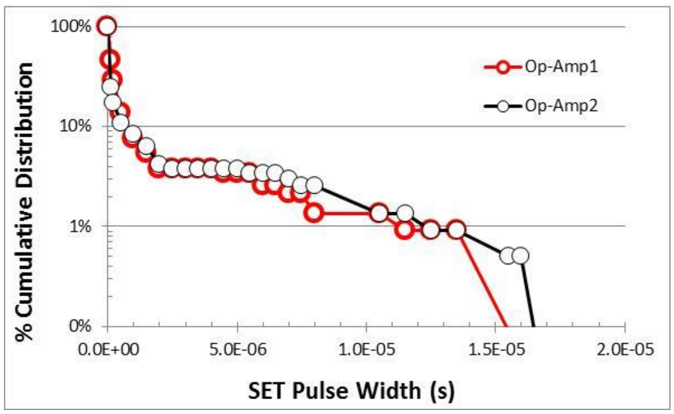


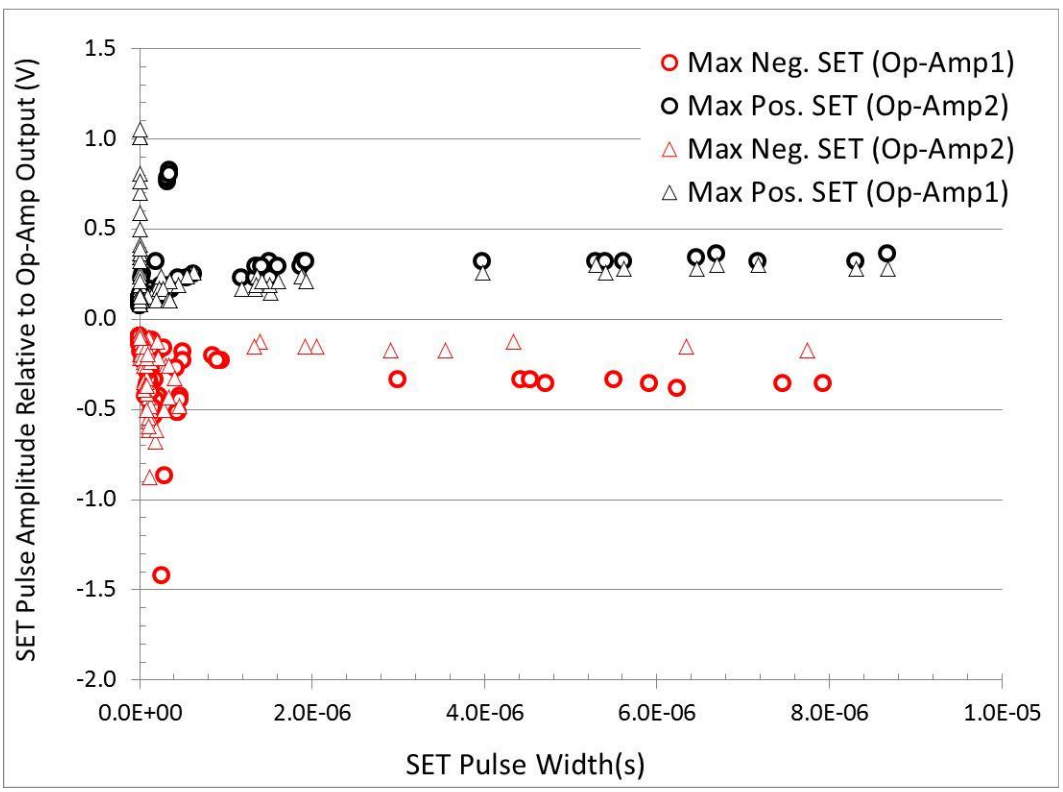




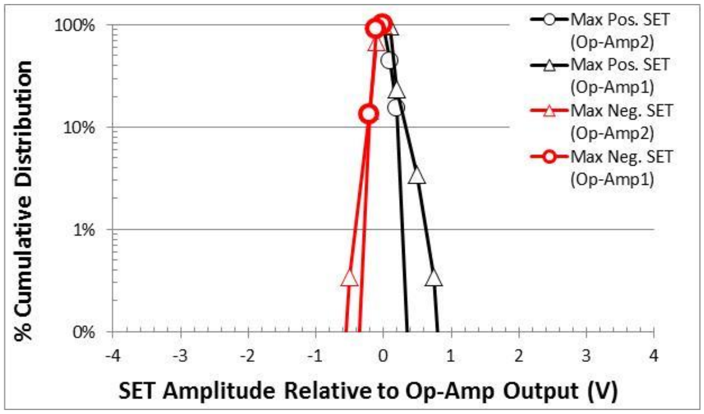
12. V supply=+/-15V; V input=+/-5V; Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 73-76)

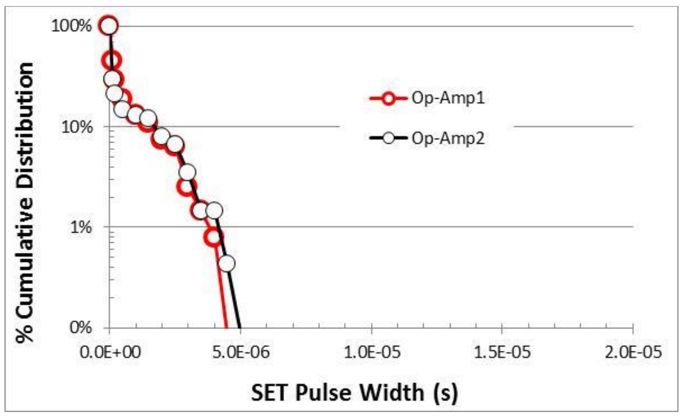


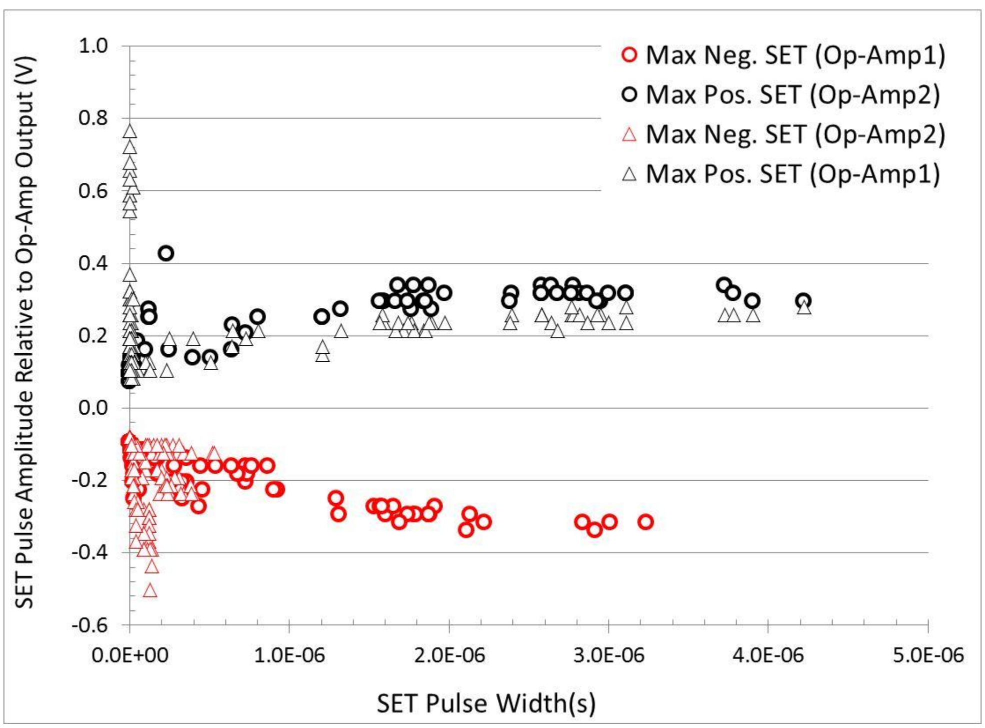




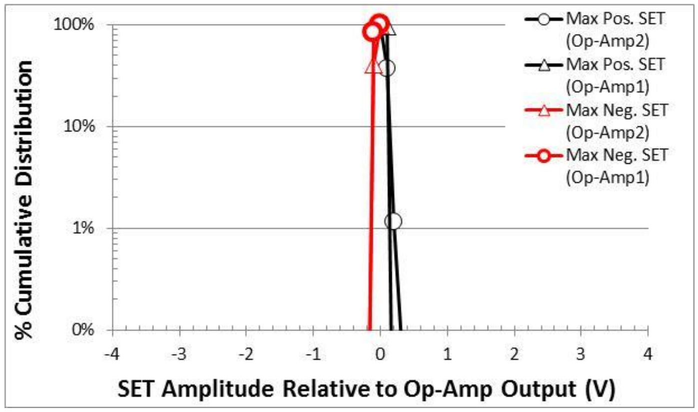
13. V supply=+/-15V; V input=+/-5V; Argon Ions; LET=9.74 $MeV.cm^2/mg$ (Runs 94-97)

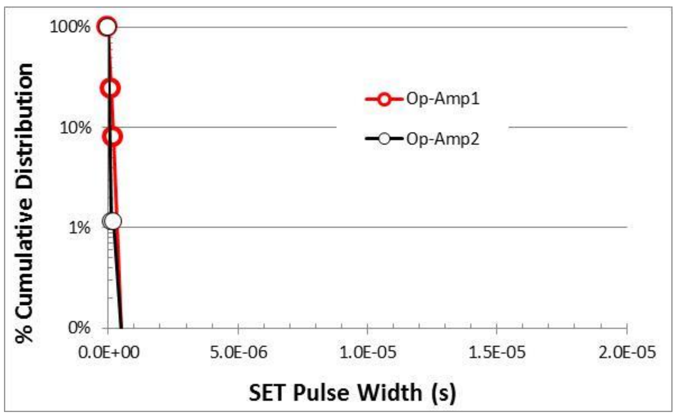


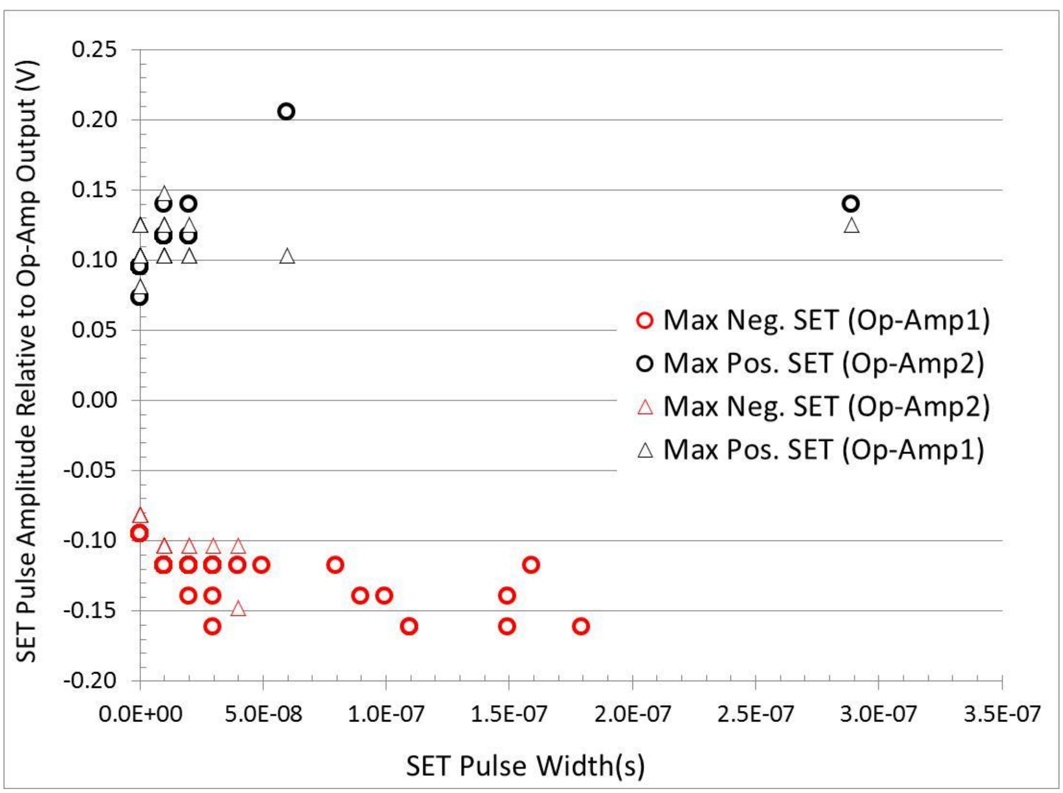




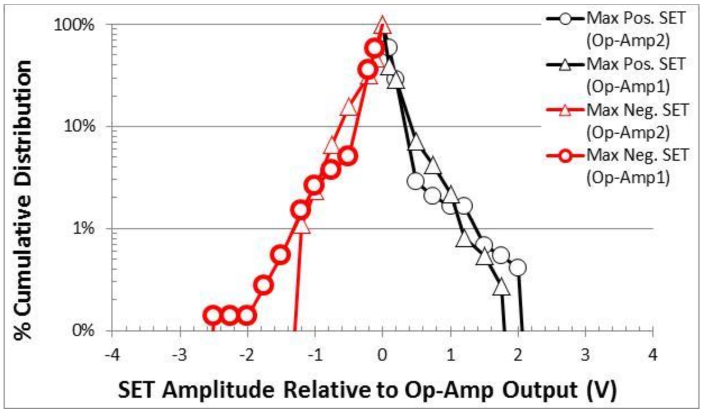
14. V supply=+/-15V; V input=+/-5V; Neon Ions; LET=3.49 MeV.cm^2/mg (Runs 110-113)

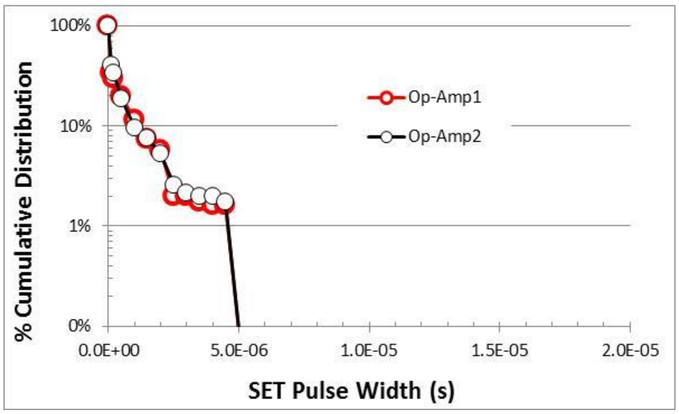


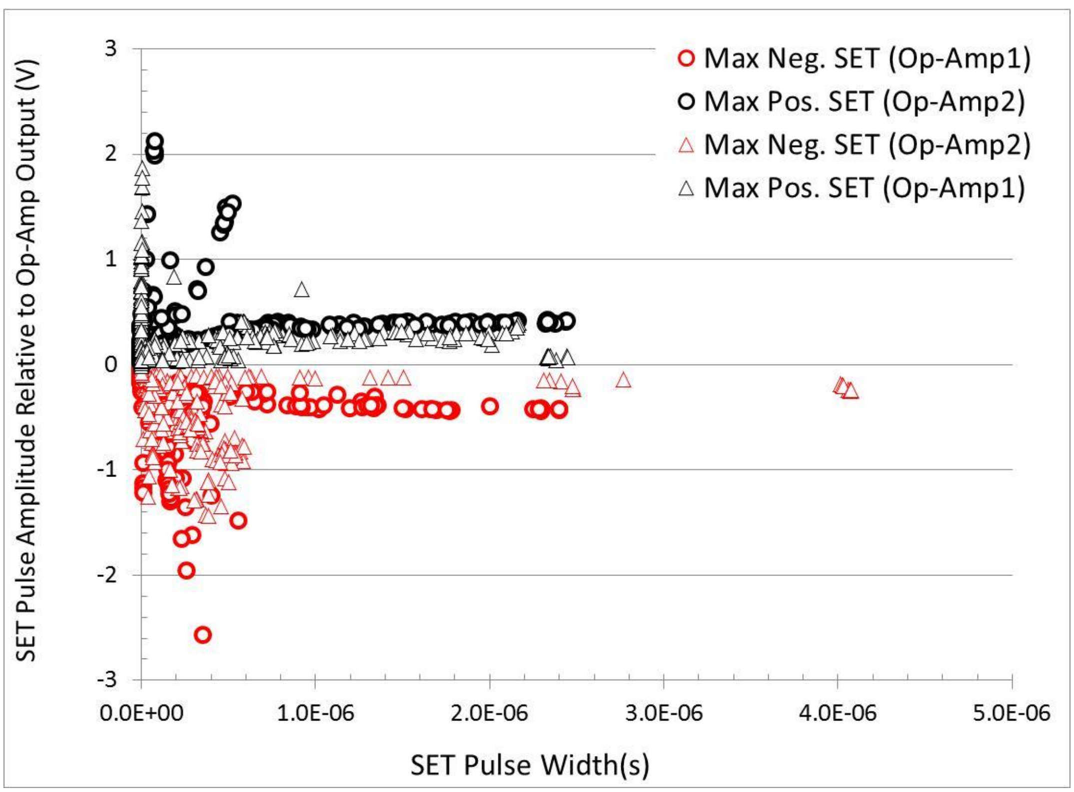




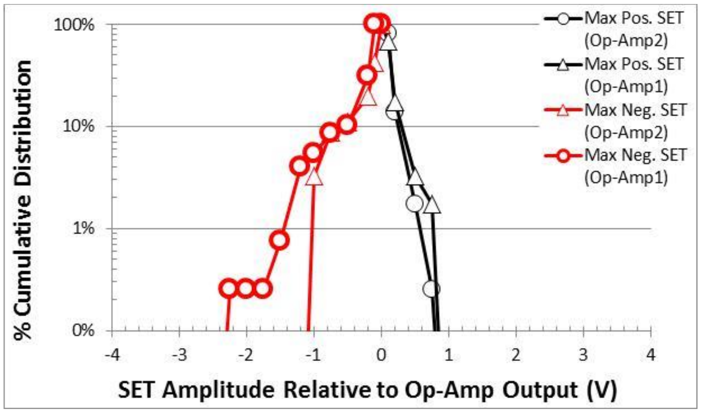
15. V supply=+/-15V; V input=+/-7.5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 15-18)

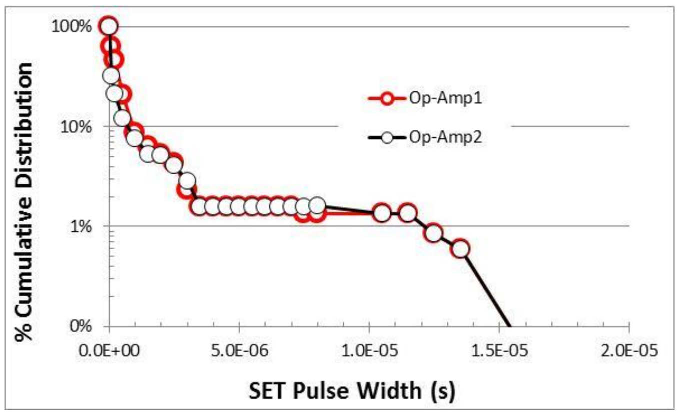


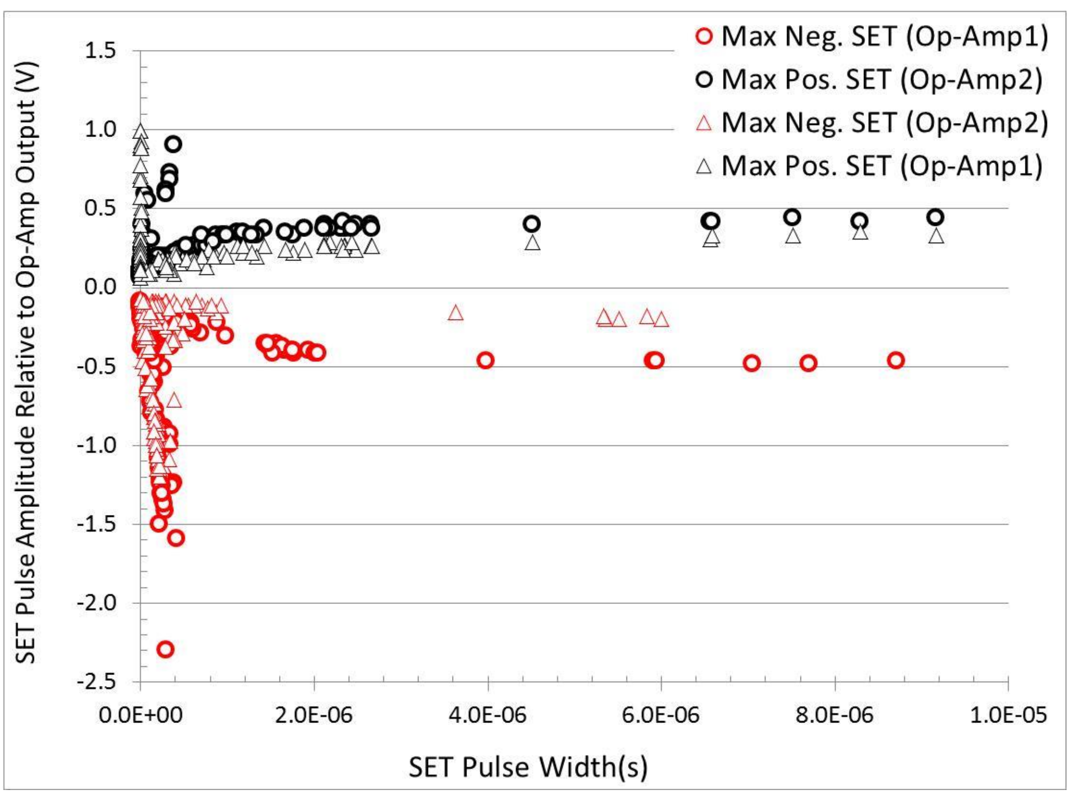




16. V supply=+/-15V; V input=+/-7.5V; Krypton Ions; LET=30.86 $MeV.cm^2/mg$ (Runs 45-48)

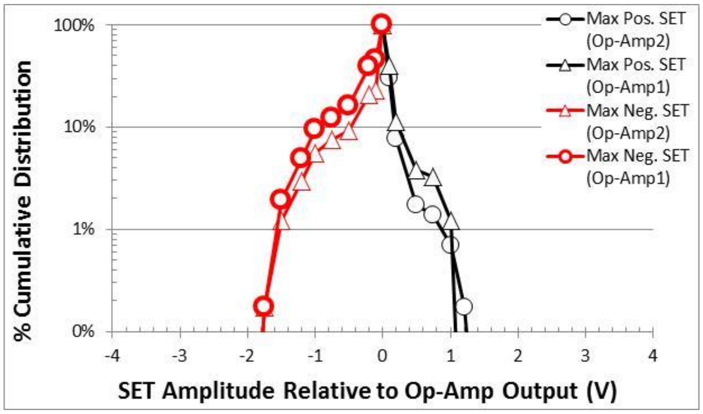


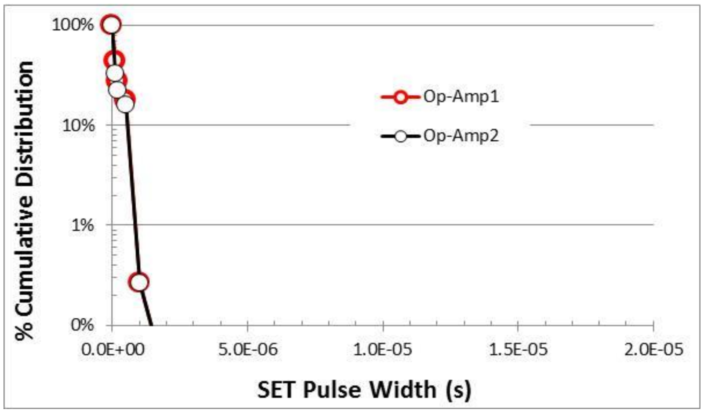


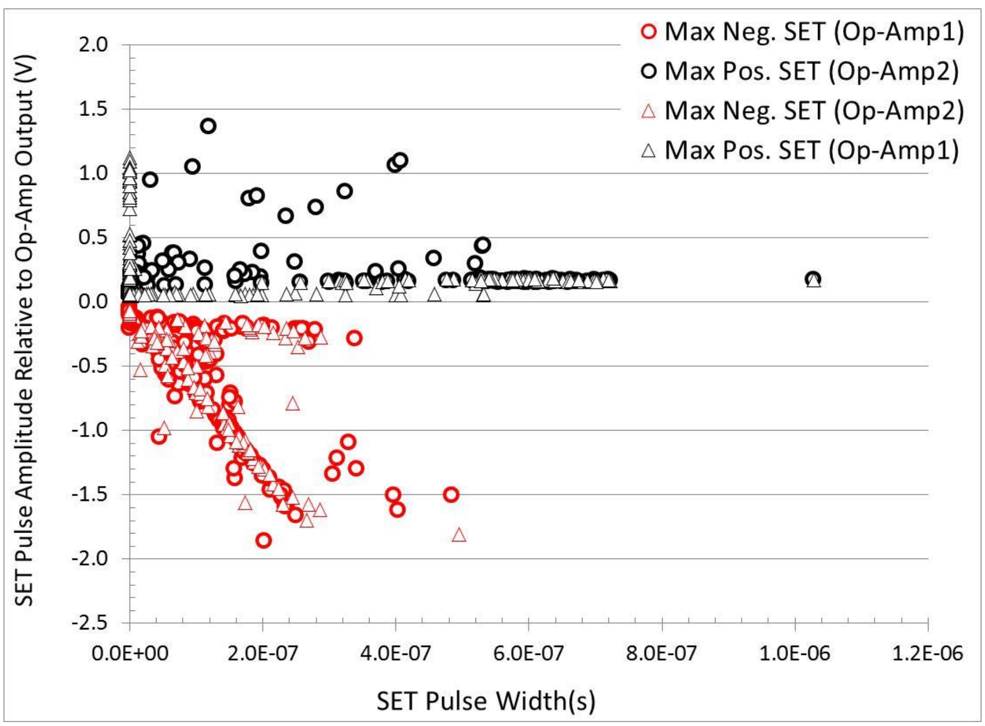


17. V supply=+/-5V; V input=+/-0.1V. The pulse widths measurements for the small amplitude SETs (<5V) are not accurate as the scope capture window was small for runs 1-30 only.

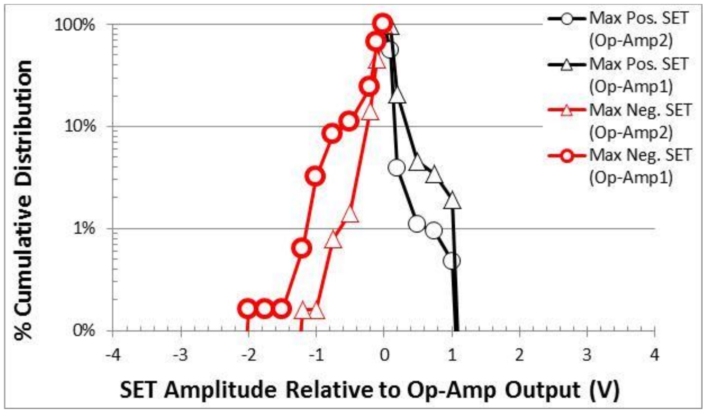
Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 19-22)

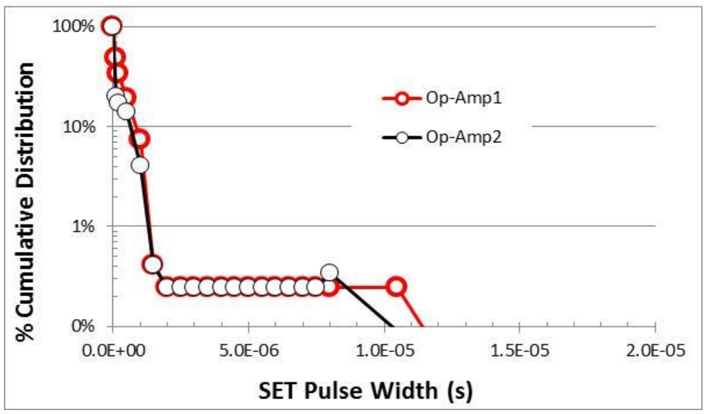


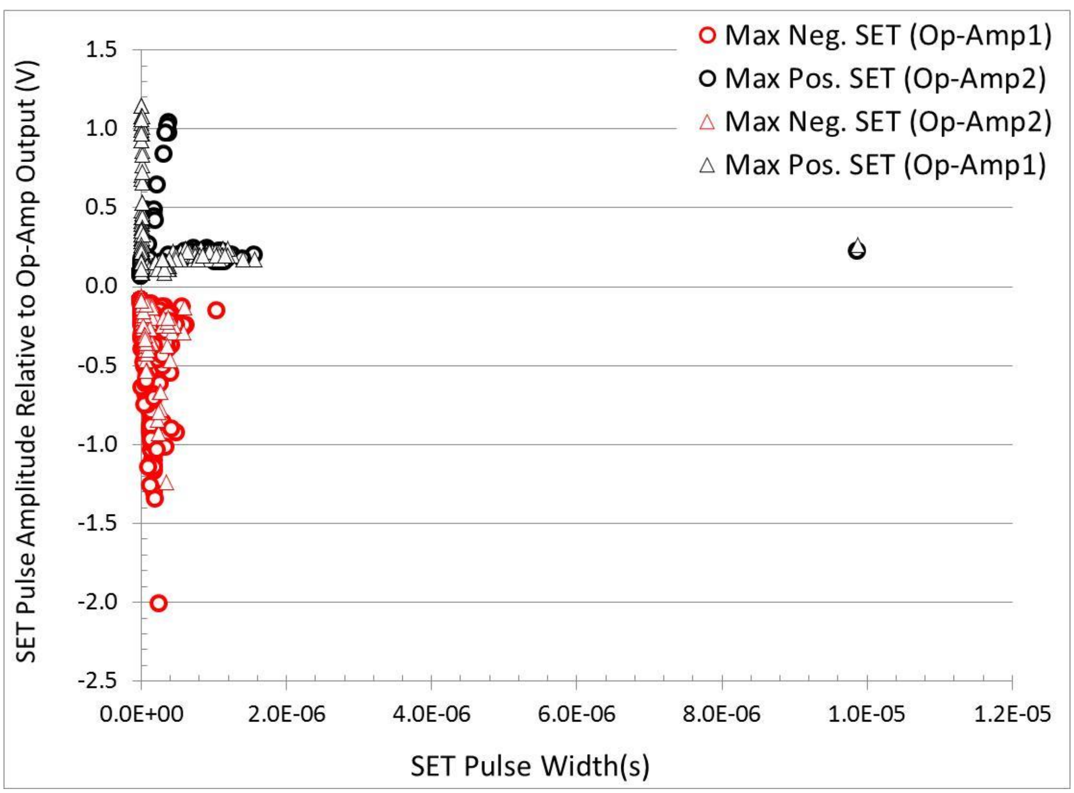




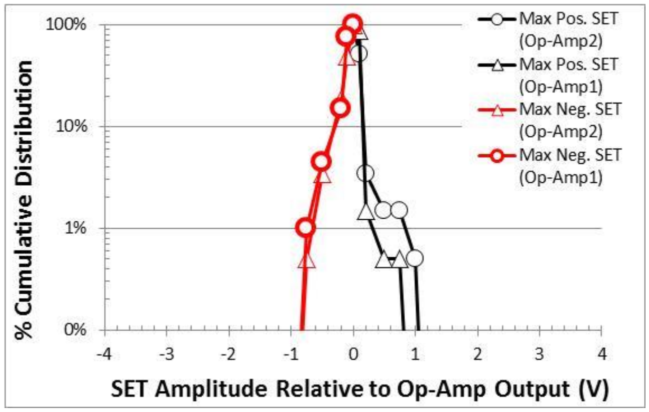
18. V supply=+/-5V; V input=+/-0.1V. Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 49-54)

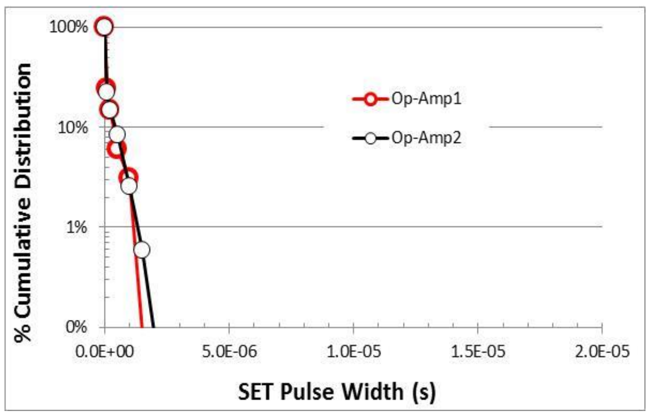


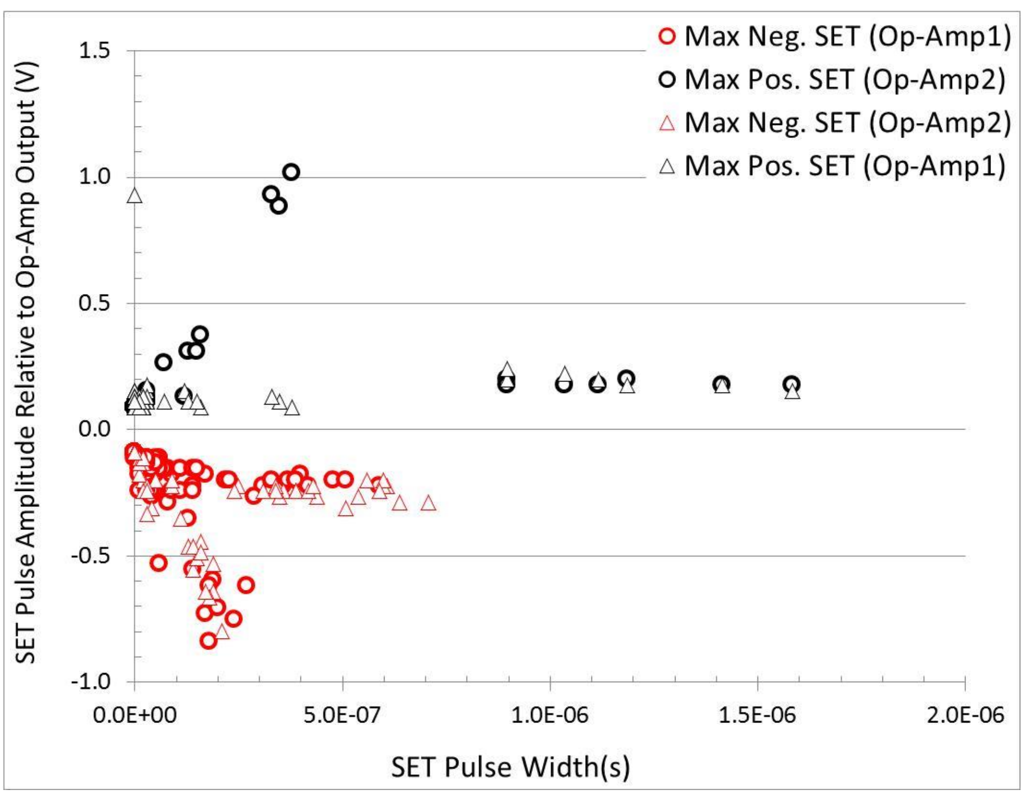




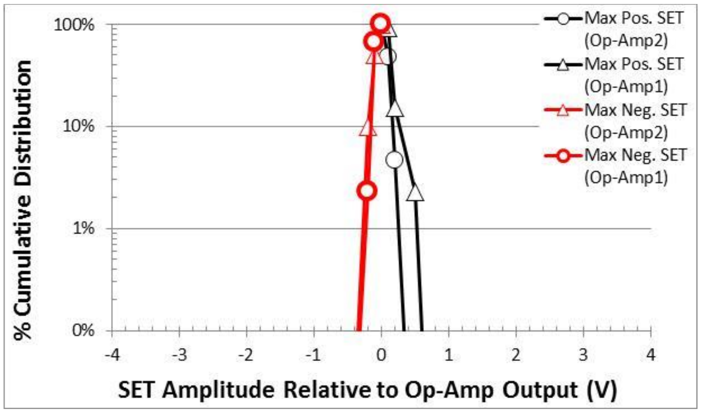
19. V supply=+/-5V; V input=+/-0.1V. Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 77-80)

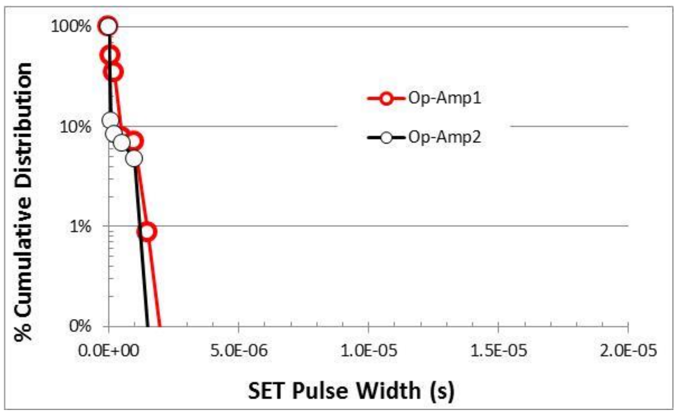


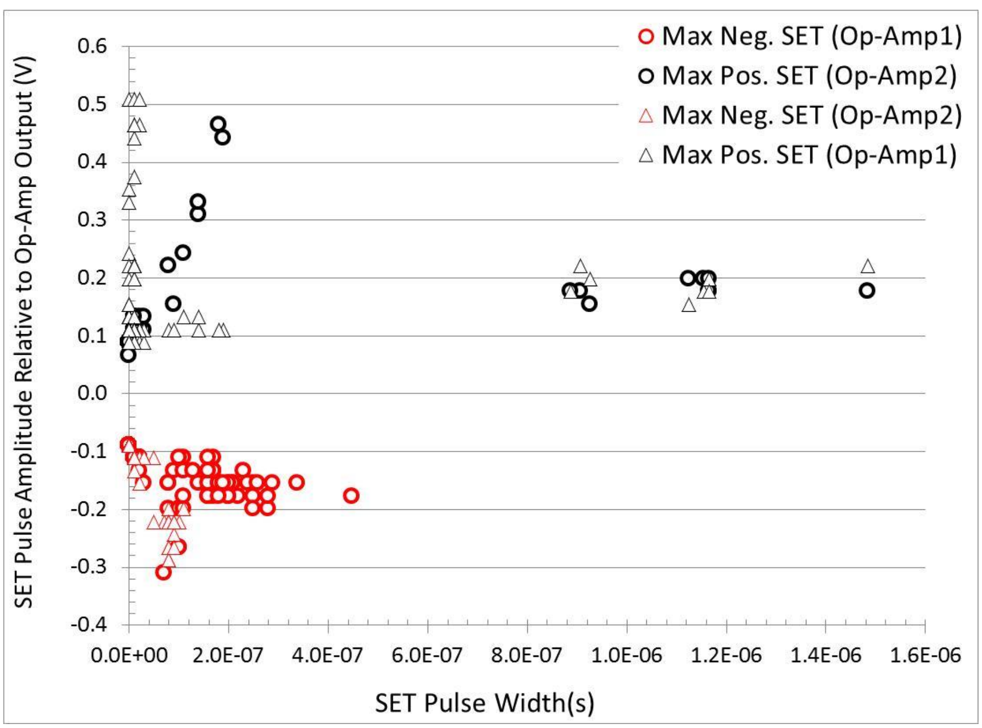




20. V supply=+/-5V; V input=+/-0.1V. Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 98-101)

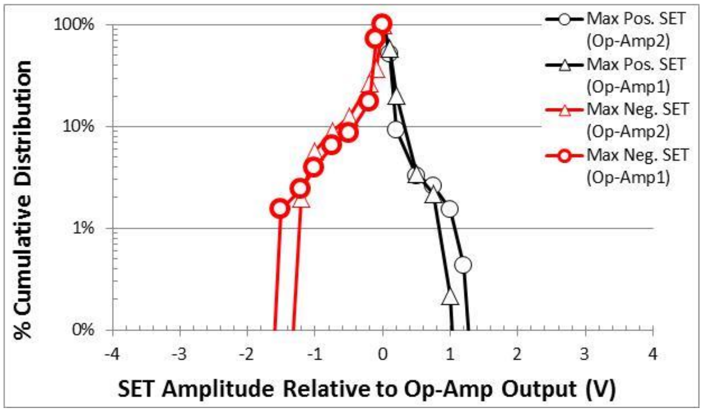


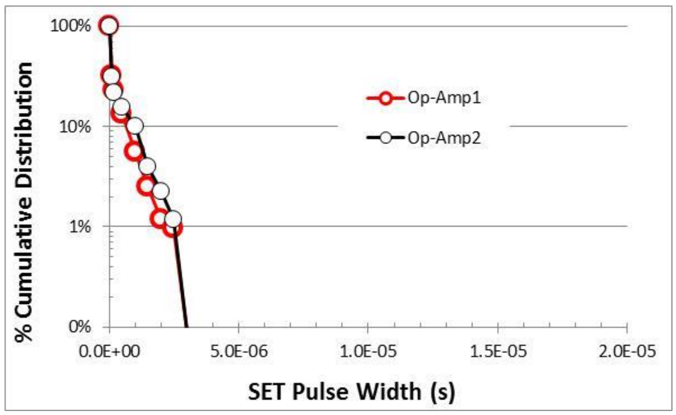


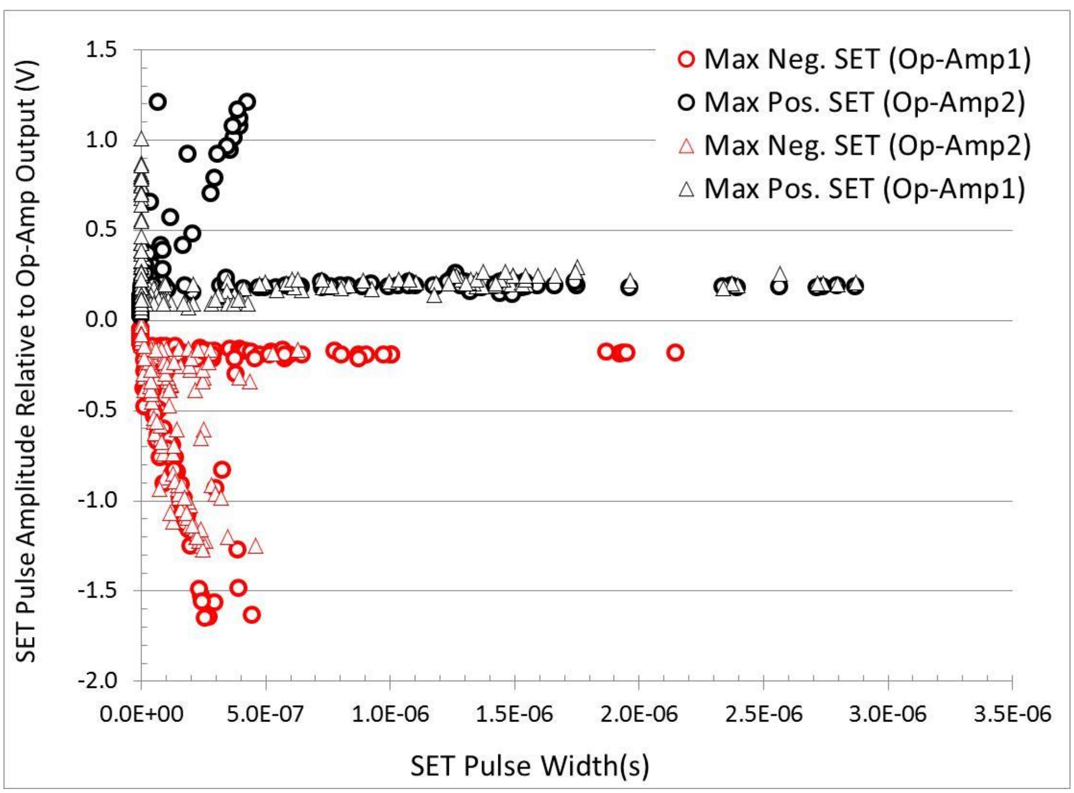


21. V supply=+/-5V; V input=+/-0.1V; Neon Ions; LET=3.49 MeV.cm^2/mg (Runs 114-117); No errors

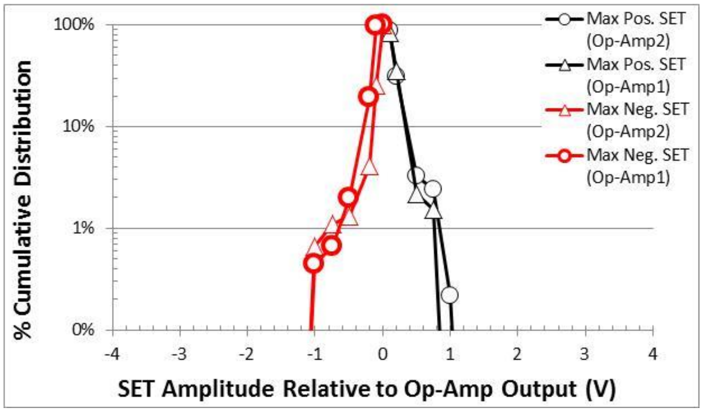
22. V supply=+/-5V; V input=+/-2.5V; Xenon Ions; LET=58.78 MeV.cm^2/mg (Runs 23-26)

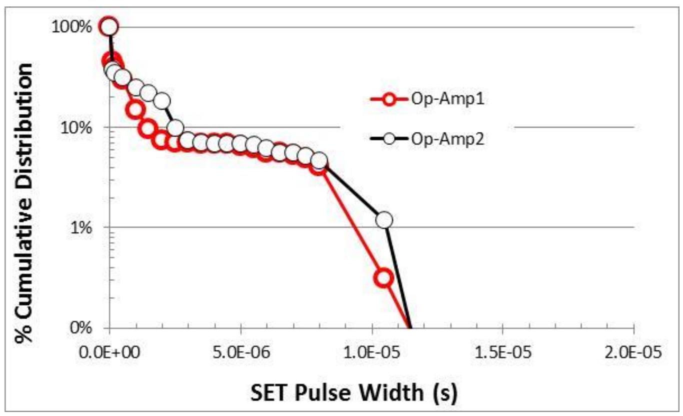


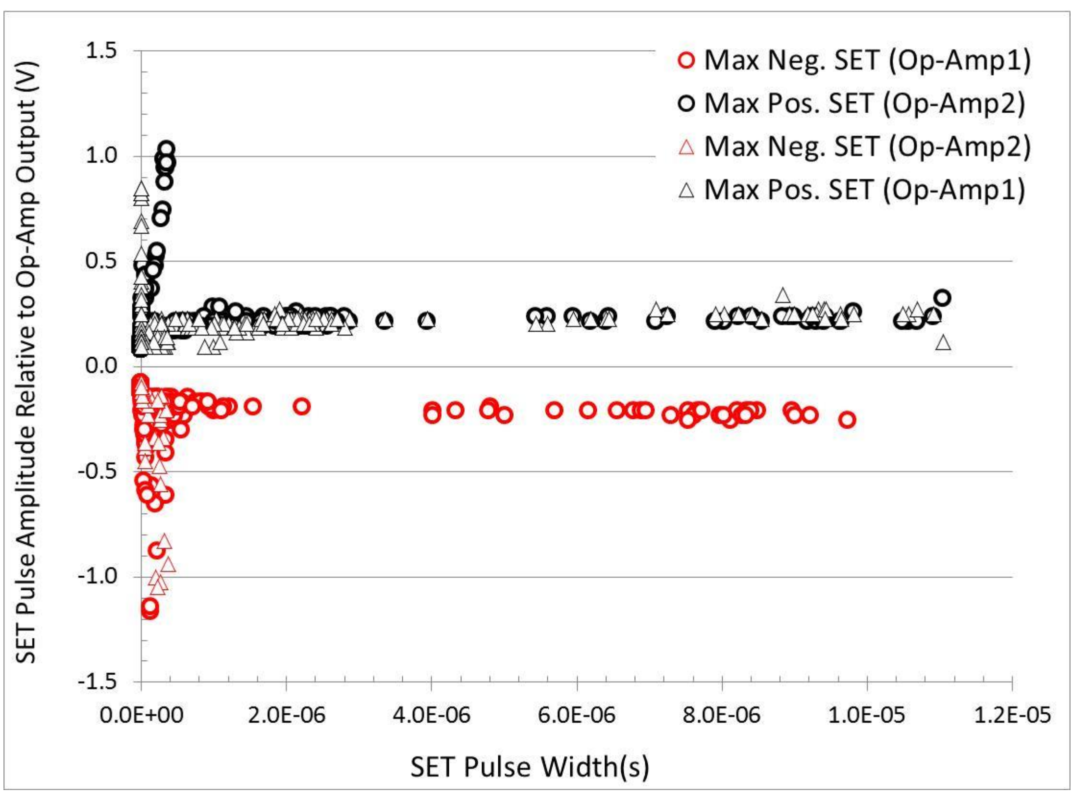




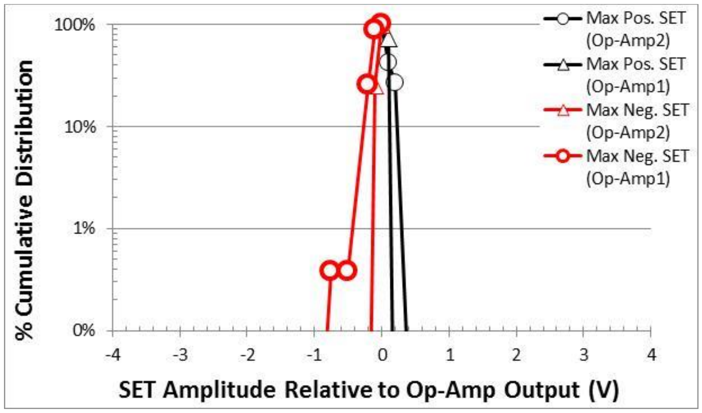
23. V supply=+/-5V; V input=+/-2.5V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 55-58)

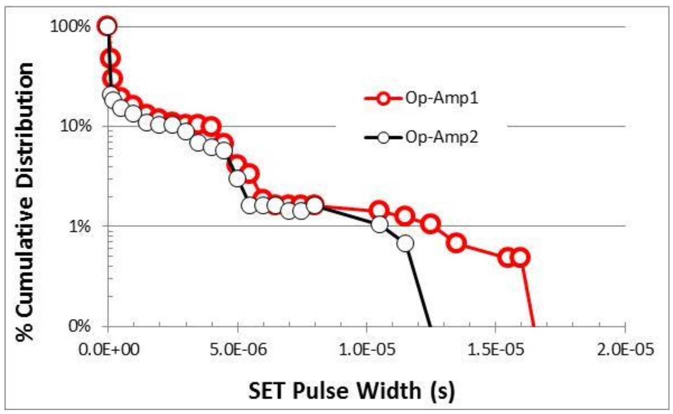


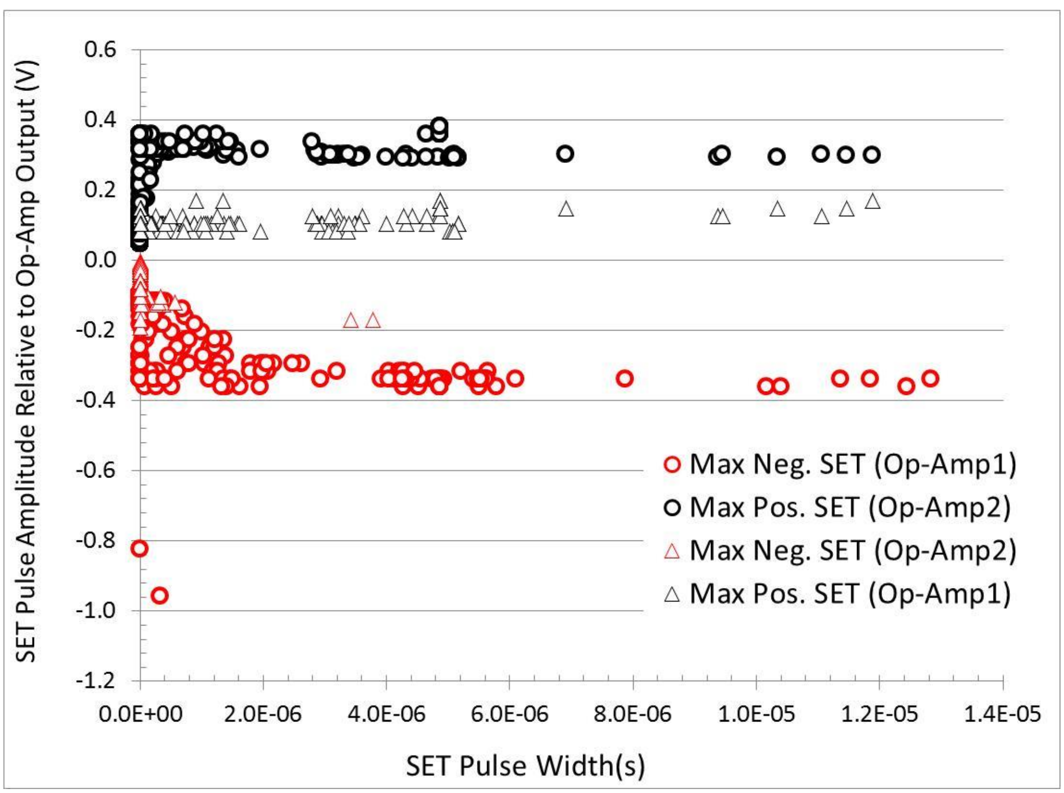




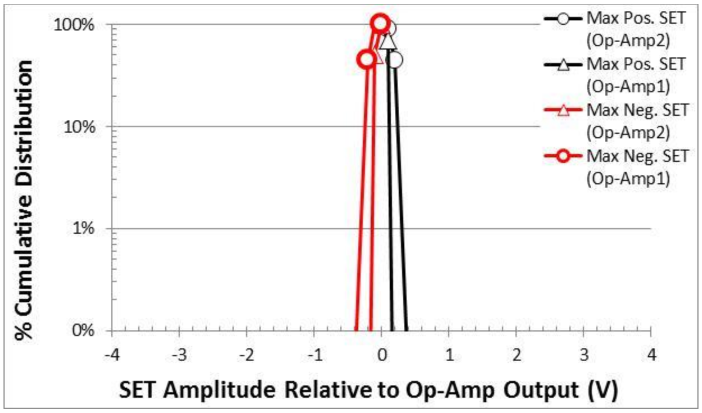
24. V supply=+/-5V; V input=+/-5V; Xenon Ions; LET=58.78 $MeV.cm^2/mg$ (Runs 27-31)

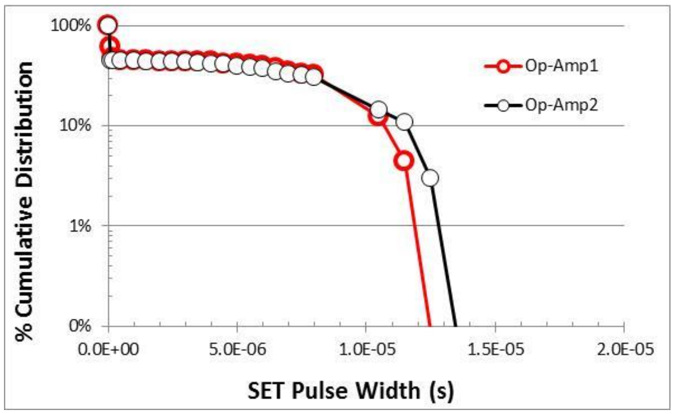


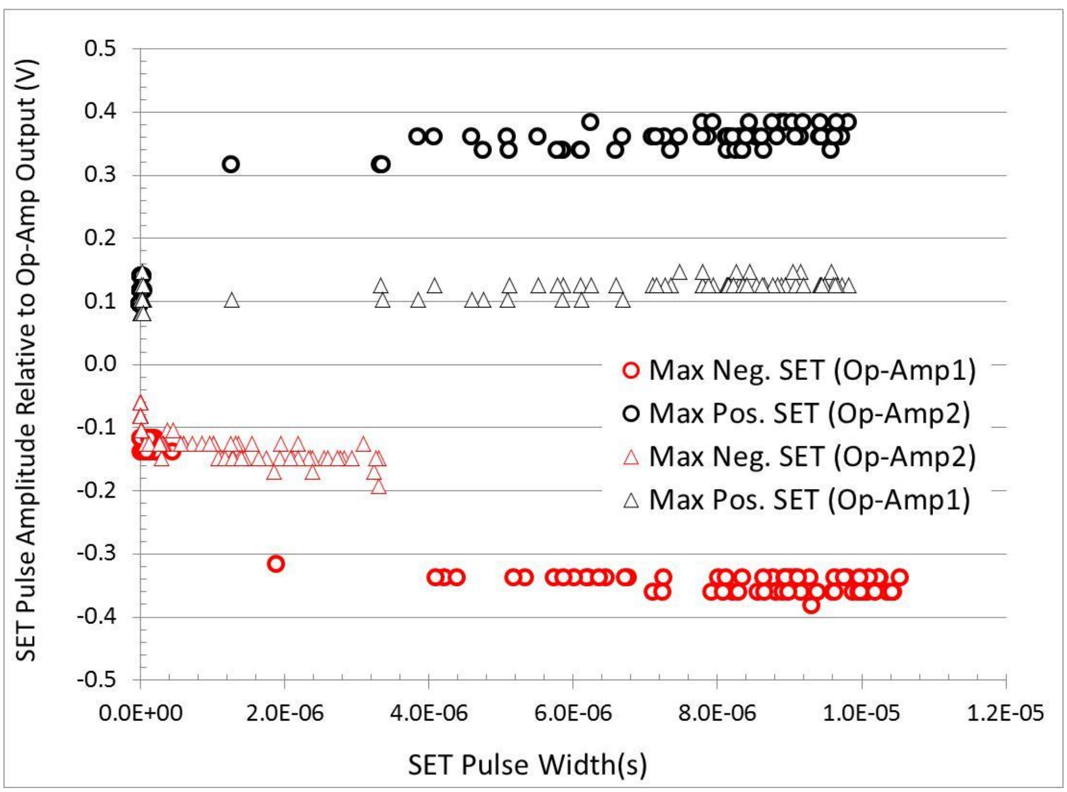




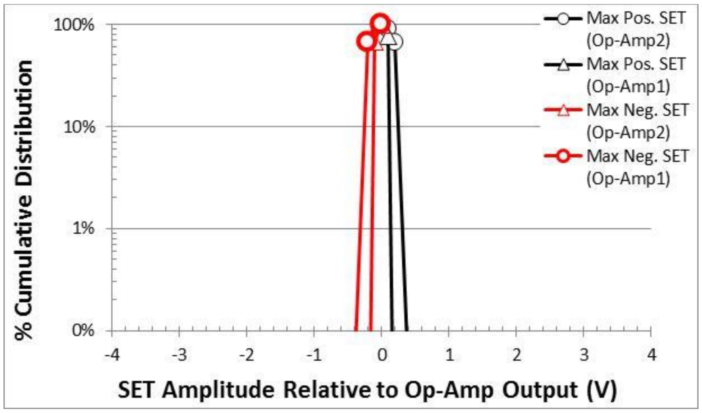
25. V supply=+/-5V; V input=+/-5V; Krypton Ions; LET=30.86 MeV.cm^2/mg (Runs 59-63)

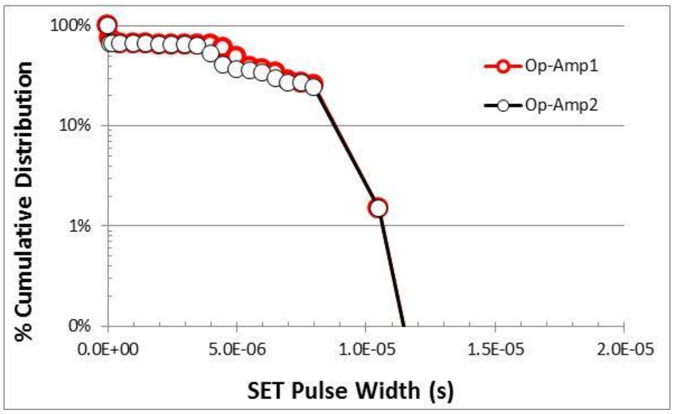


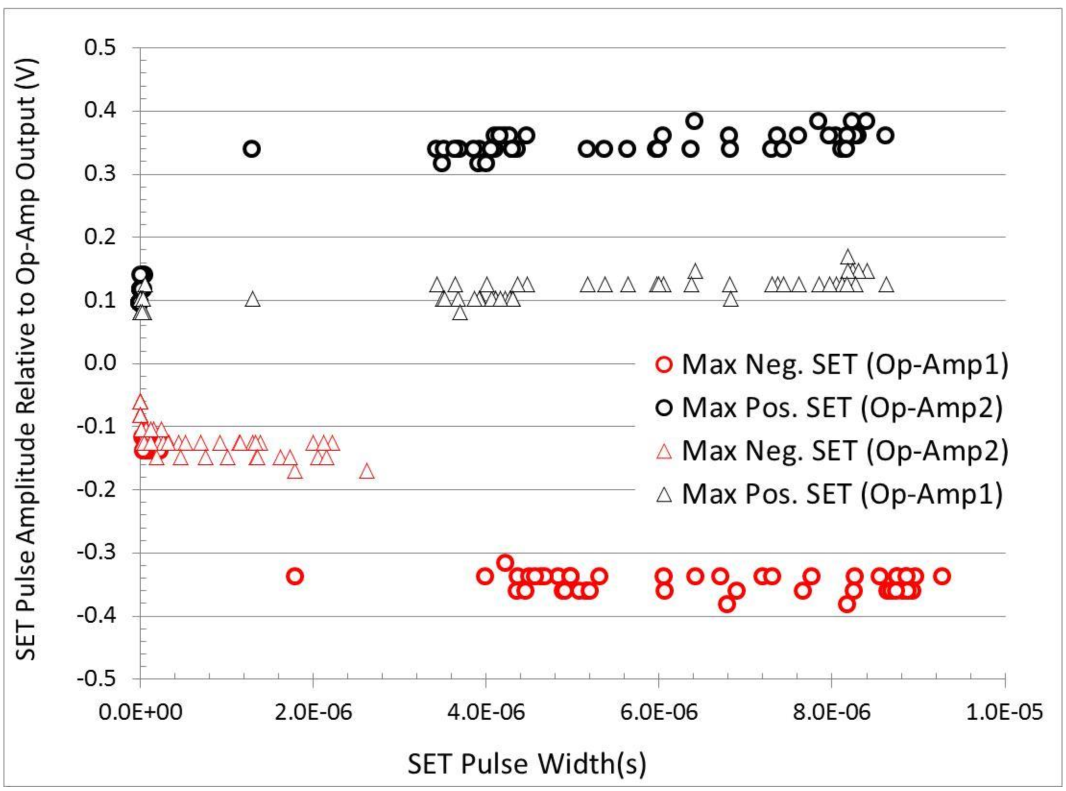




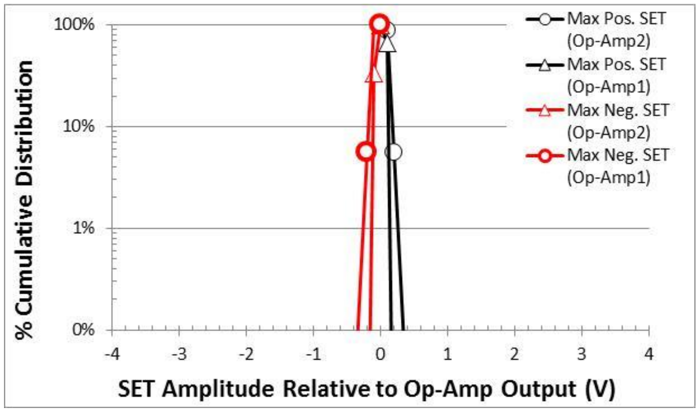
26. V supply=+/-5V; V input=+/-5V; Cupper Ions; LET=21.17 MeV.cm^2/mg (Runs 81-84)

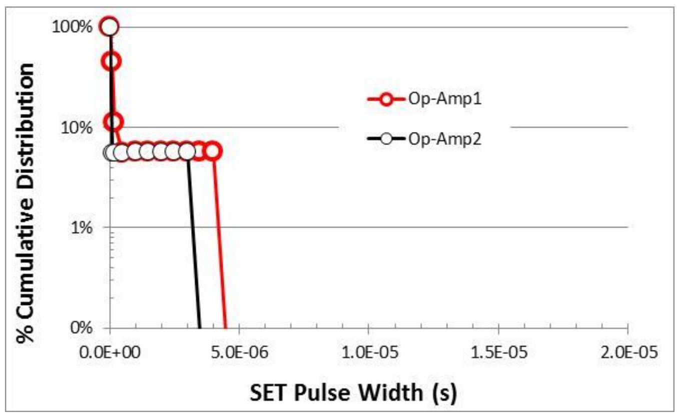


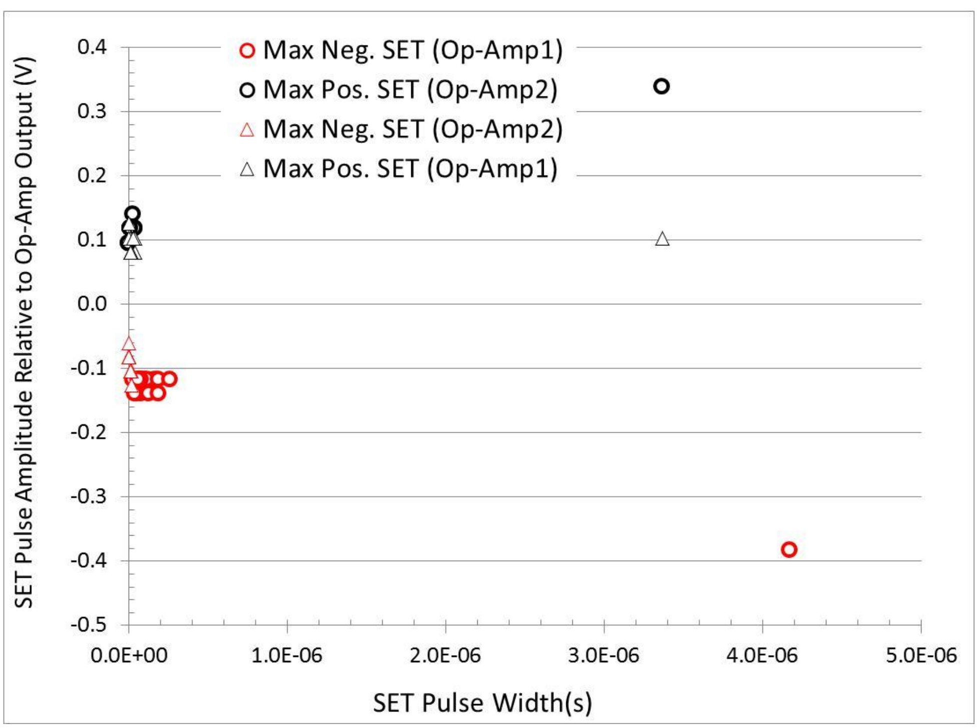




27. V supply=+/-5V; V input=+/-5V; Argon Ions; LET=9.74 MeV.cm^2/mg (Runs 102-105)







28. V supply=+/-5V; V input=+/-5V; Neon Ions; LET=3.49 MeV.cm^2/mg; No Errors

29. V supply=+/-**16.5V**; V input=+/-7.5V; Xenon Ions; LET=58.78 $MeV.cm^2/mg$ (Runs 135), without C2 or C20, and with 50Ohms Board Termination