Proton Test Report for the AD9213 – 12 bit 10.0/6.0GSPS, JESD204B, ADC

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Test Dates:
January 26, 2019

I. Introduction

The purpose of this test is to determine the proton-induced single-event effects (SEE) susceptibility of the AD9213, a 12 bit, 10.0/6.0 GSPS, RF Analog-to-Digital Converter. The AD9213 features a 16-lane JESD204B interface, supporting its maximum bandwidth capability. Single event upset (SEU), single event functional interrupt (SEFI), and single event transients (SET) were evaluated during this test. One device was tested.

II. Device Under Test

The AD9213 is a 12-bit, 10.0/6.0 GSPS RF ADC designed to support communications applications capable of direct sampling wide bandwidth analog signals up to 5GHz. The AD9213 is based on an interleaved pipeline architecture with proprietary calibration and a randomization technique that suppressed interleaving spurious artifacts into its noise floor. The AD9213 operates at 10.0/6.0 GSPS and can be controlled through an SPI port. Figure 1 shows a functional block diagram of the device. Table 1 shows the device and test equipment details. AD9213 device parameters and functional descriptions can be found in the product datasheet.

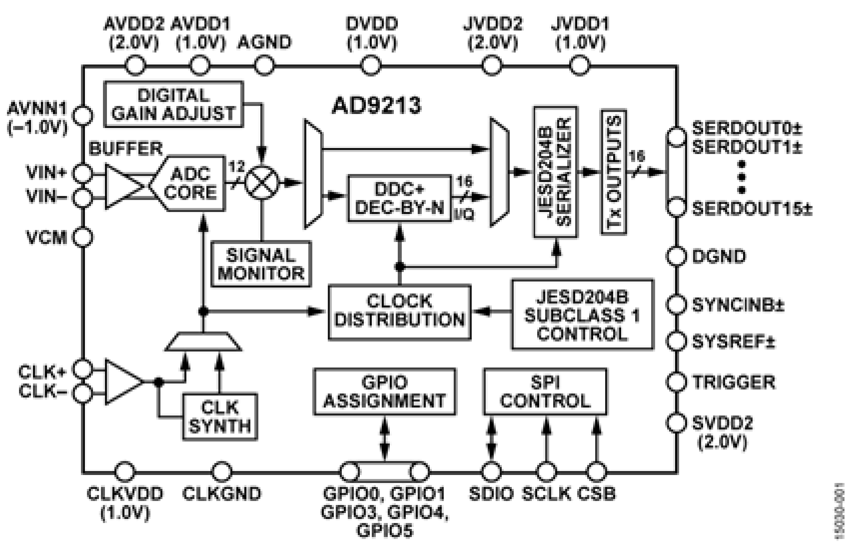

Figure 1. Schematic block diagram.

Table 1
Part and test information.

Generic Part Number:	AD9213
Date of Test:	January 26, 2019
Manufacturer:	Analog Devices Inc.
Part Function:	12-bit 10.0/6.0 GSPS ADC
Part Technology:	28 nm CMOS
Package Style:	196-Ball grid array (BGA_ED)
Test Equipment:	Power supply, SMA, Hittite T2220, High Speed ADC Eval data capture board, Laptop

III. Test Facility

The proton testing was performed at the Mayo Clinic Phoenix Proton Therapy Center, using up to a 200 MeV/nucleon mono-energetic proton beam. The Mayo Clinic is a state-of-the-art proton therapy cancer treatment facility. The facility uses a Hitachi synchrotron with a somewhat variable beam structure. The normal pencil beam output is run through a 45 mm poly-based range shifter to spread the beam in the target room. This range shifter does reduce the beam energy slightly but the straggling is minimal and the primary energy and uniformity after the range shifter has been well characterized. The beam was adjusted to provide 50 - 200 MeV mono-energetic protons to the test article. The room is equipped with a 6-axis translation and rotation patient table. The beam diameter and flux are controlled by the source-to-sample distance. A brass collimator was used as needed to reduce the beam size. Borated polyethylene is used to shield sensitive electronics from the background neutron environment during irradiation. The test board and support electronics were mounted to a sheet of poly based material for alignment in the beam.

Facility: Mayo Clinic
Beam Energy: 200MeV protons
Flux: 1e5 – 1e9 protons/cm^2/s
Fluence: 1e10 protons/cm^2

IV. Test Method

A. Test Setup

The AD9213 was configured using the ADS8-V1EBZ data capture board with a customized FPGA program to perform a Code Error Rate (CER) test. Figure 2 below shows the test setup. The AD9213 was powered up using the default register settings and a 10.0 GSPS clock was applied to the device. A coherent 700kHz sine wave was applied to the analog input and the data was captured by the ADS8-V1EBZ data capture board. A separate test was run monitoring a total of 10 registers; 7 specific registers for SEU and 3 specific registers for SEFI due to device resets. The DUT temperature was measured using an internal diode on the die. Nominal supplies were used due to damage to a power supply during shipping.

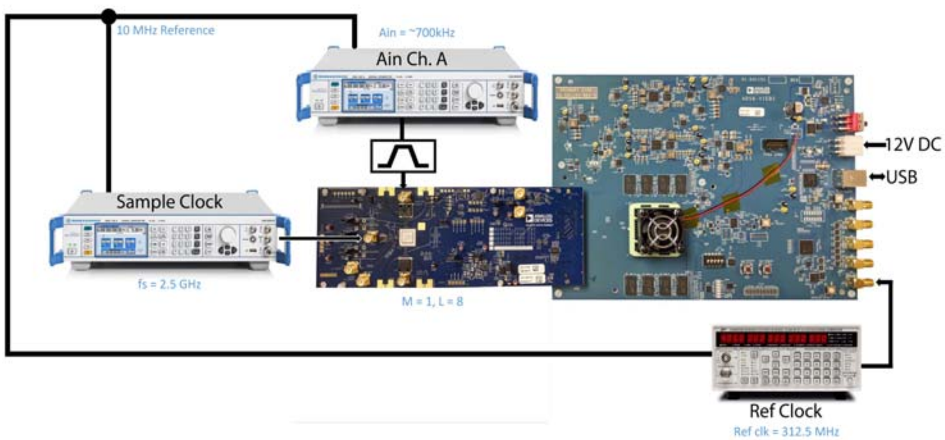

Figure 2. AD9213 data capture setup.

B. Irradiation procedure

A code error rate (CER) program was used to evaluate the SEFI/SET susceptibility. The code error rate program compared samples N and N+1, N+1 and N+2, etc, to a specified error threshold and captured specific data when the delta was over the error threshold. A custom Python script was used to control the testing with a total error quantity set to 512 since some of the errors are transients.

The DUT was subjected to protons ranging from 50MeV to 200MeV. The script was setup to digitally reset the device when a SEFI, caused by a loss of the JESD204B link was detected. The power supplies were not cycled.

A separate test was performed where 7 registers, spread out across the register section, were monitored for bit upsets. Each register contains 8 bits. The total number of upsets for each bit was recorded. This test only evaluated the registers through the SPI port. During this test 3 additional registers were also monitored to detect a device reset condition which was recorded as SEFI.

Figure 3 shows a picture of the setup for proton test at the facility.

C. *Test Conditions*

Test Temperature:	Ambient temperature - air
Operating Frequency:	10.0 GHz
Power Supply(s):	1V, 1.8V, 2.5V
Angles of Incidence:	0^{o}
Parameters:	CER - Output codes 10-Registers – SPI register reads

Figure 3
AD9213 proton test setup

V. Results

SEFI/SET – One device was tested using 200 MeV protons. Table 2 shows the test runs. The SET plots are shown in the Appendix. All SET were 1 clock cycle Digital Transients.

In all cases using protons, at the end of each run the performance verified by an FFT was equal to the FFT evaluated prior to turning on the proton beam.

In Run 41, a continuous FFT was visually monitored with no change in performance recorded. The SEFI detected in Run 43 was due to an upset of the *u*-controller. Resetting the device through the SPI port cleared the SEFI.

Table 2
SEFI/SET Test Run Log – 200MeV

Run #	DUT	Energy (MeV)	Distance from Isocenter (cm)	Spot Size (mm)	Range (mm(Si))	Total MU	SET	SEFI	Total Fluence (p/cm2)	Run Time (s)
39	8	200	134	25	139.0558	271	2	0	1.19E+10	108.4
40	8	200	134	25	139.0558	271	3	0	1.19E+10	108.4
41	8	200	134	25	139.0558	271	0	0	1.19E+10	108.4
42	8	200	134	25	139.0558	271	9	0	1.19E+10	108.4
43	8	200	134	25	139.0558	271	1	1	1.19E+10	108.4

SEU – One device was tested using 200MeV protons. Table 4 shows the test runs for 200MeV protons. An FFT evaluated at the end of each run was equal to the FFT prior to turning on the proton beam.

Table 4
SEU Test Run Log – 200MeV

Run #	DUT	Energy MeV	Distance from Isocenter (cm)	Spot Size (mm)	Range (mm(Si))	Total MU	SEU	SEFI	Total Fluence (p/cm2)	Run Time (s)
75	8	200	134	25	139.1	390.0	0	0	1.71E+10	156
76	8	200	134	25	139.1	390.0	0	0	1.71E+10	156
77	8	200	134	25	139.1	390.0	0	0	1.71E+10	156

SEFI/SET – One device was tested using 50 MeV and 100 MeV protons. Table 3 shows the test runs. The SET plots are shown in Appendix A for runs 44 - 48. Repeating transients were not plotted. FFTs evaluated after Runs 44-46, 49, and 50 were identical to the FFTs evaluated prior to turning on the proton beam.

Run 47 had the longest SET at ~17 clock cycles.

Run 48 experienced the highest quantity of SET as well as a SEFI. An FFT evaluated at the end of the run showed an increase in the noise floor of 30dB. A SPI reset was required to clear the SEFI.

Table 3
SEFI/SET Test Run Log – 100MeV & 50MeV

Run #	DUT	Energy MeV	Distance from Isocenter (cm)	Spot Size (mm)	Range (mm(Si))	Total MU	SET	SEFI	Total Fluence (p/cm2)	Run Time (s)
44	8	100	52	25	41.8	390.0	12	0	1.08E+10	156
45	8	100	52	25	41.8	390.0	0	0	1.08E+10	156
46	8	100	52	25	41.8	390.0	0	0	1.08E+10	156
47	8	100	52	25	41.8	390.0	23	0	1.08E+10	156
48	8	50	52	38.6	12.2	1241.0	87	1	1.09E+10	496
49	8	50	52	38.6	12.2	1241.0	0	0	1.09E+10	496
50	8	50	52	38.6	12.2	1241.0	2	0	1.09E+10	496

SEU – One device was tested using 50MeV and 100MeV protons. Tables 5 shows the test runs. In each run, an FFT evaluated at the end of the run showed a ~2-4dB increase in the noise floor. An SPI reset and register reload returned the FFT to normal.

Table 5
SEU Test Run Log – 100MeV & 50MeV

Run #	DUT	Energy MeV	Distance from Isocenter (cm)	Spot Size (mm)	Range (mm(Si))	Total MU	SEU	SEFI	Total Fluence (p/cm2)	Run Time (s)
51	8	50	52	38.6	12.2	1241.0	0	0	1.09E+10	496
52	8	100	52	25	41.8	390.0	0	0	1.08E+10	156

Appendix

AD9213 Register Single Event Upset Data Summary

An SEU in the registers may lead to a Single Event Functional Interrupt (SEFI). The end user may need to reload the register settings to return to normal operation.

7 device registers were monitored via a Python script. These 7 registers are distributed around the register space of the die. The Python script continuously polls the SPI port of the AD9213 to monitor any changes in the bit values and records the occurrences to a file. The script executes approximately twice per second to compare each of the bits in these 7 registers. Single bit upsets are logged when any single bit of any of the 7 registers is upset. Examples of Multi-Bit Upsets are also captured.

In order to determine reset SEFIs, three scratch registers were programmed to a value of 0xFE and monitored to determine if any returned to 0x00. If any of these registers met this condition, a SEFI event (reset) was flagged so this data point would not be considered in the SEU count. The data was analyzed to verify that no single bit upsets coincided with a SEFI event (reset). If one had occurred simultaneously then it would have been due to the reset register upset, it would have been flagged as part of a SEFI, and it would not be an SEU event.

AD9213 Single Event Transient Data Summary

The following plots illustrate the single event transient (SET) performance of the AD9213.

To observe the SETs of the AD9213 an FPGA program was generated to compare consecutive output samples and record the data to memory when the delta exceeds an error threshold. The comparison is made in groups of 65 samples. When one or more consecutive samples has a delta greater than the error threshold the entire group of 65 samples is recorded to memory along with error flags, total error count, and total sample count.

The ADC is operated at a sample rate of 10 GSPS with a 700kHz analog input signal at an amplitude of -6 dBFS. The output samples are observed by the FPGA on the ADS8-V1EBZ data capture board.

SET: 200 MeV protons

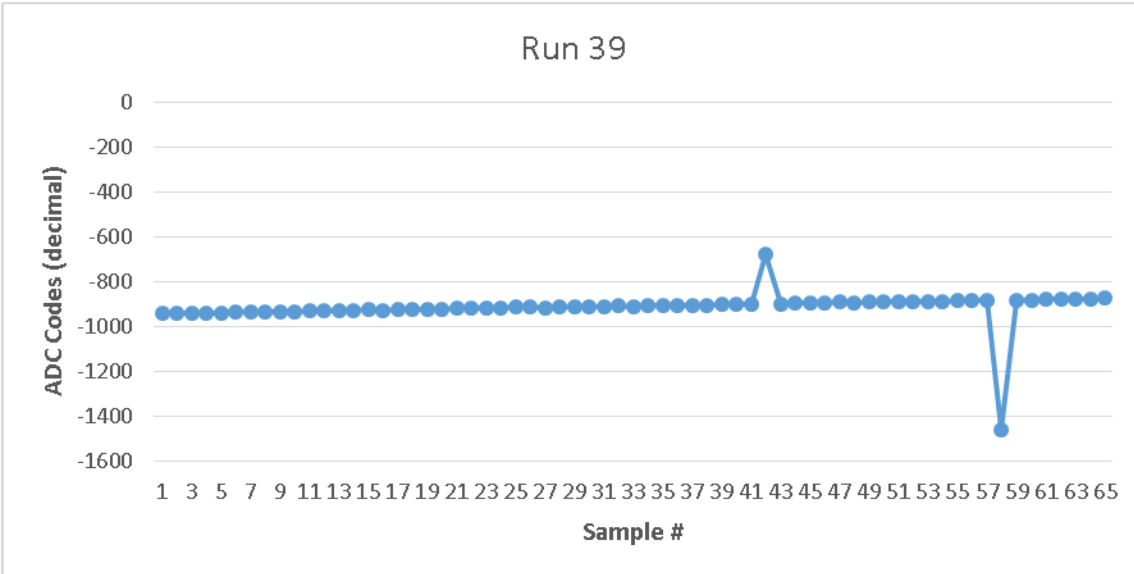

Figure 1A: SET for Run 39 – 200MeV

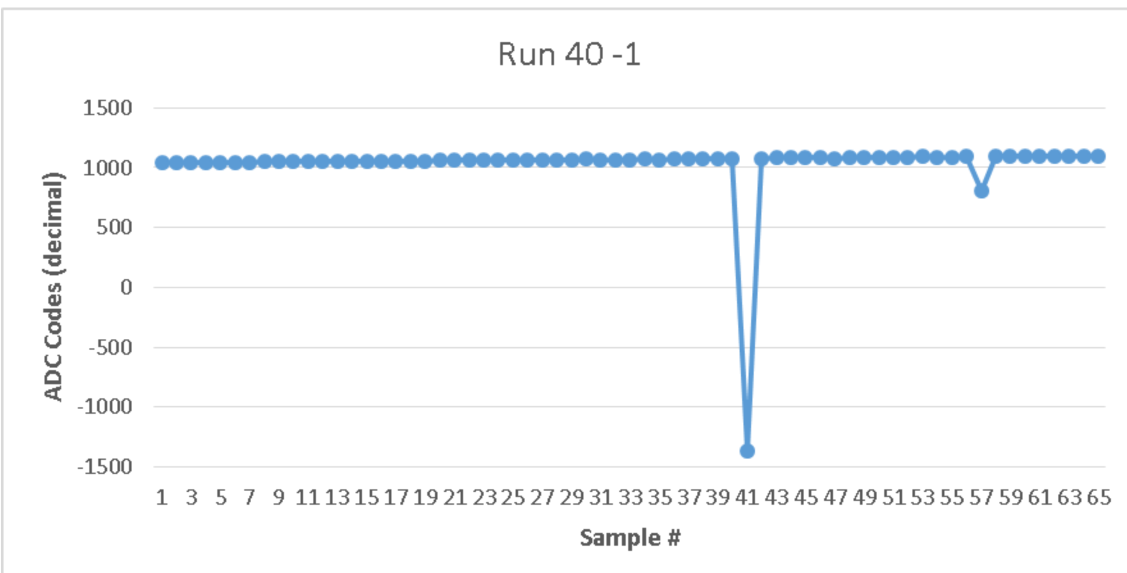

Figure 2A: SET for Run 40 – 200MeV

SET: 200 MeV protons

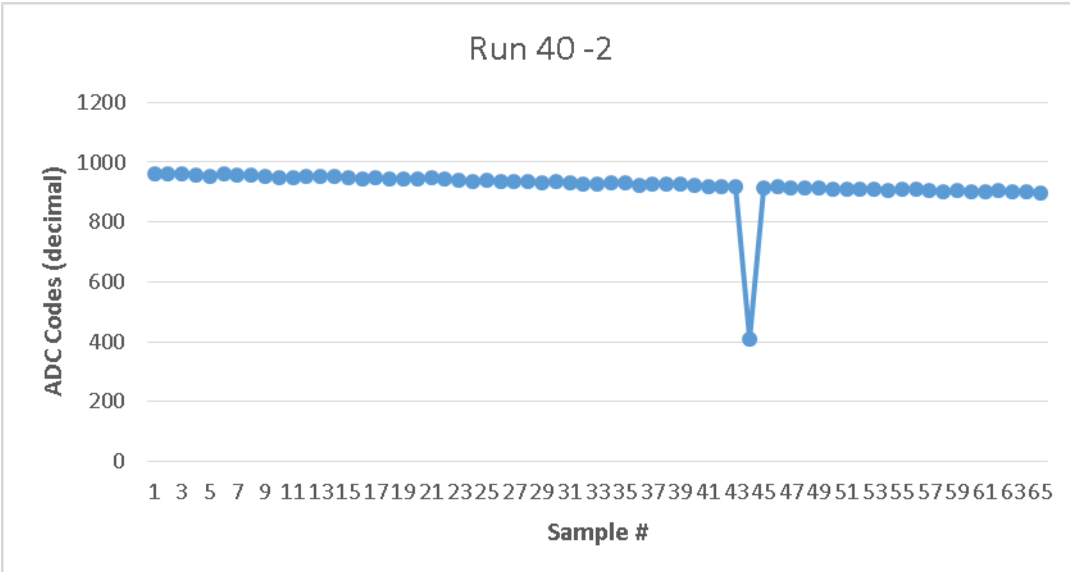

Figure 3A: SET for Run 40 – 200MeV

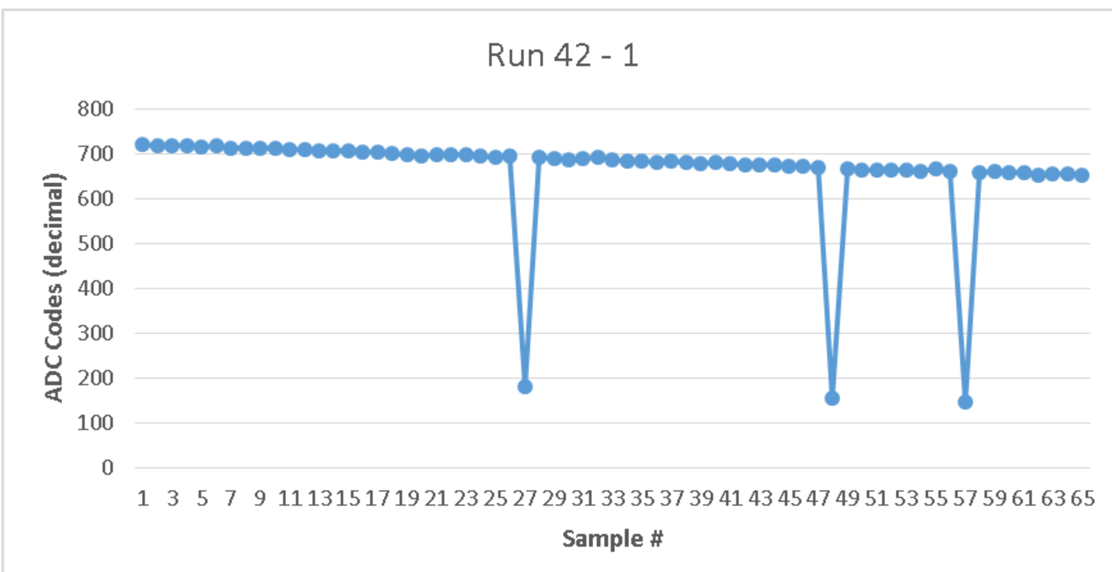

Figure 4A: SET for Run 42 – 200MeV

SET: 200 MeV protons

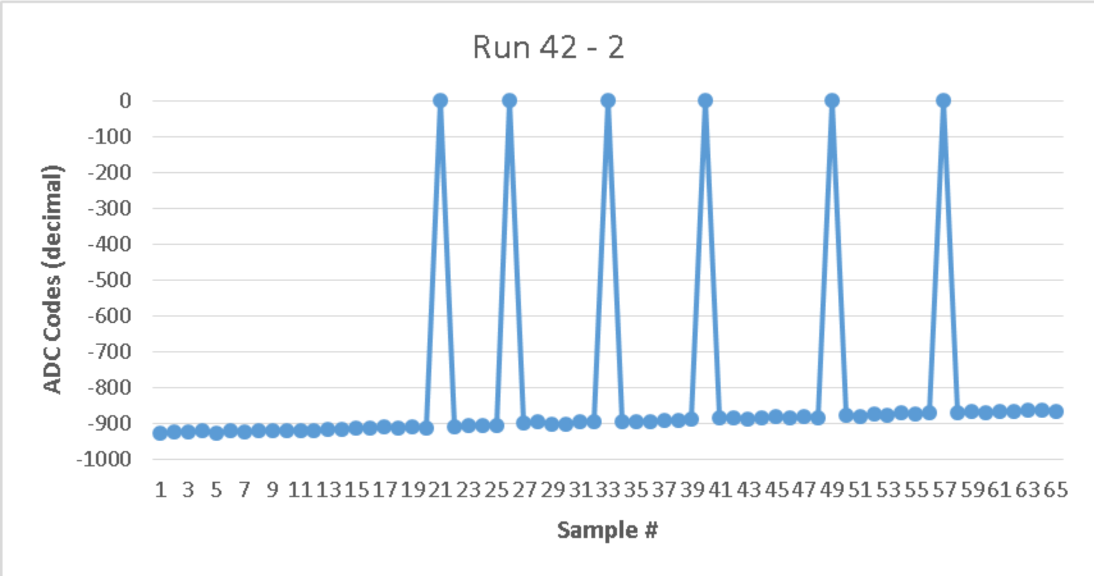

Figure 5A: SET for Run 42 – 200MeV

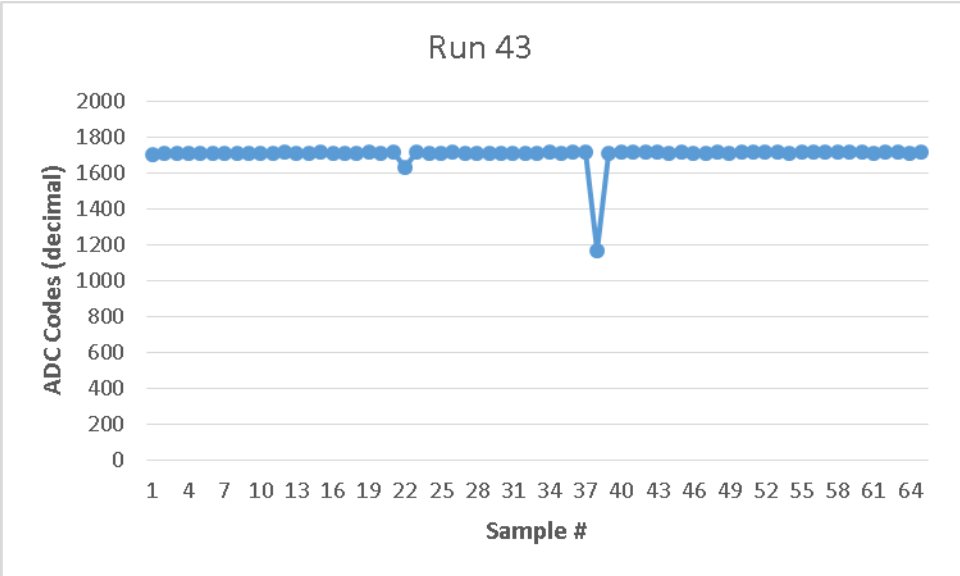

Figure 6A: SET for Run 43 – 200MeV

SET: 100 MeV protons

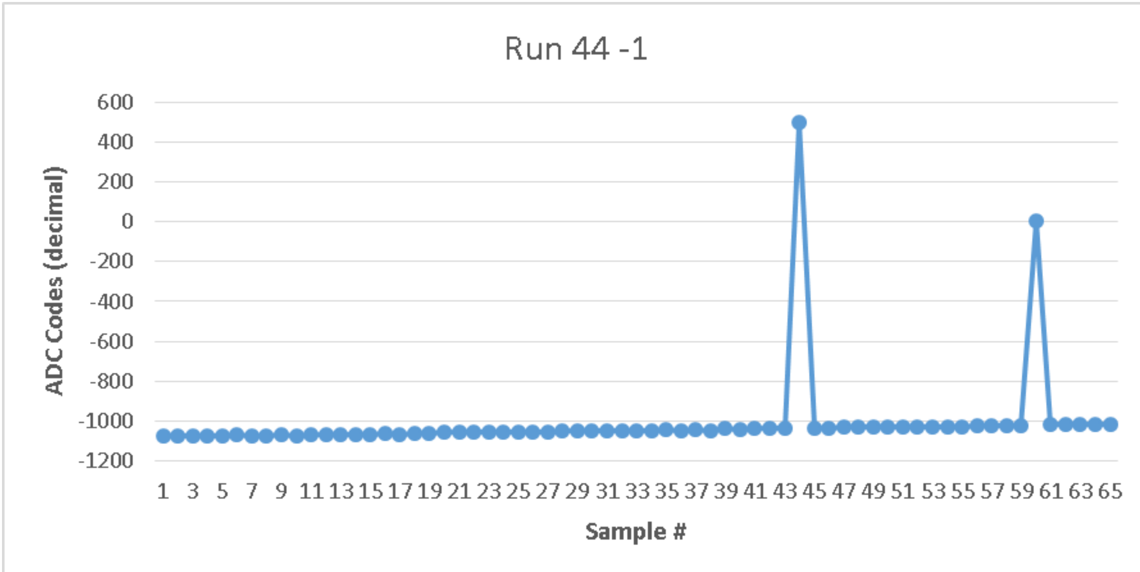

Figure 7A: SET for Run 44 – 100MeV

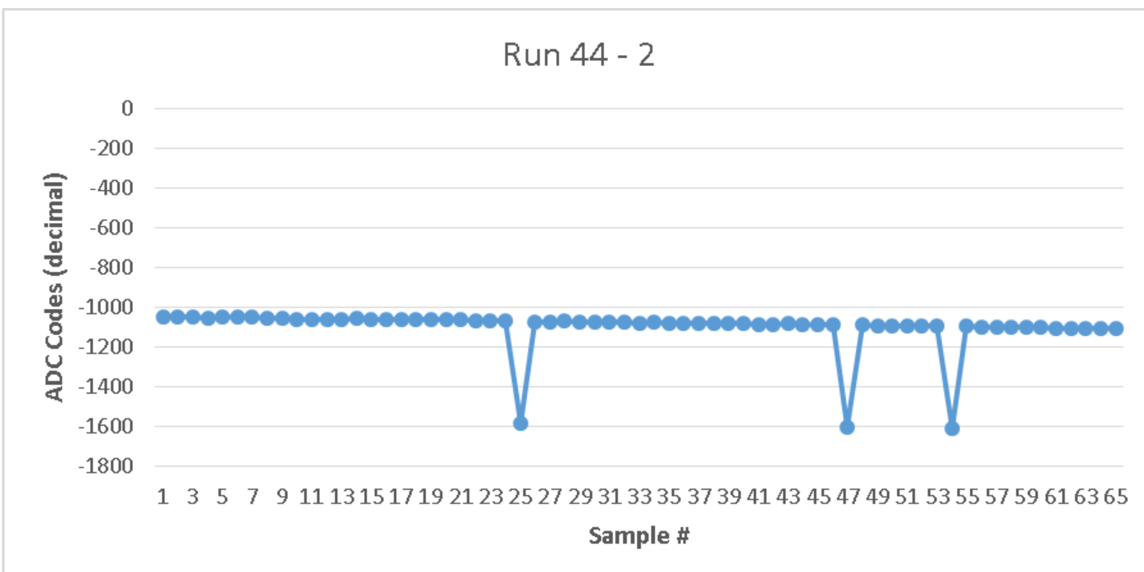

Figure 8A: SET for Run 44 – 100MeV

SET: 100 MeV protons

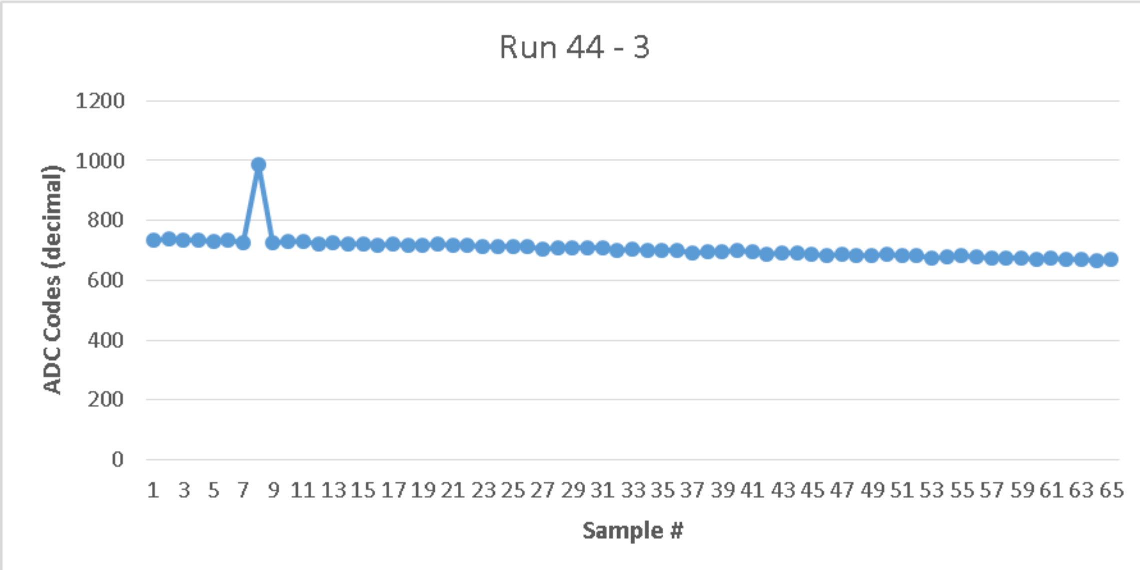

Figure 9A: SET for Run 44 – 100MeV

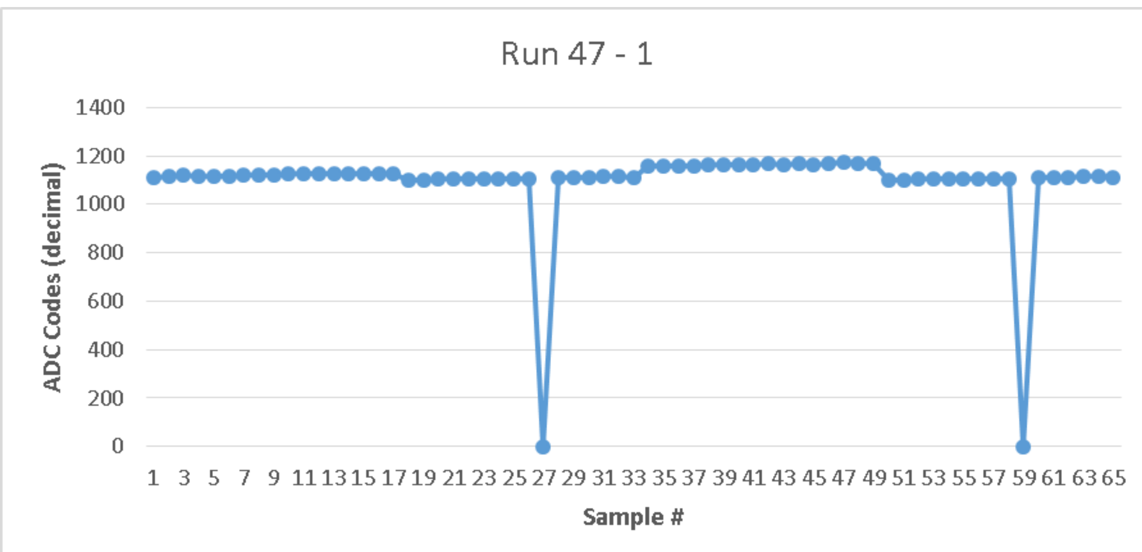

Figure 10A: SET for Run 47 – 100MeV

SET: 100 MeV protons

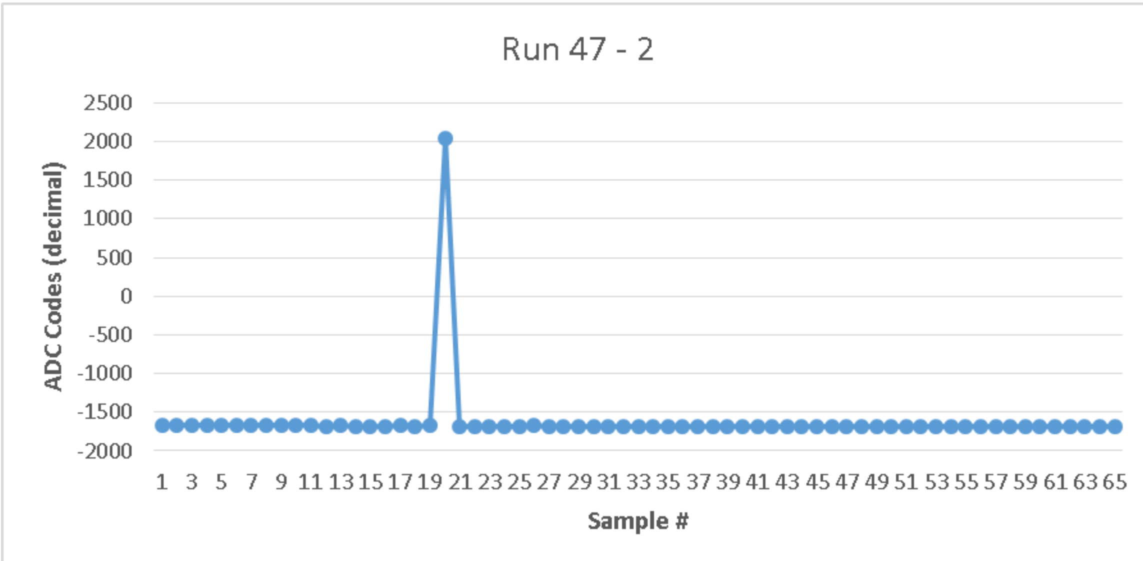

Figure 11A: SET for Run 47 – 100MeV

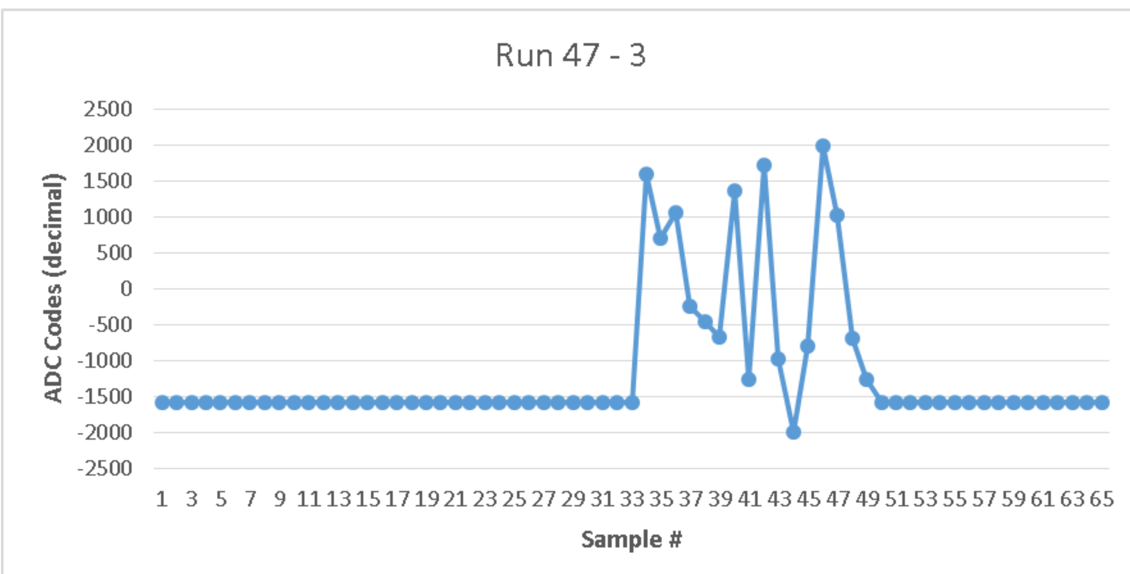

Figure 12A: SET for Run 47 – 100MeV

SET: 50 MeV protons

Figure 13A: SET for Run 48 – 50MeV

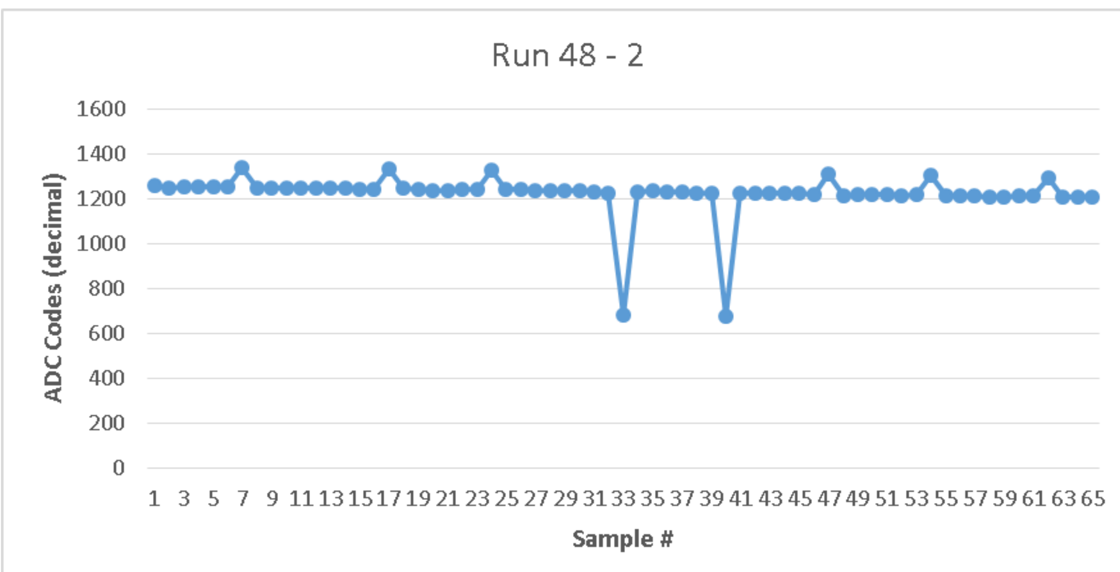

Figure 14A: SET for Run 48 – 50MeV

SET: 50 MeV protons

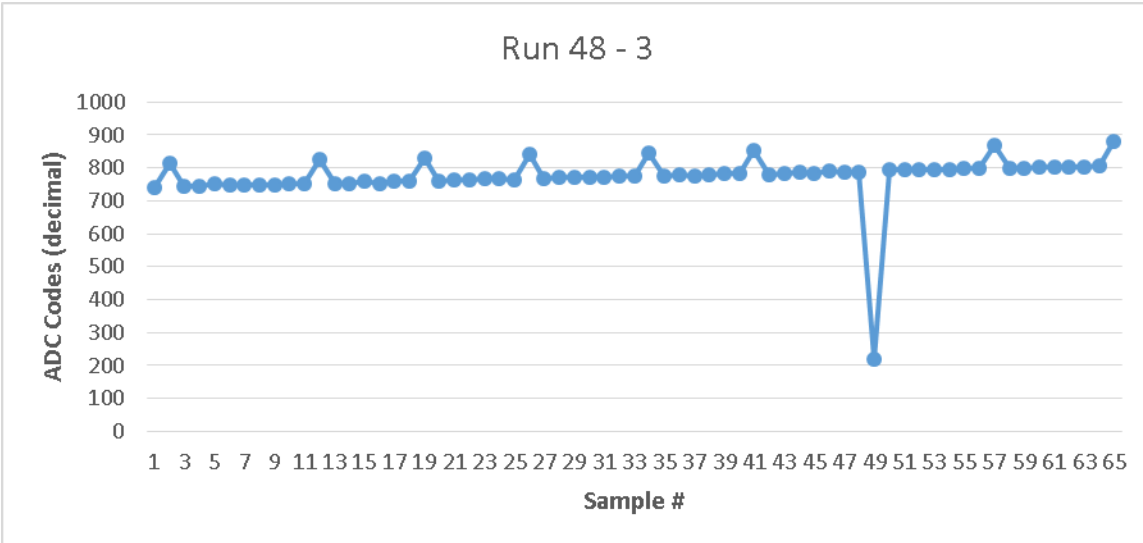

Figure 15A: SET for Run 48 – 50MeV

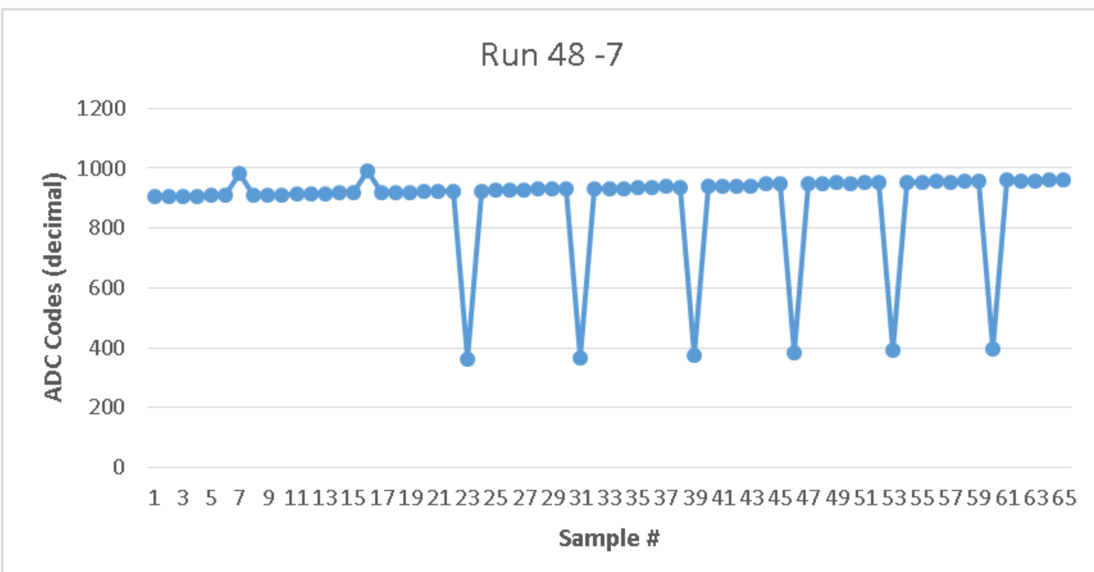

Figure 16A: SET for Run 48 – 50MeV