SINGLE EVENT EFFECTS
TEST REPORT

Test Type:	Heavy ion
Test facility:	RADEF, JYFL, University of Jyvaskyla, Jyvaskyla, Finland
Test Date:	August 2014, October 2014
Part Type:	RHF1401
Part Description:	Rad-hard 14-bit 20 Msps A/D converter
Part Manufacturer:	STMicroelectronics

ESA contract n° 4000105495/12/NL/SFe dated 27/2/2012

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SEE test report

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1 Glossary

DUT: Device under test.

Fluence (of particle radiation incident on a surface): The total amount of particle radiant energy incident on a surface in a given period of time, divided by the area of the surface.
In this document, Fluence is expressed in ions per cm2.

Flux: The time rate of flow of particle radiant energy incident on a surface, divided by the area of that surface.
In this document, Flux is expressed in ions per cm2*s.

Single-Event Effect (SEE): Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from a single energetic particle strike.
Single-event effects include single-event upset (SEU), multiple-bit upset (MBU), multiple-cell upset (MCU), single-event functional interrupt (SEFI), single-event latch-up (SEL.

Single-Event Transient (SET): A soft error caused by the transient signal induced by a single energetic particle strike.

Single-Event Latch-up (SEL): An abnormal high-current state in a device caused by the passage of a single energetic particle through sensitive regions of the device structure and resulting in the loss of device functionality.
SEL may cause permanent damage to the device. If the device is not permanently damaged, power cycling of the device (off and back on) is necessary to restore normal operation.
An example of SEL in a CMOS device is when the passage of a single particle induces the creation of parasitic bipolar (p-n-p-n) shorting of power to ground.
Single-Event Latch-up (SEL) cross-section: the number of events per unit fluence. For chip SEL cross-section, the dimensions are cm2 per chip.

Error cross-section: the number of errors per unit fluence. For device error cross-section, the dimensions are cm2 per device. For bit error cross-section, the dimensions are cm2 per bit.

Tilt angle: tilt angle, rotation axis of the DUT board is perpendicular to the beam axis; roll angle, board rotation axis is parallel to the beam axis
Weibull fit: $F(x) = A (1- \exp\{-[(x-x_0)/W]^s\})$ with:

> x = effective LET in $MeV/(mg/cm^2)$;
> $F(x)$ = SEE cross-section in cm^2;
> A = limiting or plateau cross-section;
> x_0 = onset parameter, such that $F(x) = 0$ for $x < x_0$;
> W = width parameter;
> s = a dimensionless exponent.

Error bars: error bars are computed using a confidence level of 95% and a beam flux uncertainty of +/-10% as recommended by Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100.

2 Introduction

This report presents the results of Heavy Ions test program carried out on RHF1401 part type from STMicroelectronics. RHF1401samples were used for heavy ions testing at RADEF, JYFL, University of Jyvaskyla, Jyvaskyla, Finland.
This work was performed for ESA under ESA contract n° 4000105495/12/NL/SFe dated 27/2/2012.
Two test campaigns have been implemented in August 2014 (W35) and in October 2014 (W44).

3 Applicable and Reference Documents

3.1 Applicable Documents

AD-1. Hirex proposal « Test Methods, Requirements, and Guidelines for Evaluation of Radiation Sensitivity of Analog to Digital Converters (ADC), Digital to Analog Converters (DAC) and Vertical Power MOSFETs» HRX/PRO/3624 Issue 01 /2011/10/12
AD-2. RHF1401, STMicroelectronics datasheet, DocID13317 Rev 8, October 2012

3.2 Reference Documents

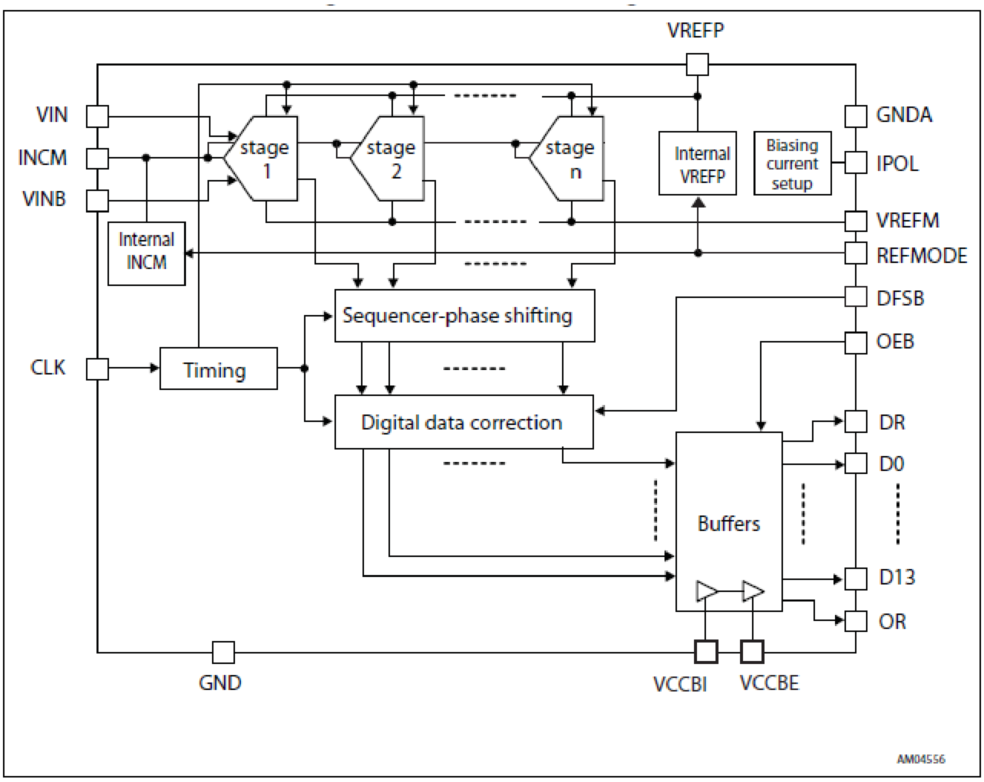
RD-1. Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100
RD-2. RHF1401, STMicroelectronics datasheet, DocID13317 Rev 9, July 2014

4 DEVICE INFORMATION

4.1 Device description

RHF1401is a Rad-hard 14-bit 20 Msps A/D converter.

Functional diagram



Part type:	RHF1401
Manufacturer:	STMicroelectronics
Manufacturer lot number:	-
Datecode:	31228A
Package:	SOIC_48
Top marking:	logo 31228A RHF1401KS01 FR
Die dimensions:	3868µ x 2429µ

4.2 Sample preparation

Samples are opened mechanically.

4.3 Sample identification

Photo 1 – Device top view

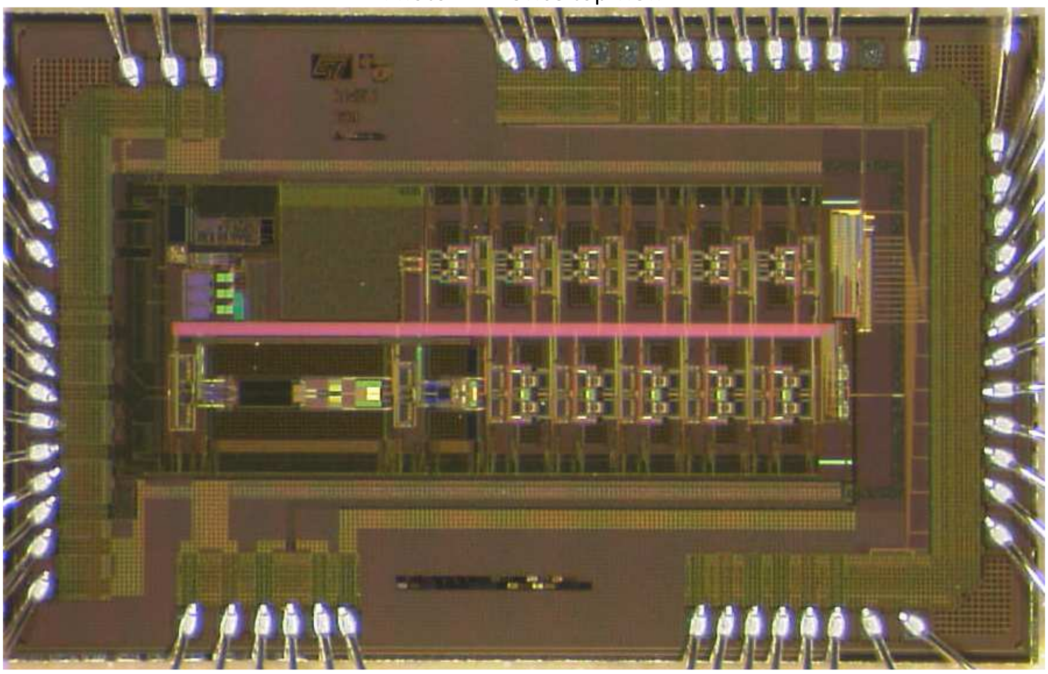


Photo 4 – Die full view

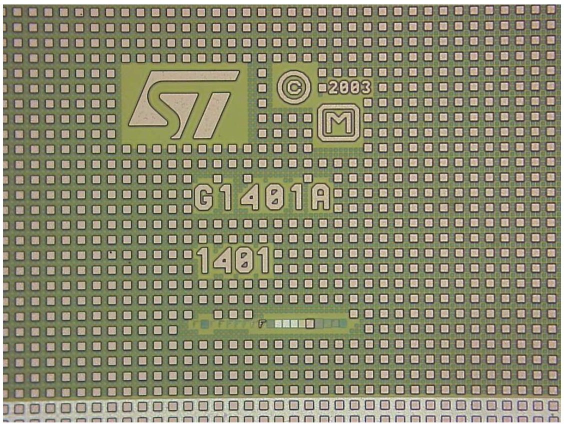


Photo 3 – Die Marking1

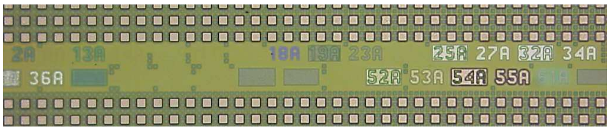


Photo 4 – Die marking2

Figure 1: RHF1401 device identification

5 RADEF Facility

Test at the cyclotron accelerator was performed at University of Jyvaskyla (JYFL) (Finland) under HIREX Engineering responsibility.
The facility includes a special beam line dedicated to irradiation studies of semiconductor components and devices. It consists of a vacuum chamber including component movement apparatus and the necessary diagnostic equipment required for the beam quality and intensity analysis.
The cyclotron is a versatile, sector-focused accelerator of beams from hydrogen to xenon equipped with three external ion sources: two electron cyclotron resonance (ECR) ion sources designed for high-charge-state heavy ions, and a multicusp ion source for intense beams of protons. The ECR's are especially valuable in the study of single event effects (SEE) in semiconductor devices. For heavy ions, the maximum energy attainable can be determined using the formula,

$$130\ Q^2/M,$$

where Q is the ion charge state and M is the mass in Atomic Mass Units.

Test chamber

Irradiation of components is performed in a vacuum chamber with an inside diameter of 75 cm and a height of 81 cm.
The vacuum in the chamber is achieved after 15 minutes of pumping, and the inflation takes only a few minutes. The position of the components installed in the linear movement apparatus inside the chamber can be adjusted in the X, Y and Z directions. The possibility of rotation around the Y-axis is provided by a round table. The free movement area reserved for the components is 25 cm x 25 cm, which allows one to perform several consecutive irradiations for several different components without breaking the vacuum.
The assembly is equipped with a standard mounting fixture. The adapters required to accommodate the special board configurations and the vacuum feed-throughs can also be made in the laboratory’s workshops.
The chamber has an entrance door, which allows rapid changing of the circuit board or individual components.
A CCD camera with a magnifying telescope is located at the other end of the beam line to determine accurate positioning of the components. The coordinates are stored in the computer’s memory allowing fast positioning of various targets during the test.

Beam quality control

For measuring beam uniformity at low intensity, a CsI(Tl) scintillator with a PIN-type photodiode readout is fixed in the mounting fixture. The uniformity is measured automatically before component irradiation and the results can be plotted immediately for more detailed analysis.
A set of four collimated PIN-CsI(Tl) detectors is located in front of the beam entrance. The detectors are operated with step motors and are located at 90 degrees with respect to each other. During the irradiation and uniformity scan they are set to the outer edge of the beam in order to monitor the stability of the homogeneity and flux.
Two beam wobblers and/or a 0.5 microns diffusion Gold foil can be used to achieve good beam homogeneity. The foil is placed 3 m in front of the chamber. The wobbler-coils vibrate the beam horizontally and vertically, the proper sweeping area being attained with the adjustable coil-currents.

Dosimetry

The flux and intensity dosimeter system contains a Faraday cup, several collimators, a scintillation counter and four PIN-CsI(Tl) detectors. Three collimators of different size and shape are placed 25 cm in front of the device under test. They can be used to limit the beam to the active area to be studied.
At low fluxes a plastic scintillator with a photomultiplier tube is used as an absolute particle counter. It is located behind the vacuum chamber and is used before the irradiation to normalize the count rates of the four PIN-CsI(Tl) detectors.

Ion	LET^{SRIM} at surface [$MeV.cm^2.mg^{-1}$]	Range [µm]	Beam energy [MeV]
$^{20}Ne^{6+}$	3.63	146	186
$^{40}Ar^{12+}$	10.2	118	372
$^{56}Fe^{15+}$	18.5	97	523
$^{82}Kr^{22+}$	32.1	94	768
$^{131}Xe^{35+}$	60.0	89	1217

SRIM-2003.26

Table 1 – Ion beam setting

6 Test Set-up

Test system Figure 2 shows the principle of the Heavy Ion test system.
The test system is based on a Virtex4 FPGA (Xilinx). It runs at 50 MHz. The test board has 168 I/Os which can be configured using several I/O standards.
The test board includes the voltage/current monitoring and the latch-up management of the DUT power supplies up to 24 independent channels.

A SEL event is detected when one of the monitored power supply channel current exceeds the corresponding given threshold current within a few microseconds; it is then followed by a device under test power reset after a given off time.

The communication between the test chamber and the controlling computer is effectively done by a 100 Mbit/s Ethernet link which safely enables high speed data transfer.

Test board has been designed so that 2 samples can be eventually tested at the same time to heavy ions. Two RHF1401 parts are mounted on the daughter board as shown in Figure 3 and RHF1401 design schematic is shown in Figure 4.

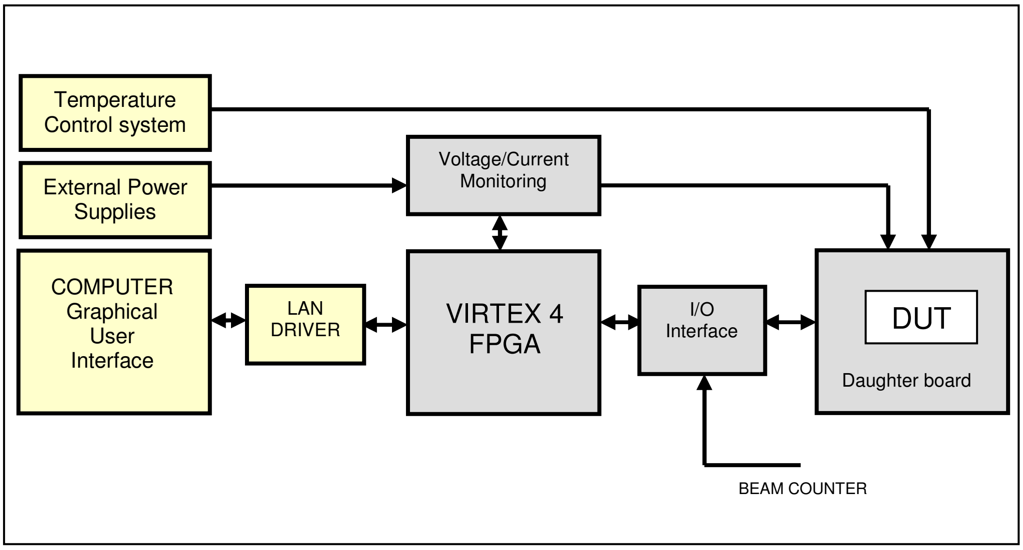


Figure 2: RHF1401, Heavy ion test set-up

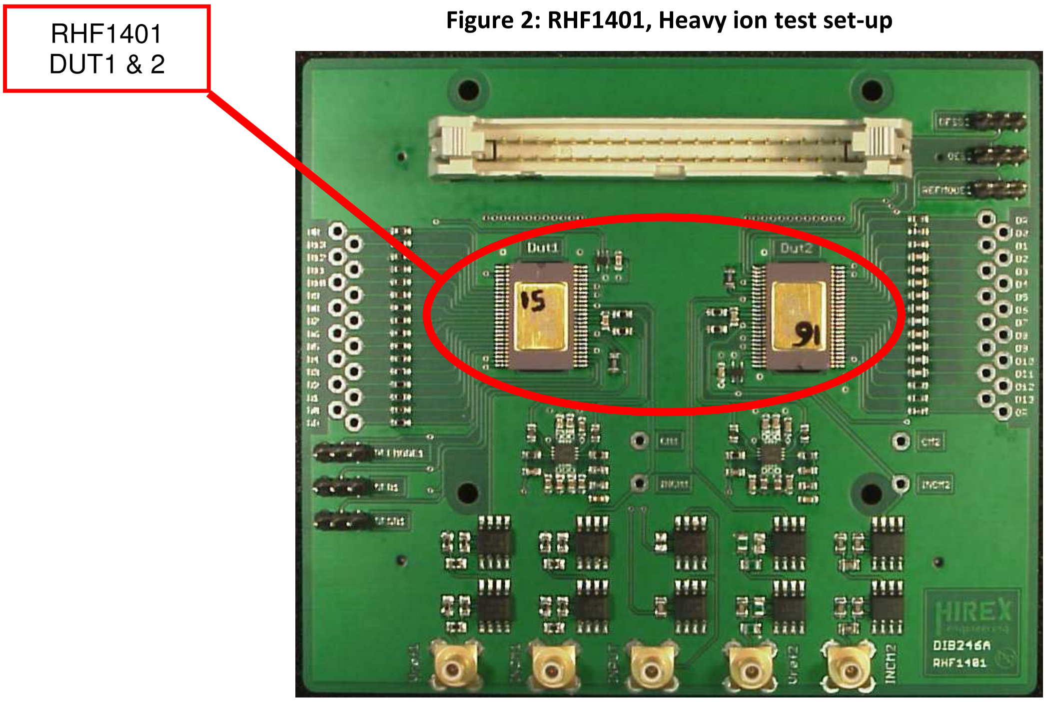


Figure 3: Daughter board (DIB246A) photo

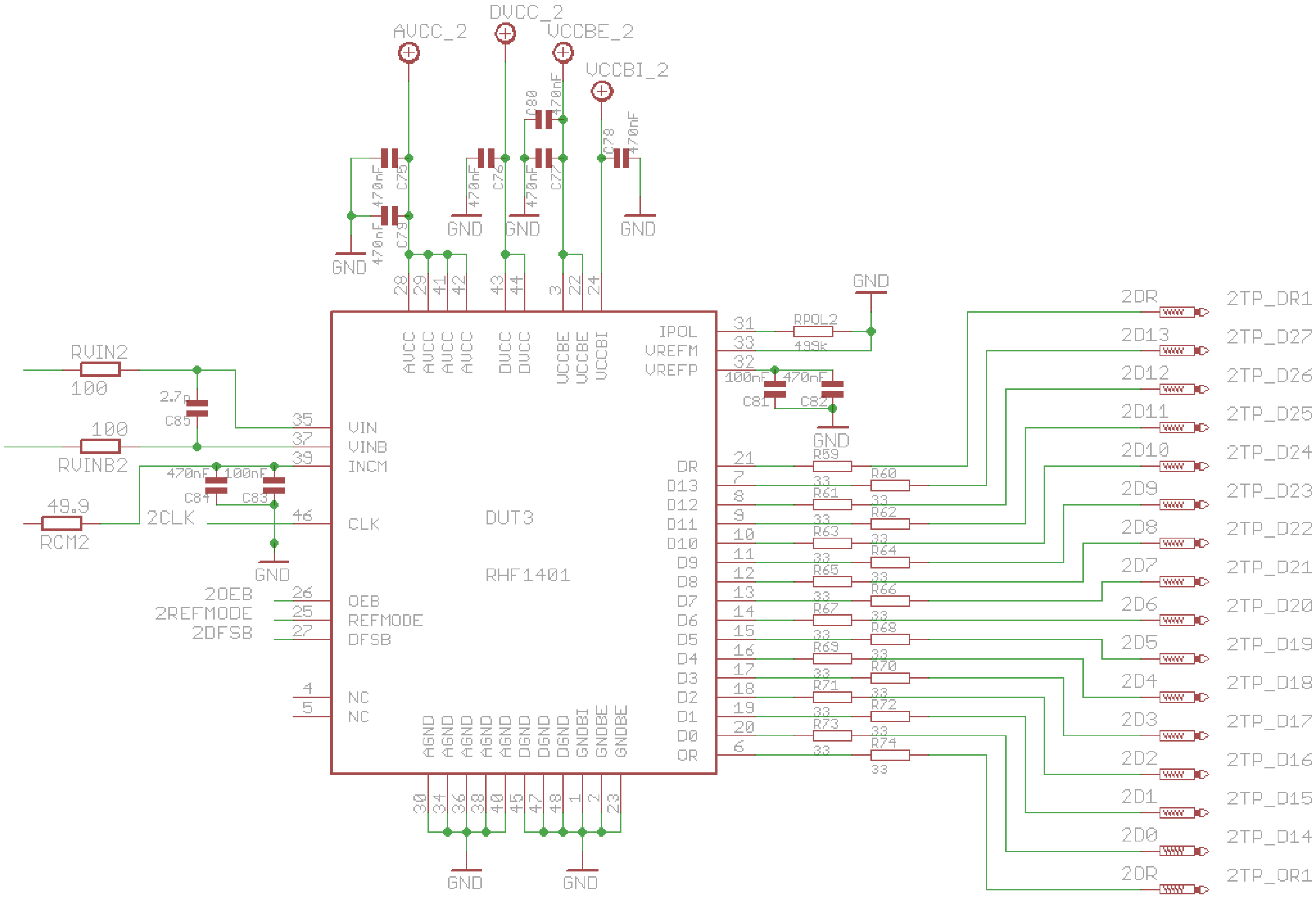


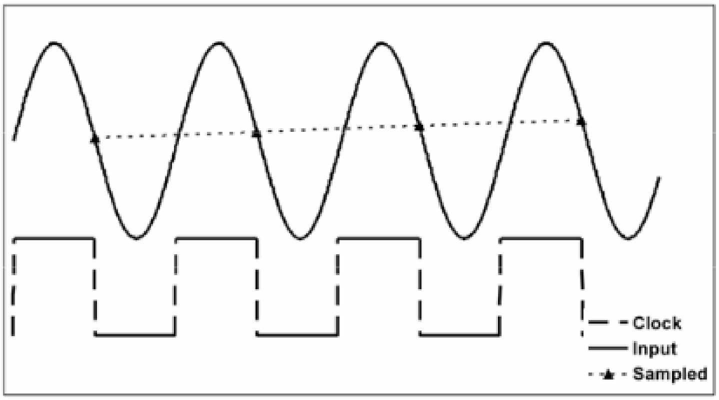
Figure 4: RHF1401 design schematic

7 Test methods

For this AD converter testing, a sinewave signal is used at RHF1401 input.
in addition to characterize the SEE behavior of the RHF1401, the objective of this test was also to compare the efficiency of different test methods based on different sets of sinewave input frequency and DUT sampling frequency. 3 test methods have then been implemented.

- beat frequency: With the input frequency f_{in} set very close to the sampling frequency, the output code of the ADC is a slow moving digital sine wave, changing at a rate of 1 LSB per clock cycle.
  Input sine frequency f_{in} and sampling frequency f_s must repond to:

$$f_{in}=f_s/(2^N*PI) \text{ with } N=14$$



- 4points: DUT sampling frequency being fixed, the selected frequency of the sinewave input is such that only 4 points of the sinewave output are converted continuously.
  Input sinewave frequency f_{in} and sampling frequency f_s must repond to:

$$f_s - f_{in}=f_s/4$$

- Hirex method: DUT sampling frequency being fixed, input frequency f_{in} is set to a much lower value than f_s with f_s a multiple of $f_{in,}$ leading to a significant number of points converted by sinewave input period.
  Input sinewave frequency f_{in} and sampling frequency f_s must repond to:
  $f_{in}=f_s/m$ with m integer
  In the present test, m was typically set to 1000.

8 Error detection and recording

For beat frequency, detection when the output shifts from the expected value is done by comparing with the previous clock conversion as it should differ only by 1 LSB and trig the data recording.
For 4 points method, this is achieved by comparing the output with the 4 clock times before output (or a multiple of 4).
For Hirex method, as for 4 points, this is achieved by comparing the output with the m clock times before output (or a multiple of m).
2048 conversions values before the detection trig and 2048 after are recorded wich allows for checking the occurrence of successive conversions in error if any. Conversion values before the event trig can then be used for the comparison of the output signal before the event and the event signal and by difference extract the error signal.
SET event amplitude and duration definition used in this report are presented in an example in Figure 5 with a detection threshold of +/- 50LSBs and a time period of 200 points between the output signal before the event (red dots) and the event (blue dots).

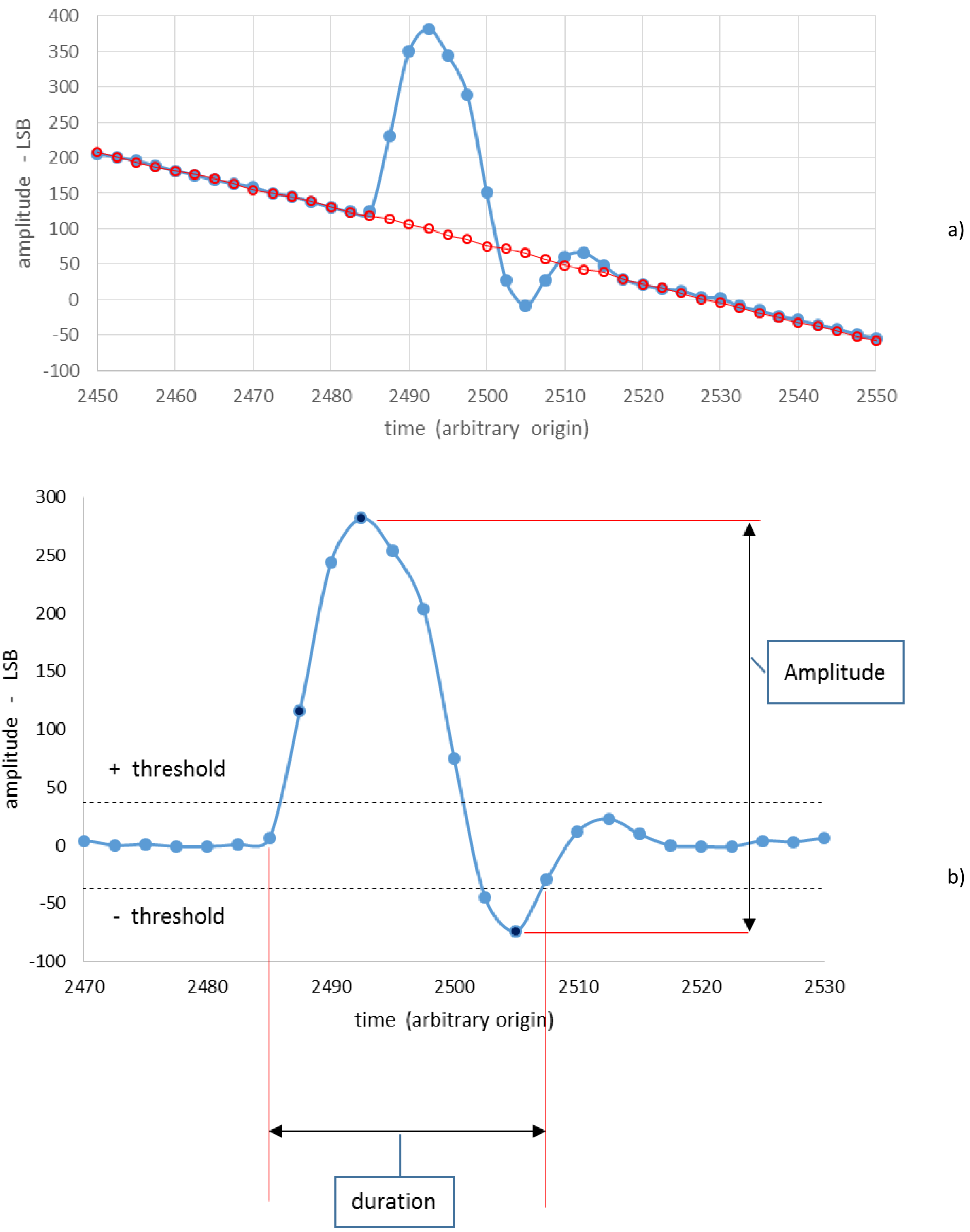


Figure a) shows ADC output (blue dot) for an event trig together with ADC output 200 periods before (red dot).

In figure b) the difference between the 2 curves of figure a) is plot. Event amplitude is defined as the maximum amplitude value minus the minimum value and event duration is the difference in time between the last point before the first conversion above threshold (dotted line) and the first point after the last conversion above threshold.

Figure 5 – SET amplitude and duration

8.1 Wave generation hardware

A specific board has been designed to produce a clock signal of frequency f_S in phase with a sine signal at the desired input frequency f_{in}, so that the three test methods can be implemented easily.
Wave generation board principle is shown in Figure 6.
A single oscillator is used to produce the system's clock. This clock feeds the FPGA's Direct Digital Synthesis (DDS) block on one hand, and the external Digital to Analog Converter (DAC).
The DDS combined to the Signal processing block can produce square and/or sinus waveforms independantly with an accuracy inferior to the millihertz for each signal frequency.
We can also set the amplitude and the offset of these output signals before the analogic conversion.
The waveforms are then converted via the DAC, amplified and symetrised if needed before entering the DUT.
The major benefit of this system is to generate two different waveforms from one single system clock. Then we can create two signals at the exact same frequency with no chance to see any unwanted phase shift.
Moreover the system allows us to set the phase shift between these two signals very precisely if we want some phase shift. This can be usefull for the 4 points testing method : we can choose what are the 4 points on the sinewave we want to observe.

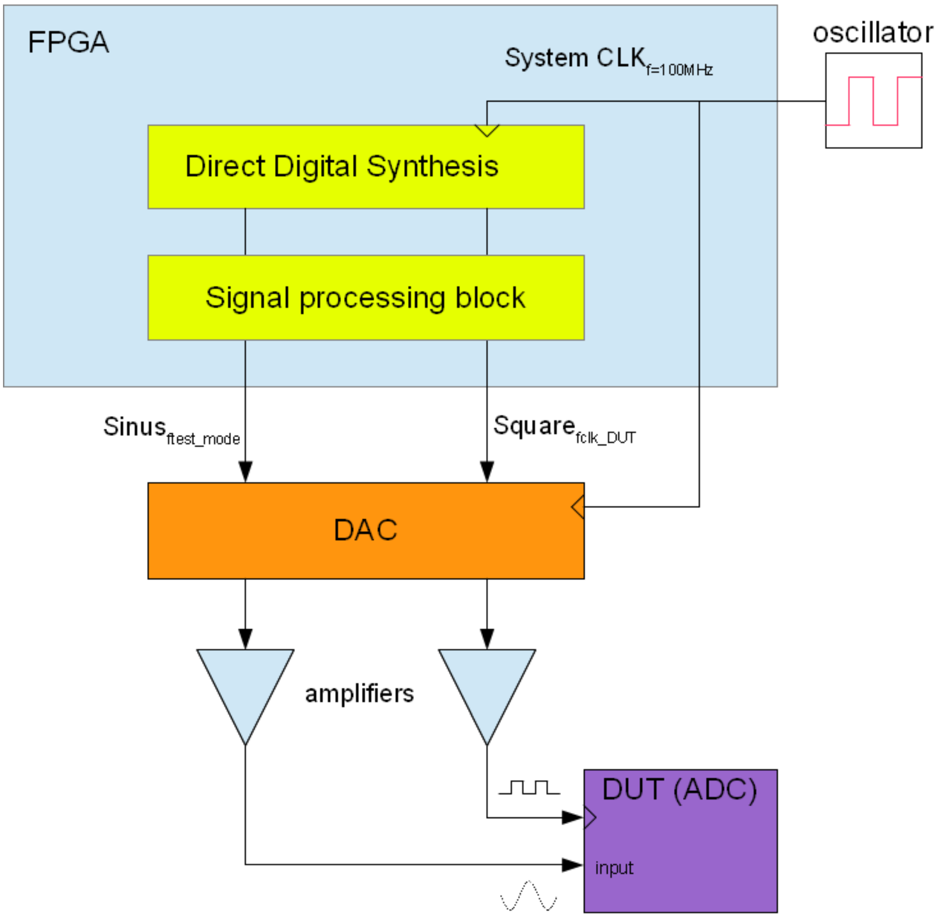


Figure 6 – Wave generation schematic

9 Bias conditions

- AVCC 2.5V
- DVCC 2.5V
- VCCBE 3.3V
- VCCBI 2.5V
- Room temperature
- Internal reference

Figure 7 – Bias conditions

10 SEE Test Results

10.1 SEU

10.2 August 2014 test campaign

1 sample is tested at a time (DUT1 or DUT2) using bias conditions of Figure 7.
The three test methods have been applied with the following sets of frequencies. For the beat frequency test method, the input frequency was adjusted manually from an external AWG unit and not using the board described in paragraph 8.1. It comes that the imput change was much lower than 1 LSB at each consecutive conversion.

	Input sinus			RHF1401
	4points	hirex	beat freq	conversion frequency
W35	3 750 000 Hz	15 000 Hz	~15 000 000 Hz	15 000 000 Hz

Input sinewave amplitude was adjusted closed to fullscale. Value of 1 LSB corresponds to 122µV.
Figure 8 show the different digital output waveforms for the three different methods.
The presence of noise at DUT output requires to apply a detection threshold without exposure between 50 and 200 LSBs.
Because of a limitation in test software, the output value is compared to the previous one 2 clocks before instead of 1 clock for beat frequency event detection. Impact on the word output comparison with the previous output value is then 2 LSBs instead of 1. Practically it does not change the test method as the threshold set includes also the noise level which is as a minimum 50 LSBs.
Run details and results are provided in Table 2 and Table 3.
All runs were performed with normal incidence beam (no tilt).
In Table 2 and Table 3 for each run, the detection threshold level in LSBs is noted (column “threshold (LSBs)”) togeteher with the number of events detected (column ‘Nb events above threshold”). As this threshold is not identical for all runs and to ease comparison, we have extracted the number of events which would have been triggered with a threshold of respectively X=50, 100, 130 and 200LSBs: see column “NB events above X LSBs”.
Column ‘period’ refers to the number of clocks to which output value is compared to the current conversion output.
In addition, the 2 tables provides the error bar values computed as indicated in §1 in columns named up, low,X-section_up,X_section_low, delta_up and delta_low using a confidence level of 95% and a beam flux uncertainty of +/-10%.

To ease the comparison between the 3 different test methods implemented during this exercise, Figure 9, Figure 10 and Figure 12 show the event cross-section for each test method and with 3 different threshold values. As it can be observed, these methods give similar event cross-section curves.
For the hirex test method, X-section curve is also given with a threshold of 50LSBs in Figure 11.
A detailed analysis for each method is provided here after.

For the three methods, 2 event populations are observed:
A first population of 1 to 2 conversion errors events with a maximum amplitude that could be quite significative and a second population of large events up to several hundred of successive conversions in error but with a much reduced error amplitude.

Figure 13 and Figure 14 show the event amplitude versus event duration for the three test methods. The delta period used for comparison between the digital output signal and the event signal is 1000 conversions.It can be observed that events durations are clamped at about 66 microseconds (for those exceeding 1000 successive conversions in error due to the detection method and the number of recorded points).
Event examples are shown, in Figure 15 to Figure 17.

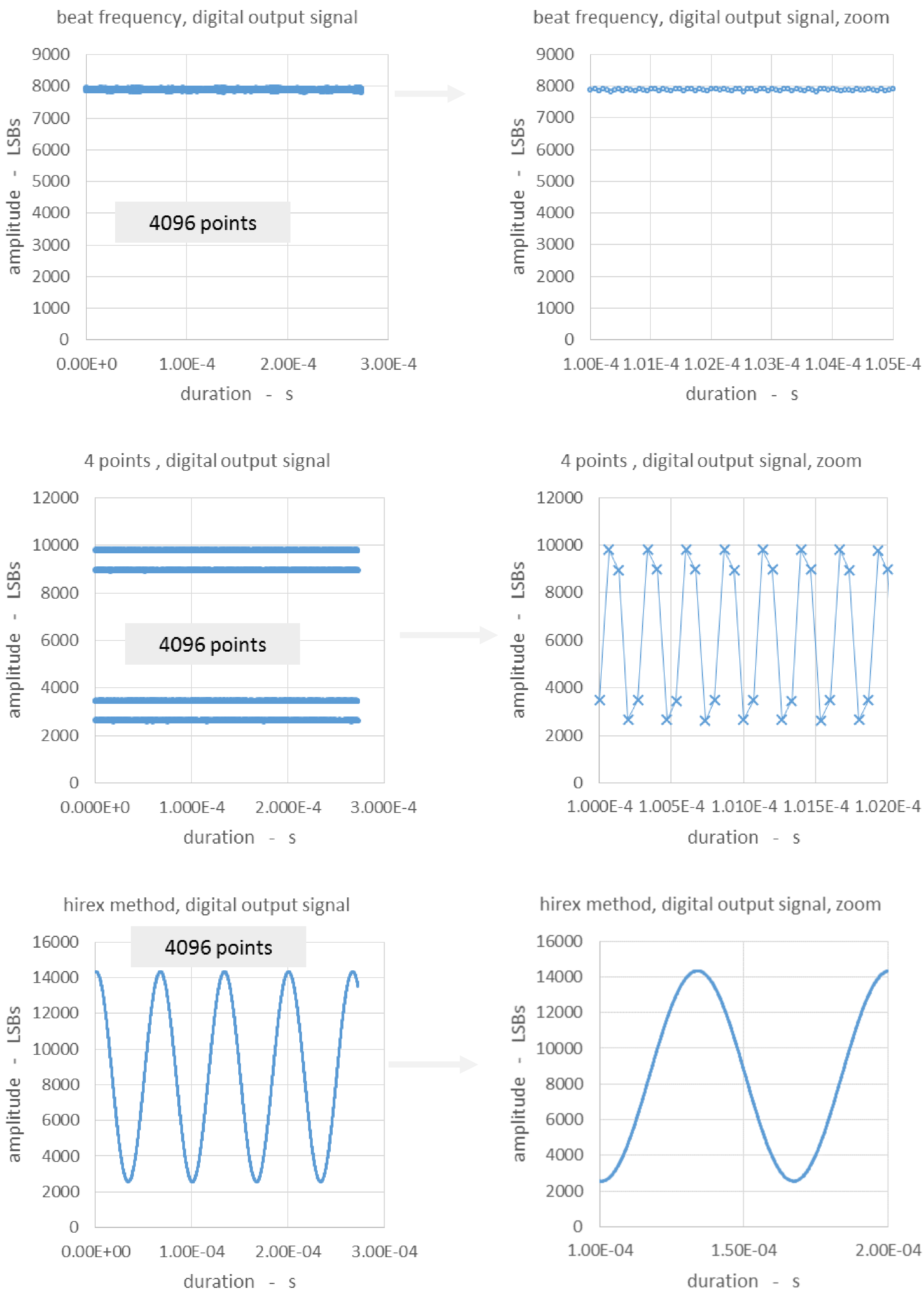


Figure 8 – Digital output waveform with the 3 different methods

														above theshold			above 100LSBs			above 130LSBs			above 200LSBs		
run_number	bias_config	Facility_run_number	dut_part_id	period	limit	test_mode	temperature	Ion	LET	roll	tilt	run_duration	entered_fluence	SET > threshold	up	low	SET >100	up	low	SET >130	up	low	SET >200	up	low
5	15MHz Fs	194	1	4	90	4 points	Room	Xe	60	0	0	479	1.12E+06	99	121	80	82	102	65	61	78	47	38	52	27
9	15MHz Fs	197	1	4	90	4 points	Room	Kr	32.2	0	0	304	2.12E+06	102	124	83	92	113	74	76	95	60	57	74	43
24	15MHz Fs	210	1	4	100	4 points	Room	Fe	18.5	0	0	241	5.17E+06	111	134	91	111	134	91	82	102	65	42	57	30
25	15MHz Fs	211	1	4	100	4 points	Room	Ar	10.2	0	0	336	2.47E+06	21	32	13	21	32	13	14	23	8	11	20	5
26	15MHz Fs	212	1	4	100	4 points	Room	Ar	10.2	0	0	565	1.00E+07	108	130	89	108	130	89	83	103	66	51	67	38
38	15MHz Fs	224	1	4	100	4 points	Room	Ne	3.63	0	0	251	1.00E+07	21	32	13	21	32	13	12	21	6	6	13	2
7	15MHz Fs	196	2	4	90	4 points	Room	Kr	32.2	0	0	242	2.09E+06	108	130	89	99	121	80	77	96	61	58	75	44
23	15MHz Fs	209	2	4	100	4 points	Room	Fe	18.5	0	0	247	5.39E+06	124	148	103	124	148	103	93	114	75	58	75	44
27	15MHz Fs	213	2	4	100	4 points	Room	Ar	10.2	0	0	522	1.00E+07	98	119	80	98	119	80	76	95	60	48	64	35
37	15MHz Fs	223	2	4	100	4 points	Room	Ne	3.63	0	0	270	1.00E+07	26	38	17	27	39	18	19	30	11	5	12	2
1	15MHz Fs	190	1	2	200	Beat frequency	Room	Xe	60	0	0	505	2.27E+06	103	125	84							103	125	84
14	15MHz Fs	201	1	2	220	Beat frequency	Room	Kr	32.2	0	0	381	4.67E+06	103	125	84							103	125	84
20	15MHz Fs	207	1	2	220	Beat frequency	Room	Fe	18.5	0	0	297	8.82E+06	106	128	87							106	128	87
29	15MHz Fs	215	1	2	220	Beat frequency	Room	Ar	10.2	0	0	215	1.00E+07	40	54	29							40	54	29
35	15MHz Fs	221	1	2	210	Beat frequency	Room	Ne	3.63	0	0	382	1.00E+07	6	13	2							6	13	2
2	15MHz Fs	191	2	2	200	Beat frequency	Room	Xe	60	0	0	325	2.69E+06	101	123	82							101	123	82
13	15MHz Fs	200	2	2	210	Beat frequency	Room	Kr	32.2	0	0	383	4.19E+06	104	126	85							104	126	85
21	15MHz Fs	208	2	2	210	Beat frequency	Room	Fe	18.5	0	0	341	1.00E+07	105	127	86							105	127	86
28	15MHz Fs	214	2	2	210	Beat frequency	Room	Ar	10.2	0	0	1029	1.00E+07	56	73	42							56	73	42
36	15MHz Fs	222	2	2	210	Beat frequency	Room	Ne	3.63	0	0	397	1.00E+07	4	10	1							4	10	1
4	15MHz Fs	193	1	1000	50	Hirex	Room	Xe	60	0	0	463	1.00E+06	190	219	164	93	114	75	76	95	60	55	72	41
10	15MHz Fs	198	1	1000	50	Hirex	Room	Kr	32.2	0	0	140	1.42E+06	135	160	113	70	88	55	53	69	40	33	46	23
19	15MHz Fs	206	1	1000	50	Hirex	Room	Fe	18.5	0	0	141	3.56E+06	134	159	112	60	77	46	50	66	37	35	49	24
30	15MHz Fs	216	1	1000	50	Hirex	Room	Ar	10.2	0	0	301	6.02E+06	113	136	93	62	79	48	54	70	41	35	49	24
34	15MHz Fs	220	1	1000	50	Hirex	Room	Ne	3.63	0	0	321	1.00E+07	53	69	40	26	38	17	18	28	11	6	13	2
3	15MHz Fs	191	2	1000	50	Hirex	Room	Xe	60	0	0	173	1.02E+06	145	171	122	80	100	63	60	77	46	46	61	34
11	15MHz Fs	199	2	1000	50	Hirex	Room	Kr	32.2	0	0	245	1.47E+06	101	123	82	53	69	40	37	51	26	28	40	19
18	15MHz Fs	205	2	1000	50	Hirex	Room	Fe	18.5	0	0	136	2.88E+06	240	272	211	137	162	115	107	129	88	81	101	64
31	15MHz Fs	217	2	1000	55	Hirex	Room	Ar	10.2	0	0	763	7.82E+06	112	135	92	62	79	48	45	60	33	34	48	24
32	15MHz Fs	218	2	1000	55	Hirex	Room	Ne	3.63	0	0	257	1.00E+07	45	60	33	23	35	15	16	26	9	9	17	4
33	15MHz Fs	219	2	1000	55	Hirex	Room	Ne	3.63	0	0	274	1.00E+07	32	45	22	13	22	7	10	18	5	8	16	3

In the column “above xxx LSBs”, a red mark means that the threshold was higher than xxx LSBs and was the one in the “threshold ‘LSBs)” column.

Table 2 – RADEF, August 2014(W35), RHF1401, run table

														above theshold					above 100LSBs					above 130LSBs					above 200LSBs				
run_number	bias_config	Facility_run_number	dut_part_id	period	limit	test_mode	temperature	Ion	LET	roll	tilt	run_duration	entered_fluence	X-section	X-section_up	X-section_low	delta_up	delta_low	X-section	X-section_up	X-section_low	delta_up	delta_low	X-section	X-section_up	X-section_low	delta_up	delta_low	X-section	X-section_up	X-section_low	delta_up	delta_low
5	15MHz Fs	194	1	4	90	4 points	Room	Xe	60	0	0	479	1.12E+06	8.8E-05	1.1E-04	7.2E-05	1.9E-05	1.7E-05	7.3E-05	9.1E-05	5.8E-05	1.8E-05	1.5E-05	5.4E-05	7.0E-05	4.2E-05	1.5E-05	1.3E-05	3.4E-05	4.7E-05	2.4E-05	1.3E-05	9.9E-06
9	15MHz Fs	197	1	4	90	4 points	Room	Kr	32.2	0	0	304	2.12E+06	4.8E-05	5.8E-05	3.9E-05	1.0E-05	8.9E-06	4.3E-05	5.3E-05	3.5E-05	9.8E-06	8.4E-06	3.6E-05	4.5E-05	2.8E-05	9.0E-06	7.6E-06	2.7E-05	3.5E-05	2.0E-05	7.9E-06	6.5E-06
24	15MHz Fs	210	1	4	100	4 points	Room	Fe	18.5	0	0	241	5.17E+06	2.1E-05	2.6E-05	1.8E-05	4.4E-06	3.8E-06	2.1E-05	2.6E-05	1.8E-05	4.4E-06	3.8E-06	1.6E-05	2.0E-05	1.3E-05	3.8E-06	3.2E-06	8.1E-06	1.1E-05	5.9E-06	2.9E-06	2.3E-06
25	15MHz Fs	211	1	4	100	4 points	Room	Ar	10.2	0	0	336	2.47E+06	8.5E-06	1.3E-05	5.3E-06	4.5E-06	3.2E-06	8.5E-06	1.3E-05	5.3E-06	4.5E-06	3.2E-06	5.7E-06	9.5E-06	3.1E-06	3.8E-06	2.6E-06	4.5E-06	8.0E-06	2.2E-06	3.5E-06	2.2E-06
26	15MHz Fs	212	1	4	100	4 points	Room	Ar	10.2	0	0	565	1.00E+07	1.1E-05	1.3E-05	8.9E-06	2.2E-06	1.9E-06	1.1E-05	1.3E-05	8.9E-06	2.2E-06	1.9E-06	8.3E-06	1.0E-05	6.6E-06	2.0E-06	1.7E-06	5.1E-06	6.7E-06	3.8E-06	1.6E-06	1.3E-06
38	15MHz Fs	224	1	4	100	4 points	Room	Ne	3.63	0	0	251	1.00E+07	2.1E-06	3.2E-06	1.3E-06	1.1E-06	8.0E-07	2.1E-06	3.2E-06	1.3E-06	1.1E-06	8.0E-07	1.2E-06	2.1E-06	6.2E-07	9.0E-07	5.8E-07	6.0E-07	1.3E-06	2.2E-07	7.1E-07	3.8E-07
7	15MHz Fs	196	2	4	90	4 points	Room	Kr	32.2	0	0	242	2.09E+06	5.2E-05	6.2E-05	4.2E-05	1.1E-05	9.3E-06	4.7E-05	5.8E-05	3.8E-05	1.0E-05	8.9E-06	3.7E-05	4.6E-05	2.9E-05	9.2E-06	7.8E-06	2.8E-05	3.6E-05	2.1E-05	8.1E-06	6.7E-06
23	15MHz Fs	209	2	4	100	4 points	Room	Fe	18.5	0	0	247	5.39E+06	2.3E-05	2.7E-05	1.9E-05	4.4E-06	3.9E-06	2.3E-05	2.7E-05	1.9E-05	4.4E-06	3.9E-06	1.7E-05	2.1E-05	1.4E-05	3.9E-06	3.3E-06	1.1E-05	1.4E-05	8.2E-06	3.2E-06	2.6E-06
27	15MHz Fs	213	2	4	100	4 points	Room	Ar	10.2	0	0	522	1.00E+07	9.8E-06	1.2E-05	8.0E-06	2.1E-06	1.8E-06	9.8E-06	1.2E-05	8.0E-06	2.1E-06	1.8E-06	7.6E-06	9.5E-06	6.0E-06	1.9E-06	1.6E-06	4.8E-06	6.4E-06	3.5E-06	1.6E-06	1.3E-06
37	15MHz Fs	223	2	4	100	4 points	Room	Ne	3.63	0	0	270	1.00E+07	2.6E-06	3.8E-06	1.7E-06	1.2E-06	9.0E-07	2.7E-06	3.9E-06	1.8E-06	1.2E-06	9.2E-07	1.9E-06	3.0E-06	1.1E-06	1.1E-06	7.6E-07	5.0E-07	1.2E-06	1.6E-07	6.7E-07	3.4E-07
1	15MHz Fs	190	1	2	200	Beat frequency	Room	Xe	60	0	0	505	2.27E+06	4.5E-05	5.5E-05	3.7E-05	9.7E-06	8.3E-06															
14	15MHz Fs	201	1	2	220	Beat frequency	Room	Kr	32.2	0	0	381	4.67E+06	2.2E-05	2.7E-05	1.8E-05	4.7E-06	4.1E-06															
20	15MHz Fs	207	1	2	220	Beat frequency	Room	Fe	18.5	0	0	297	8.82E+06	1.2E-05	1.5E-05	9.8E-06	2.5E-06	2.2E-06															
29	15MHz Fs	215	1	2	220	Beat frequency	Room	Ar	10.2	0	0	215	1.00E+07	4.0E-06	5.4E-06	2.9E-06	1.4E-06	1.1E-06															
35	15MHz Fs	221	1	2	210	Beat frequency	Room	Ne	3.63	0	0	382	1.00E+07	6.0E-07	1.3E-06	2.2E-07	7.1E-07	3.8E-07															
2	15MHz Fs	191	2	2	200	Beat frequency	Room	Xe	60	0	0	325	2.69E+06	3.8E-05	4.6E-05	3.1E-05	8.1E-06	7.0E-06															
13	15MHz Fs	200	2	2	210	Beat frequency	Room	Kr	32.2	0	0	383	4.19E+06	2.5E-05	3.0E-05	2.0E-05	5.3E-06	4.5E-06															
21	15MHz Fs	208	2	2	210	Beat frequency	Room	Fe	18.5	0	0	341	1.00E+07	1.1E-05	1.3E-05	8.6E-06	2.2E-06	1.9E-06															
28	15MHz Fs	214	2	2	210	Beat frequency	Room	Ar	10.2	0	0	1029	1.00E+07	5.6E-06	7.3E-06	4.2E-06	1.7E-06	1.4E-06															
36	15MHz Fs	222	2	2	210	Beat frequency	Room	Ne	3.63	0	0	397	1.00E+07	4.0E-07	1.0E-06	1.1E-07	6.2E-07	2.9E-07															
4	15MHz Fs	193	1	1000	50	Hirex	Room	Xe	60	0	0	463	1.00E+06	1.9E-04	2.2E-04	1.6E-04	2.9E-05	2.6E-05	9.3E-05	1.1E-04	7.5E-05	2.1E-05	1.8E-05	7.6E-05	9.5E-05	6.0E-05	1.9E-05	1.6E-05	5.5E-05	7.2E-05	4.1E-05	1.7E-05	1.4E-05
10	15MHz Fs	198	1	1000	50	Hirex	Room	Kr	32.2	0	0	140	1.42E+06	9.5E-05	1.1E-04	8.0E-05	1.7E-05	1.5E-05	4.9E-05	6.2E-05	3.8E-05	1.3E-05	1.1E-05	3.7E-05	4.9E-05	2.8E-05	1.1E-05	9.4E-06	2.3E-05	3.3E-05	1.6E-05	9.4E-06	7.2E-06
19	15MHz Fs	206	1	1000	50	Hirex	Room	Fe	18.5	0	0	141	3.56E+06	3.8E-05	4.5E-05	3.2E-05	6.9E-06	6.1E-06	1.7E-05	2.2E-05	1.3E-05	4.8E-06	4.0E-06	1.4E-05	1.9E-05	1.0E-05	4.5E-06	3.6E-06	9.8E-06	1.4E-05	6.8E-06	3.8E-06	3.0E-06
30	15MHz Fs	216	1	1000	50	Hirex	Room	Ar	10.2	0	0	301	6.02E+06	1.9E-05	2.3E-05	1.5E-05	3.8E-06	3.3E-06	1.0E-05	1.3E-05	7.9E-06	2.9E-06	2.4E-06	9.0E-06	1.2E-05	6.7E-06	2.7E-06	2.2E-06	5.8E-06	8.1E-06	4.0E-06	2.3E-06	1.8E-06
34	15MHz Fs	220	1	1000	50	Hirex	Room	Ne	3.63	0	0	321	1.00E+07	5.3E-06	6.9E-06	4.0E-06	1.6E-06	1.3E-06	2.6E-06	3.8E-06	1.7E-06	1.2E-06	9.0E-07	1.8E-06	2.8E-06	1.1E-06	1.0E-06	7.3E-07	6.0E-07	1.3E-06	2.2E-07	7.1E-07	3.8E-07
3	15MHz Fs	191	2	1000	50	Hirex	Room	Xe	60	0	0	173	1.02E+06	1.4E-04	1.7E-04	1.2E-04	2.5E-05	2.2E-05	7.8E-05	9.8E-05	6.2E-05	1.9E-05	1.6E-05	5.9E-05	7.6E-05	4.5E-05	1.7E-05	1.4E-05	4.5E-05	6.0E-05	3.3E-05	1.5E-05	1.2E-05
11	15MHz Fs	199	2	1000	50	Hirex	Room	Kr	32.2	0	0	245	1.47E+06	6.9E-05	8.3E-05	5.6E-05	1.5E-05	1.3E-05	3.6E-05	4.7E-05	2.7E-05	1.1E-05	9.0E-06	2.5E-05	3.5E-05	1.8E-05	9.5E-06	7.4E-06	1.9E-05	2.8E-05	1.3E-05	8.5E-06	6.4E-06
18	15MHz Fs	205	2	1000	50	Hirex	Room	Fe	18.5	0	0	136	2.88E+06	8.3E-05	9.5E-05	7.3E-05	1.1E-05	1.0E-05	4.8E-05	5.6E-05	4.0E-05	8.7E-06	7.6E-06	3.7E-05	4.5E-05	3.0E-05	7.7E-06	6.7E-06	2.8E-05	3.5E-05	2.2E-05	6.8E-06	5.8E-06
31	15MHz Fs	217	2	1000	55	Hirex	Room	Ar	10.2	0	0	763	7.82E+06	1.4E-05	1.7E-05	1.2E-05	2.9E-06	2.5E-06	7.9E-06	1.0E-05	6.1E-06	2.2E-06	1.8E-06	5.8E-06	7.7E-06	4.2E-06	1.9E-06	1.6E-06	4.3E-06	6.1E-06	3.0E-06	1.7E-06	1.3E-06
32	15MHz Fs	218	2	1000	55	Hirex	Room	Ne	3.63	0	0	257	1.00E+07	4.5E-06	6.0E-06	3.3E-06	1.5E-06	1.2E-06	2.3E-06	3.5E-06	1.5E-06	1.2E-06	8.4E-07	1.6E-06	2.6E-06	9.1E-07	1.0E-06	6.9E-07	9.0E-07	1.7E-06	4.1E-07	8.1E-07	4.9E-07
33	15MHz Fs	219	2	1000	55	Hirex	Room	Ne	3.63	0	0	274	1.00E+07	3.2E-06	4.5E-06	2.2E-06	1.3E-06	1.0E-06	1.3E-06	2.2E-06	6.9E-07	9.2E-07	6.1E-07	1.0E-06	1.8E-06	4.8E-07	8.4E-07	5.2E-07	8.0E-07	1.6E-06	3.5E-07	7.8E-07	4.5E-07

Table 3 – RADEF, August 2014(W35), RHF1401, run table with corresponding event cross-sections for different threshold values

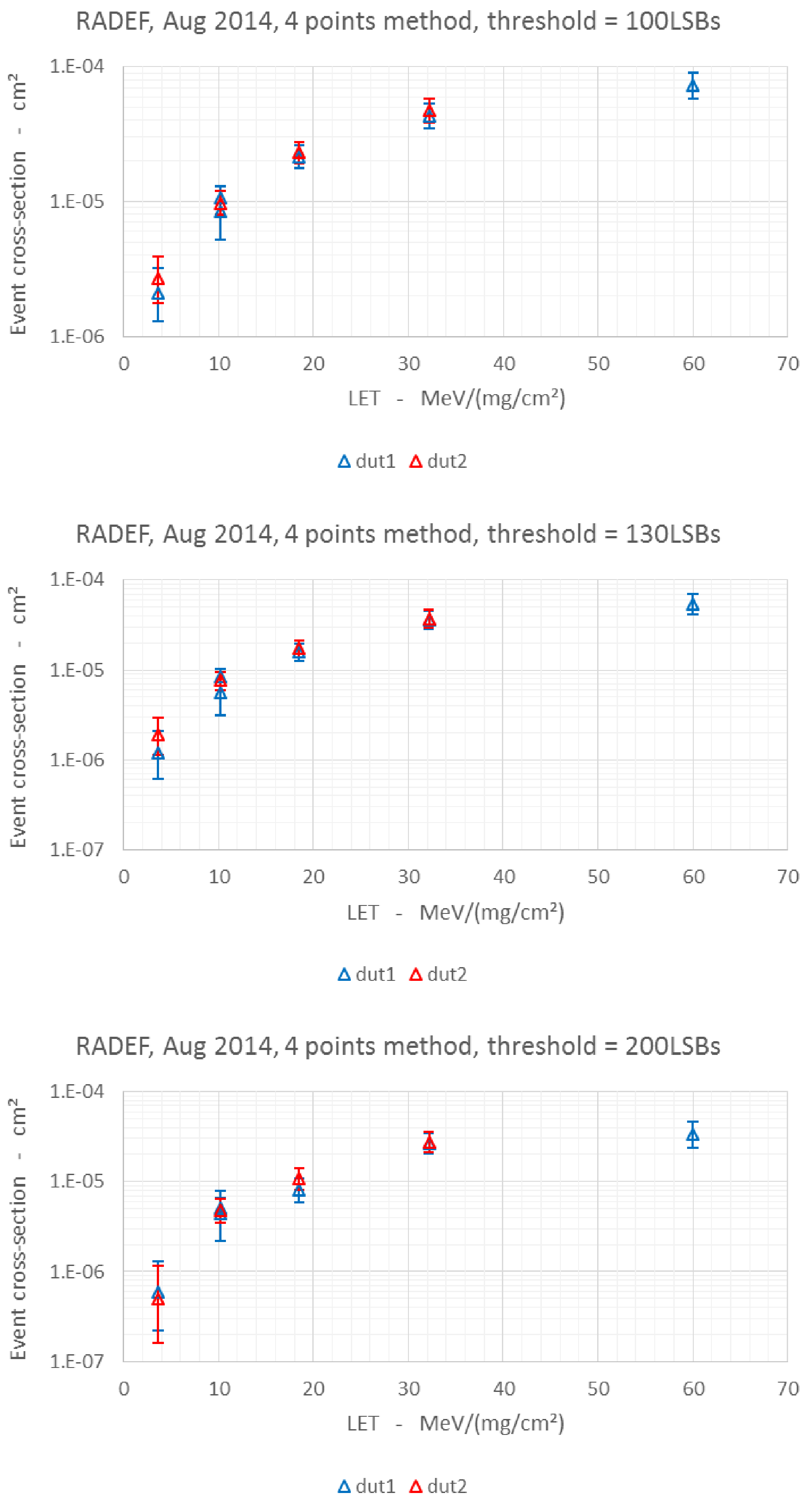


Figure 9 – SET event cross-section for the 4points test method with 3 different thresholds

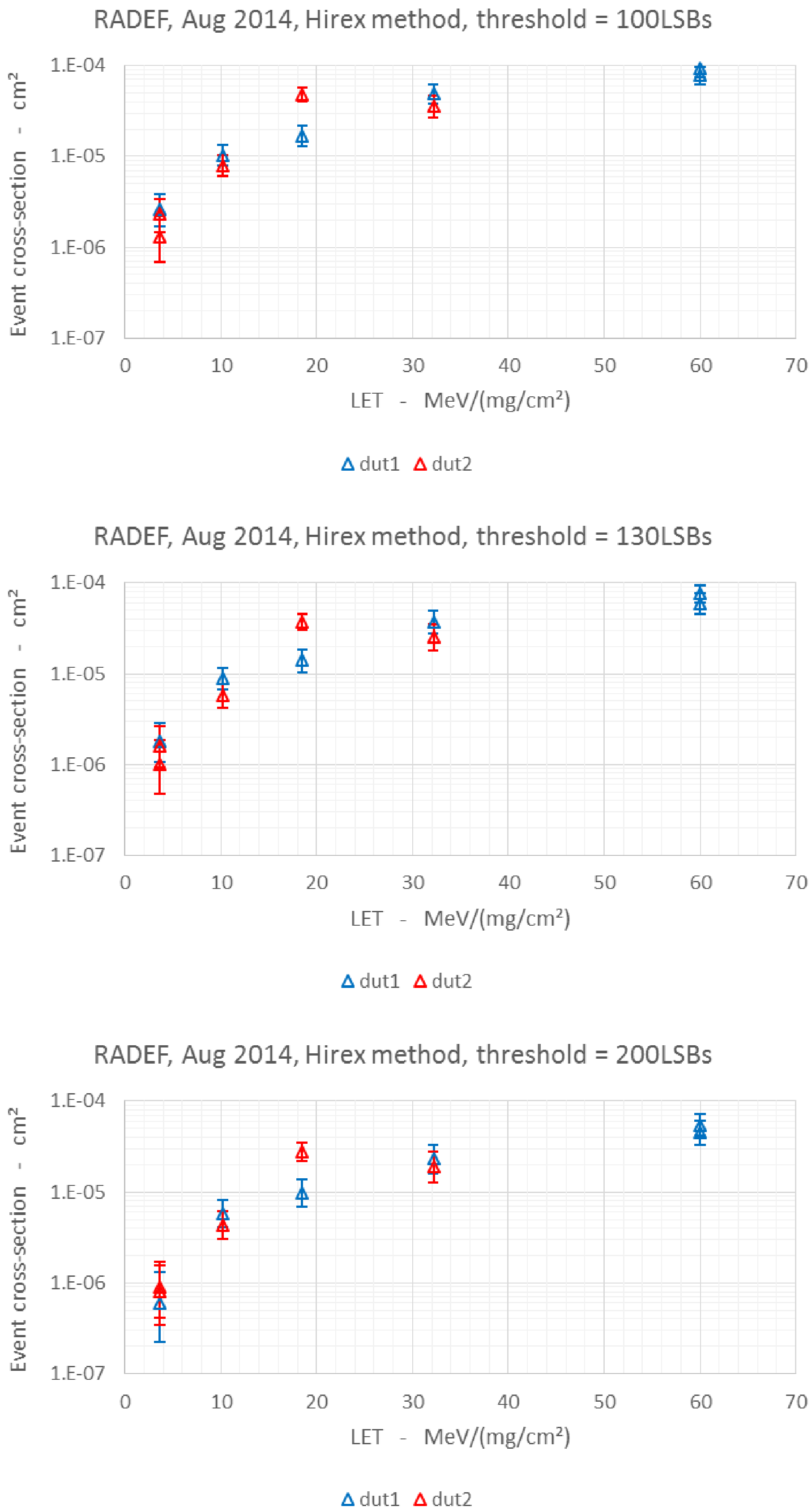


Figure 10 – SET event cross-section for the hrx test method with 3 different thresholds

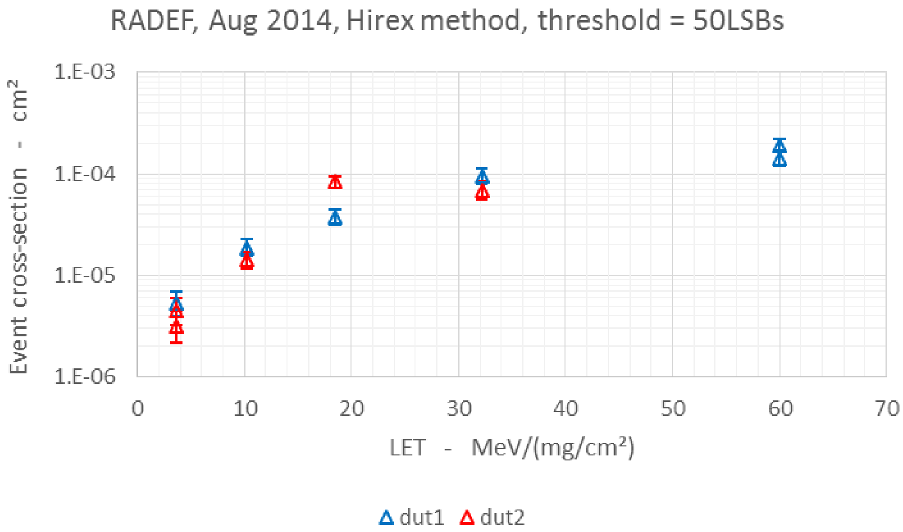


Figure 11 – SET event cross-section for the hirex test method and with a threshold of 50LSBs

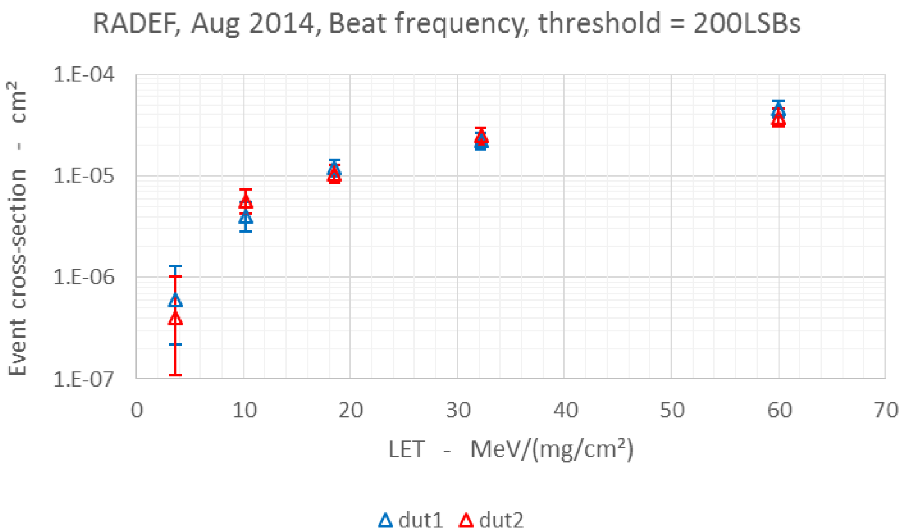
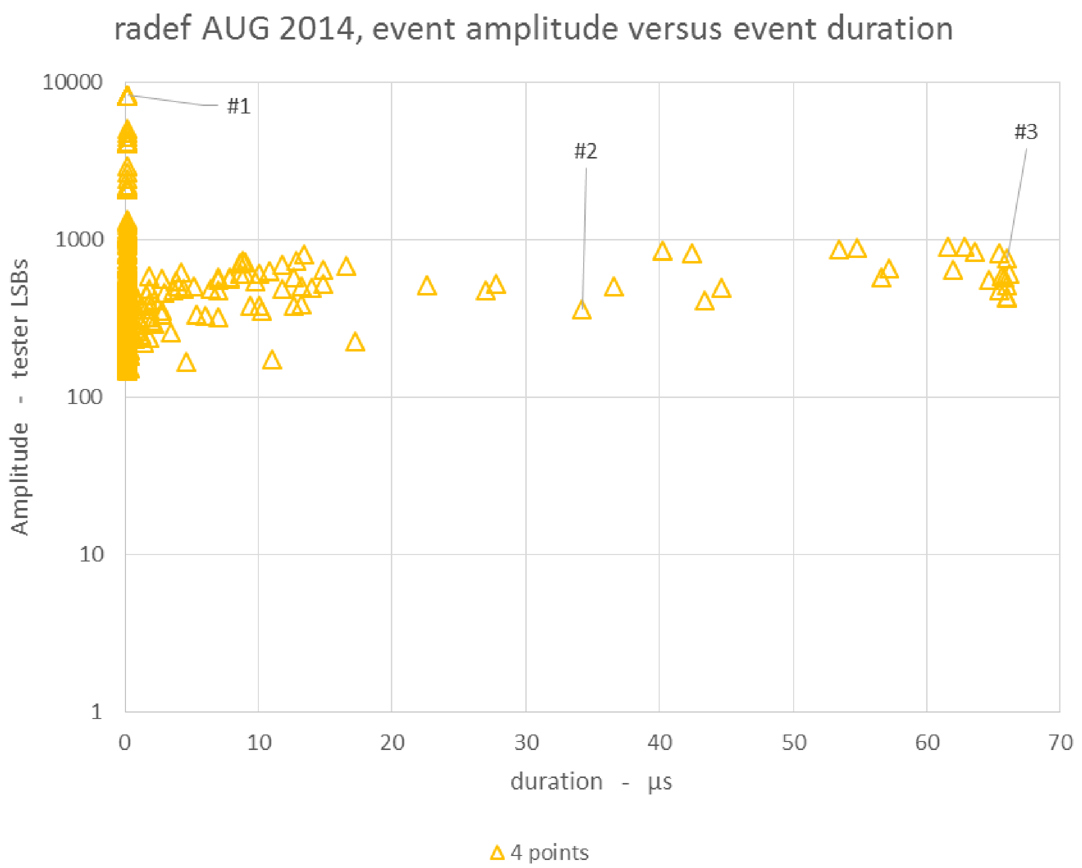
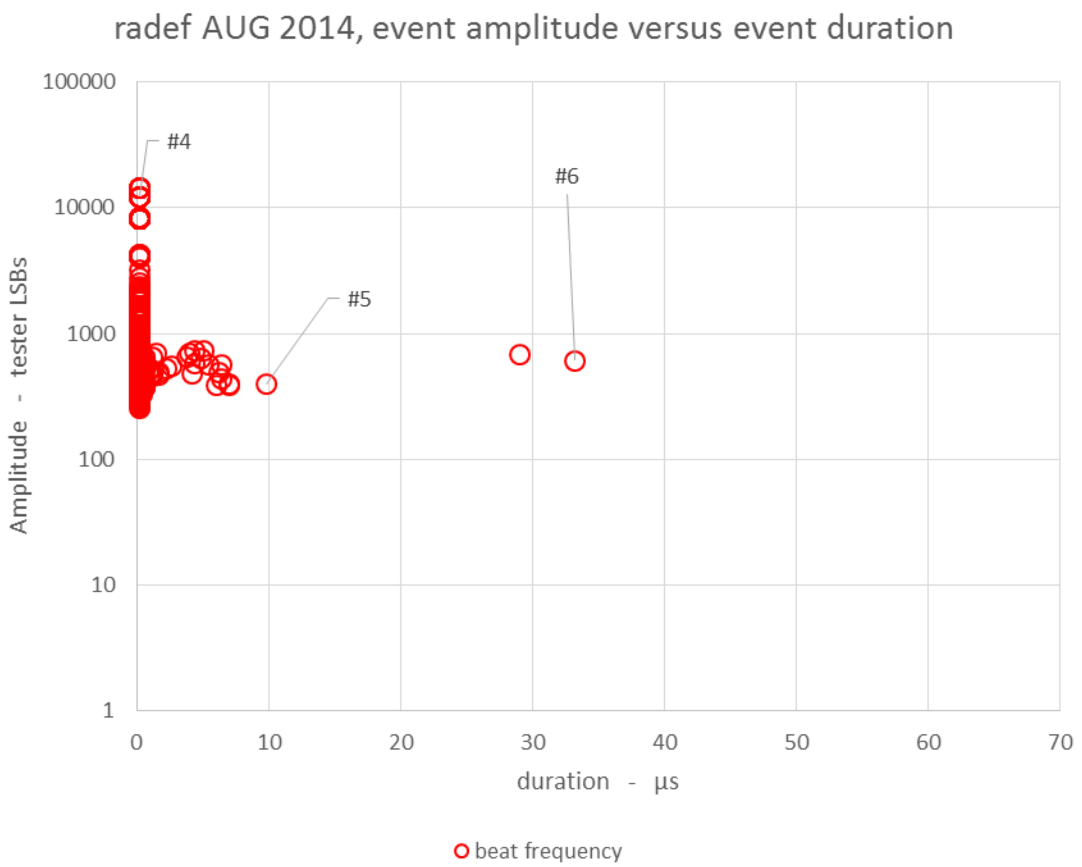


Figure 12 – SET event cross-section for the beat frequency test method with 200LSBs threshold



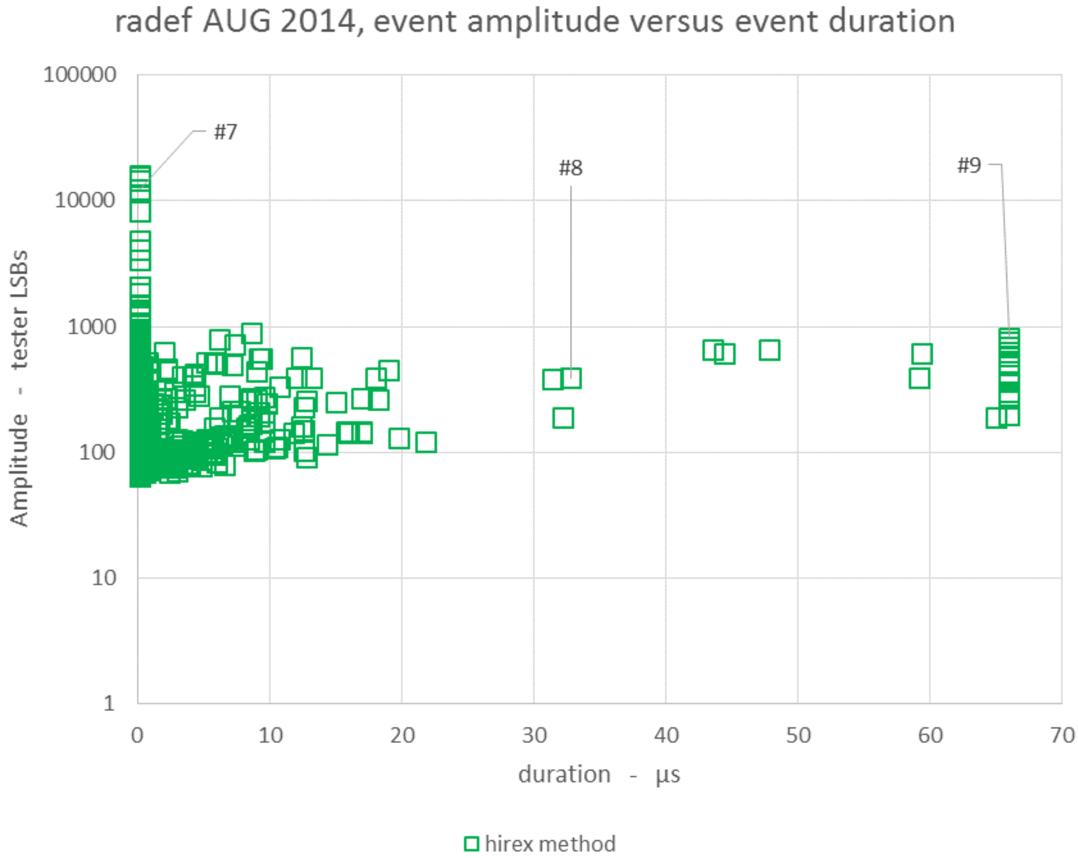
a)



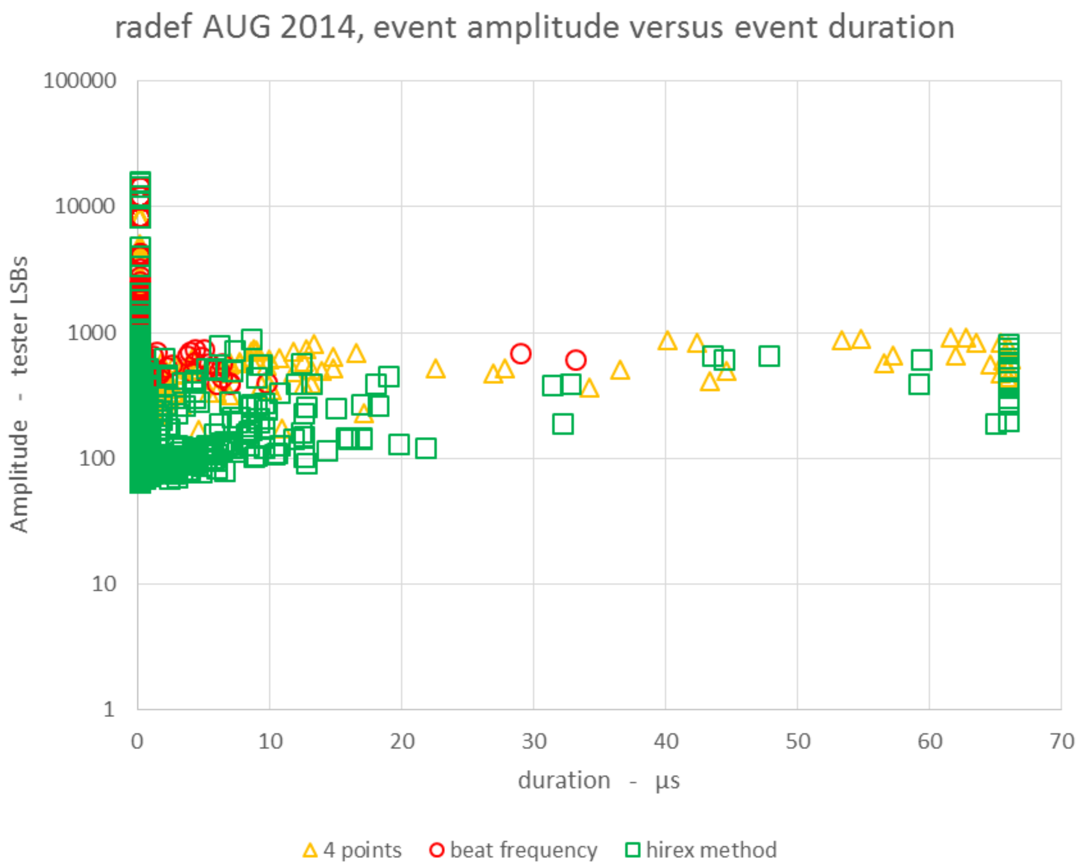
b)

#numbers in the plots refer to event waves shown in the following pages

Figure 13 – RADEF, August 2014, RHF1401 events distribution, 4 points and beat frequency



c)



d)

#numbers in the plots refer to event waves shown in the following pages

Figure 14 – RADEF, August 2014, DAC5675 events distribution, hirex method and all methods

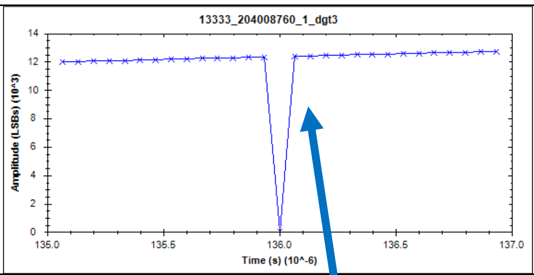
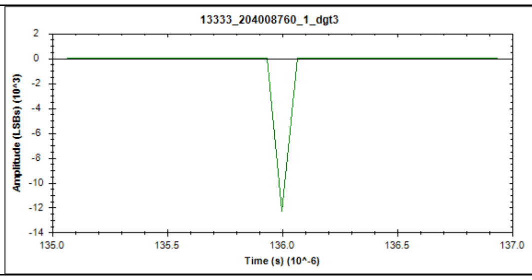
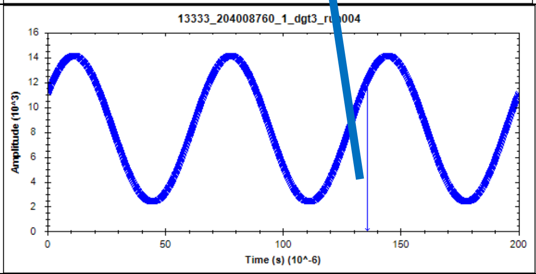
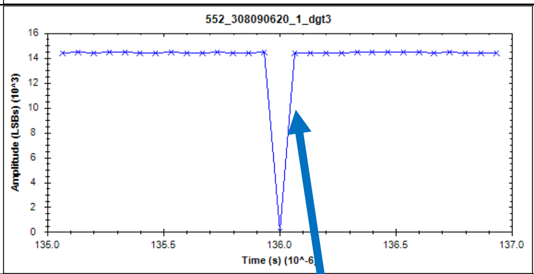
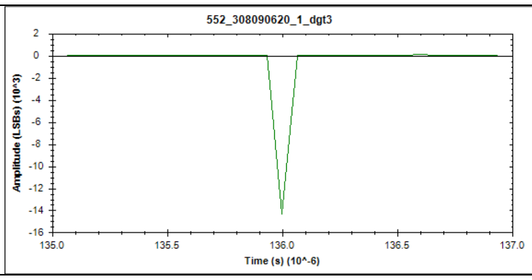
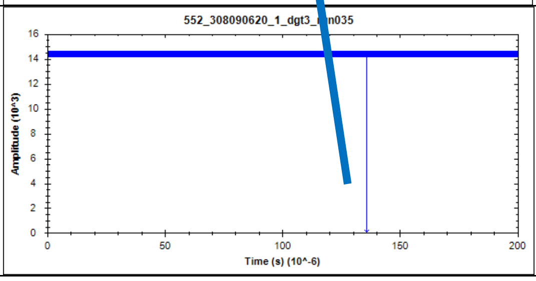
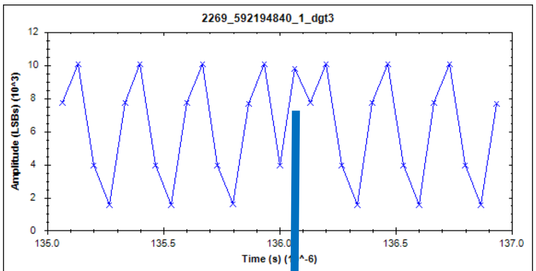
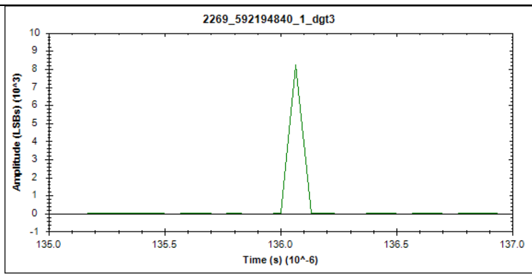
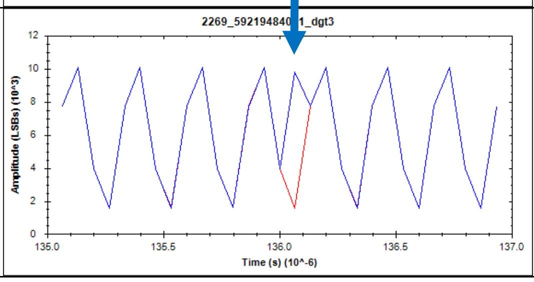
#7 RUN004 stampdate: 13333.20400876 **Hirex method** Xenon Amplitude: 12314 tester LSBs Duration: 0.13µs		
		
#4 RUN035 stampdate: 552.3080906203 **Beat frequency** Ne Amplitude: 14411 tester LSBs Duration: 0.13µs		
		
#1 RUN038 stampdate: 2269.592194840 **4 points** Ne Amplitude: 8275 tester LSBs Duration: 0.13µs		
		

Figure 15 – RADEF, August 2014, SET events examples, high amplitude small duration

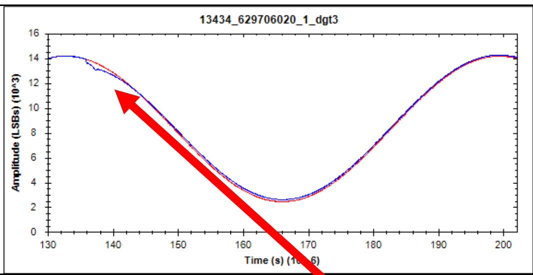
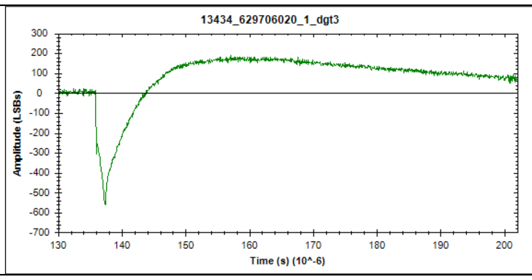
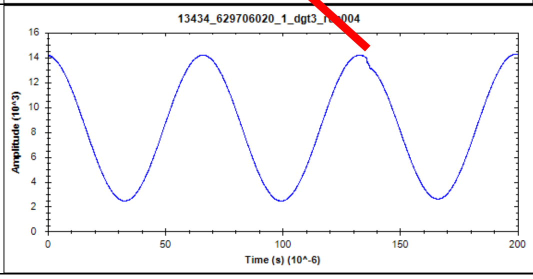
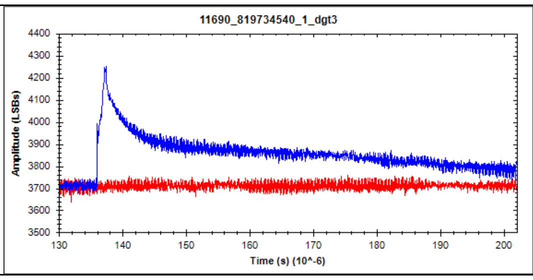
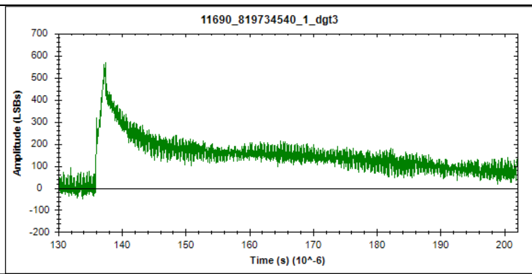
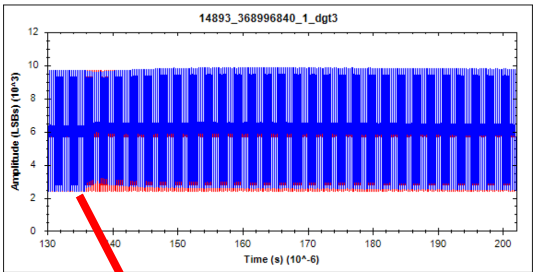
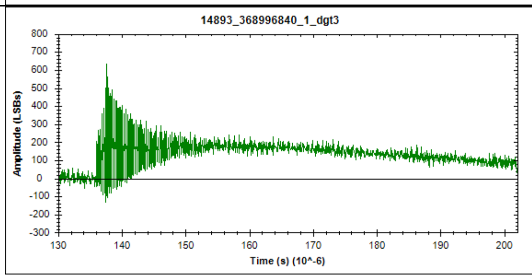
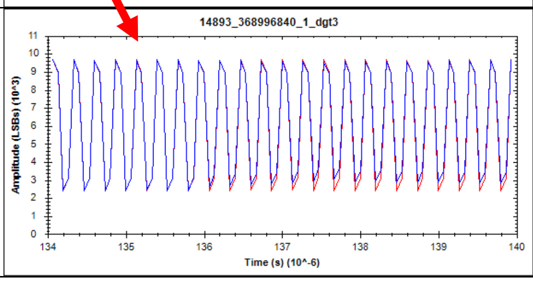
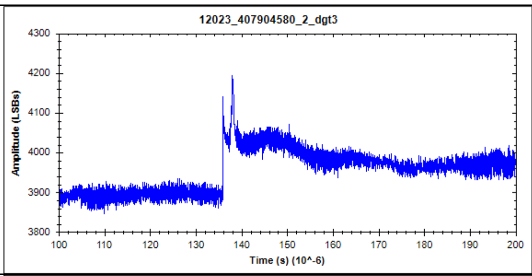
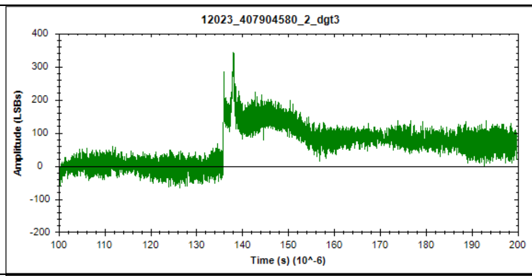
#9 RUN004 timestamp: 13434.629706020 **Hirex method** Xenon Amplitude: 751 tester LSBs Duration: 66µs		
		
#6 RUN001 timestamp: 11690.819734540 **Beat frequency** Xenon Amplitude: 617 tester LSBs Duration: 33.2µs		
#2 RUN005 timestamp: 14893.368996840 **4 points** Xenon Amplitude: 7650 tester LSBs Duration: 66µs		
		

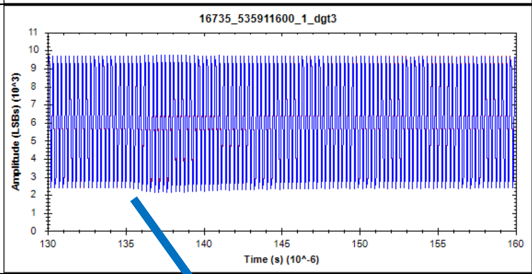
Figure 16 – RADEF, August 2014, SET events examples, high duration

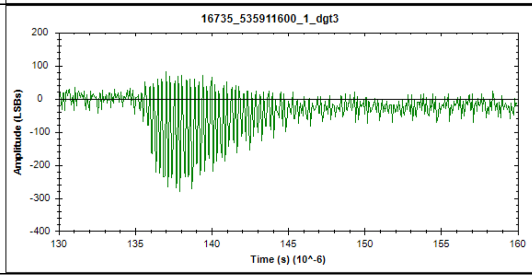
#5
RUN002 datestamp:
12023.407904580
Beat frequency
Xenon
Amplitude: 399 tester LSBs
Duration: 9.8µs

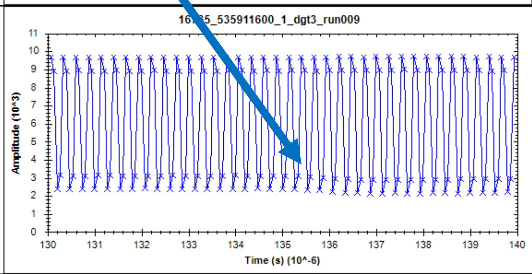




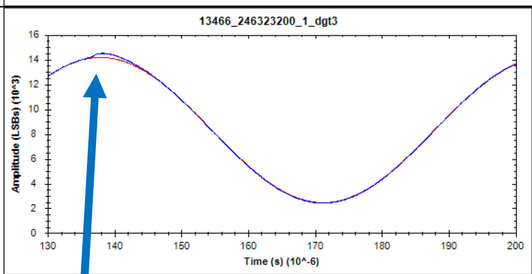
#2
RUN009 datestamp:
16735.535911600
4 points
Krypton
Amplitude: 361 tester LSBs
Duration: 34.2 µs

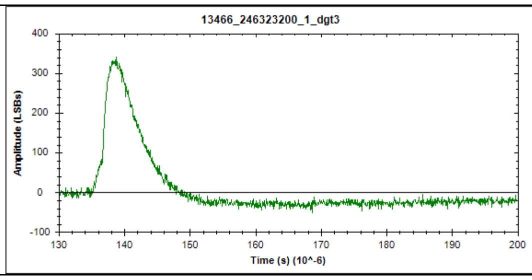






#8
RUN004 datestamp:
13466.246323200
Hirex method
Xenon
Amplitude: 390 tester LSBs
Duration: 32.8 µs





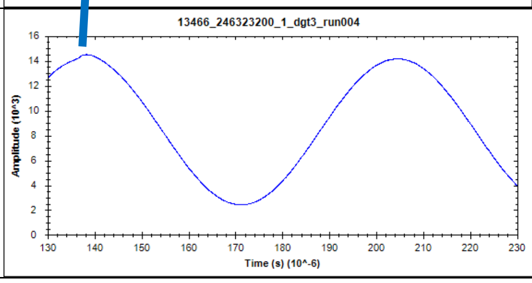


Figure 17 – RADEF, August 2014, SET events examples, medium amplitude and duration

10.3 October 2014 test campaign

1 sample is tested at a time (DUT1 or DUT2) using bias conditions of Figure 7.

The three test methods presented in paragraph 7 have been applied with the following sets of frequencies.

	Input sinus			RHF1401
	4points	hirex	beat freq	conversion frequency
W44	3 750 000 Hz	150 000 Hz	14 999 708.6 Hz	15 000 000 Hz
W44	7 500 000 Hz	300 000 Hz	29 999 417.2 Hz	30 000 000 Hz

Input sinewave amplitude was adjusted closed to fullscale. Value of 1 LSB value corresponds to 122µV.

The presence of noise at DUT output requires to apply a detection threshold without exposure between 90 and 175 LSBs.
Because of a limitation in test software, the output value is compared to the previous one 2 clocks before instead of 1 clock for beat frequency event detection. Impact on the word output comparison with the previous output value is then 2 LSBs instead of 1. Practically it does not change the test method as the threshold set includes also the noise level which is as a minimum 50 LSBs.
Run details and results are provided in Table 2 and Table 3.
All runs were performed with normal incidence beam (no tilt).
In Table 2 and Table 3 for each run, the detection threshold level in LSBs is noted (column "threshold (LSBs)") togeteher with the number of events detected (column 'Nb events above threshold"). As this threshold is not identical for all runs and to ease comparison, we have extracted the number of events which would have been triggered with a threshold of 175LSBs: see column "NB events above 175LSBs".
Column 'period' refers to the number of clocks to which output value is compared to the current conversion output.
In addition, the 2 tables provides the error bar values computed as indicated in §1 in columns named up, low,X-section_up,X_section_low, delta_up and delta_low low using a confidence level of 95% and a beam flux uncertainty of +/-10%.

For the three methods, again 2 event populations are observed:
A first population of 1 to 2 conversion errors events with a maximum amplitude that could be quite significative and a second population of large events up to several hundred of successive conversions in error with a much reduced error amplitude.

Figure 18 show the event cross-section for beat frequency method with the 15 and 30 Msps conversion frequency and a comparison of the three test methods with Xenon ion.

#numbers in the plots refer to event waves shown in the following pages
Figure 19 to Figure 21 show the event amplitude versus event duration for the three test methods. In these figures, the delta period used for comparison between the digital output signal and the event signal is 1000 conversions for 4 points and hirex methods and 100 for the beat frequency. The reason is that with this last method, the conversions recorded do not cover a complete signal period and then an amplitude error is introduced in the difference between the outpout signal and the event signal.
Events durations are clamped at about 66 microseconds and 33 microseconds for 15Msps and 30 Msps conversion frequency and 4 points and hirex methods. For beat frequency events are clamped to 6.6 respectively 3.3 microseconds.

Event examples are shown, in Figure 15 to Figure 17.

run	Facility	medium	run_number	Facility_run_number	board_id	dut_part_id	bias_config	test_mode	Threshold	period	temperature	Ion	LET	roll	tilt	run_duration	on_fluence	Event count above threshold	Event X-section	X-section_up	X-section_low	delta_up	delta_low	Event count above 175 LSBs	Event X-section	X-section_up	X-section_low	delta_up	delta_low
RUN020	RADEF	vacuum	20	42	1	1	15MHz	4 points	135	4	room	Xe	60	0	0	467	2.37E+06	173	7.29E-05	8.46E-05	6.24E-05	1.2E-05	1.0E-05	148	6.23E-05	7.32E-05	5.27E-05	1.1E-05	9.6E-06
RUN019	RADEF	vacuum	19	42	1	2	30MHz	4 points	100	4	room	Xe	60	0	0	456	2.31E+06	197	8.53E-05	9.80E-05	7.38E-05	1.3E-05	1.1E-05	129	5.58E-05	6.63E-05	4.66E-05	1.1E-05	9.2E-06
RUN010	RADEF	vacuum	10	34	1	1	15MHz	Beat frequency	130	2	room	Fe	18.5	0	0	708	1.87E+07	251	1.34E-05	1.52E-05	1.18E-05	1.8E-06	1.6E-06	211	1.13E-05	1.29E-05	9.79E-06	1.6E-06	1.5E-06
RUN012	RADEF	vacuum	12	35	1	1	15MHz	Beat frequency	130	2	room	Kr	32.2	0	0	850	9.12E+06	225	2.47E-05	2.81E-05	2.15E-05	3.4E-06	3.1E-06	194	2.13E-05	2.45E-05	1.84E-05	3.2E-06	2.9E-06
RUN016	RADEF	vacuum	16	38	1	1	15MHz	Beat frequency	130	2	room	Xe	60	0	0	719	4.51E+06	221	4.90E-05	5.59E-05	4.28E-05	6.9E-06	6.3E-06	196	4.35E-05	5.00E-05	3.76E-05	6.5E-06	5.9E-06
RUN008	RADEF	vacuum	8	32	1	2	15MHz	Beat frequency	100	2	room	Fe	18.5	0	0	534	1.10E+07	186	1.70E-05	1.96E-05	1.46E-05	2.6E-06	2.4E-06	119	1.09E-05	1.30E-05	8.99E-06	2.1E-06	1.9E-06
RUN014	RADEF	vacuum	14	37	1	2	15MHz	Beat frequency	105	2	room	Kr	32.2	0	0	336	7.70E+06	225	2.92E-05	3.33E-05	2.55E-05	4.1E-06	3.7E-06	182	2.36E-05	2.73E-05	2.03E-05	3.7E-06	3.3E-06
RUN015	RADEF	vacuum	15	37	1	2	15MHz	Beat frequency	105	2	room	Xe	60	0	0	697	4.10E+06	259	6.31E-05	7.13E-05	5.57E-05	8.2E-06	7.5E-06	180	4.39E-05	5.08E-05	3.77E-05	6.9E-06	6.2E-06
RUN001	RADEF	vacuum	1	14	1	1	30MHz	Beat frequency	160	2	room	Ar	10.2	0	0	676	2.00E+07	113	5.64E-06	6.79E-06	4.65E-06	1.1E-06	9.9E-07	107	5.34E-06	6.46E-06	4.38E-06	1.1E-06	9.6E-07
RUN003	RADEF	vacuum	3	17	1	1	30MHz	Beat frequency	160	2	room	Ar	10.2	0	0	560	2.00E+07	99	4.94E-06	6.01E-06	4.01E-06	1.1E-06	9.2E-07	94	4.69E-06	5.74E-06	3.79E-06	1.0E-06	9.0E-07
RUN004	RADEF	vacuum	4	18	1	1	30MHz	Beat frequency	160	2	room	Ne	3.63	0	0	326	2.00E+07	18	9.01E-07	1.42E-06	5.34E-07	5.2E-07	3.7E-07	15	7.50E-07	1.24E-06	4.20E-07	4.9E-07	3.3E-07
RUN007	RADEF	vacuum	7	31	1	1	30MHz	Beat frequency	175	2	room	Fe	18.5	0	0	658	1.32E+07	187	1.41E-05	1.63E-05	1.22E-05	2.2E-06	2.0E-06	187	1.41E-05	1.63E-05	1.22E-05	2.2E-06	2.0E-06
RUN017	RADEF	vacuum	17	39	1	1	30MHz	Beat frequency	175	2	room	Xe	60	0	0	700	4.50E+06	195	4.33E-05	4.99E-05	3.75E-05	6.5E-06	5.9E-06	195	4.33E-05	4.99E-05	3.75E-05	6.5E-06	5.9E-06
RUN002	RADEF	vacuum	2	15	1	2	30MHz	Beat frequency	160	2	room	Ar	10.2	0	0	478	1.80E+07	88	4.89E-06	6.02E-06	3.92E-06	1.1E-06	9.7E-07	83	4.61E-06	5.71E-06	3.67E-06	1.1E-06	9.4E-07
RUN006	RADEF	vacuum	6	19	1	2	30MHz	Beat frequency	170	2	room	Ne	3.63	0	0	323	2.01E+07	21	1.05E-06	1.60E-06	6.48E-07	5.5E-07	4.0E-07	21	1.05E-06	1.60E-06	6.48E-07	5.5E-07	4.0E-07
RUN018	RADEF	vacuum	18	41	1	2	30MHz	Beat frequency	160	2	room	Xe	60	0	0	1660	8.58E+06	470	5.47E-05	5.99E-05	4.99E-05	5.2E-06	4.8E-06	446	5.20E-05	5.70E-05	4.72E-05	5.1E-06	4.7E-06
RUN022	RADEF	vacuum	22	46	1	1	30MHz	Hirex	130	100	room	Xe	60	0	0	620	3.54E+06	261	7.36E-05	8.31E-05	6.50E-05	9.5E-06	8.7E-06	214	6.04E-05	6.90E-05	5.25E-05	8.7E-06	7.8E-06
RUN023	RADEF	vacuum	23	47	1	2	15MHz	Hirex	90	100	room	Xe	60	0	0	195	3.21E+06	343	1.07E-04	1.19E-04	9.58E-05	1.2E-05	1.1E-05	198	6.17E-05	7.09E-05	5.34E-05	9.2E-06	8.3E-06

Table 4 – RADEF, October 2014(W44), RHF1401, run table with corresponding event cross-sections

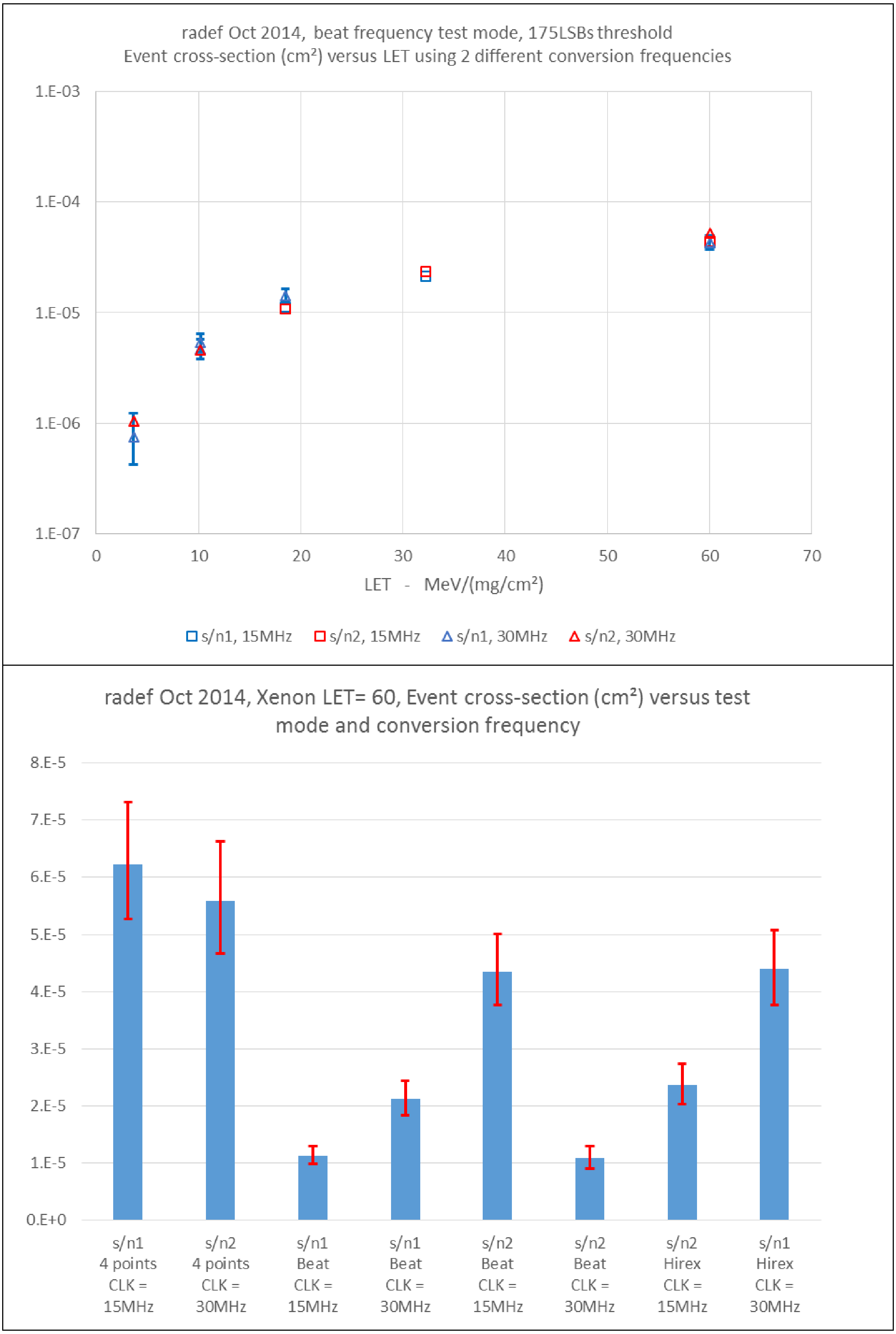
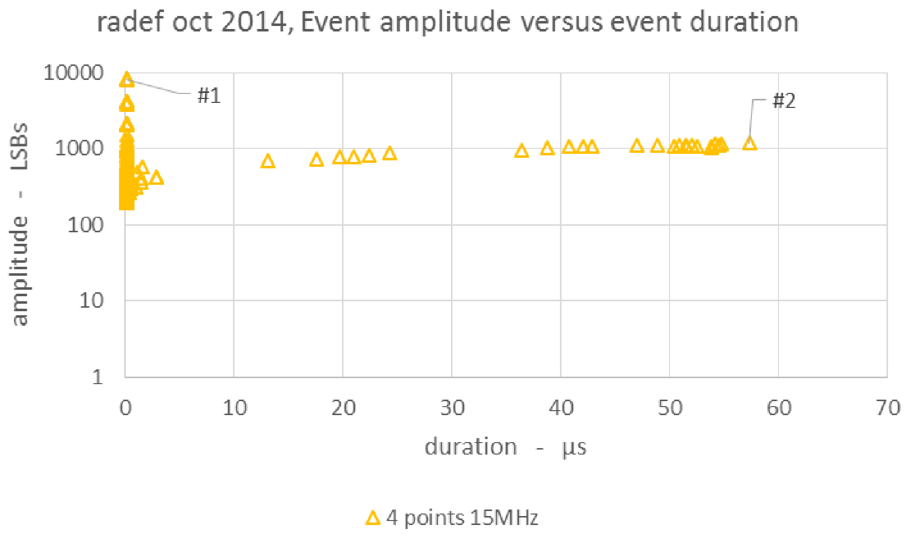
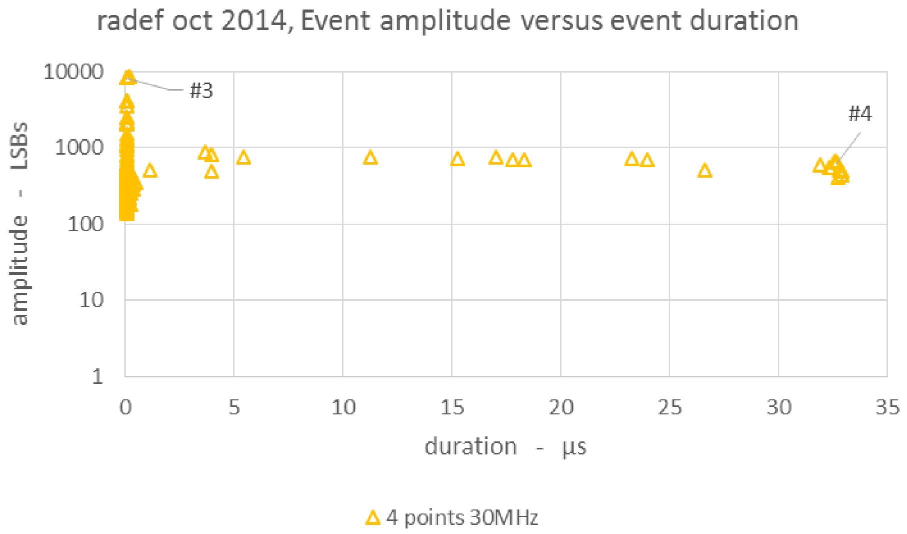


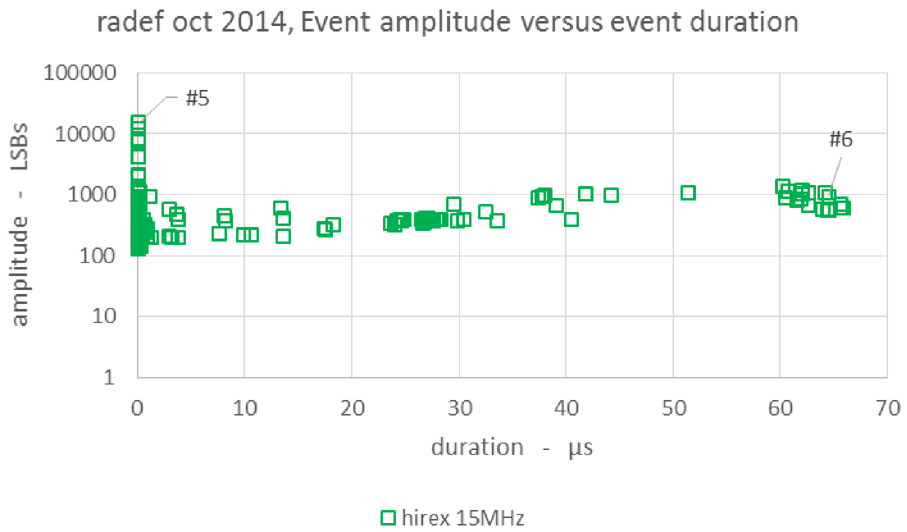
Figure 18 – SET event cross-section with a threshold of 175LSBs

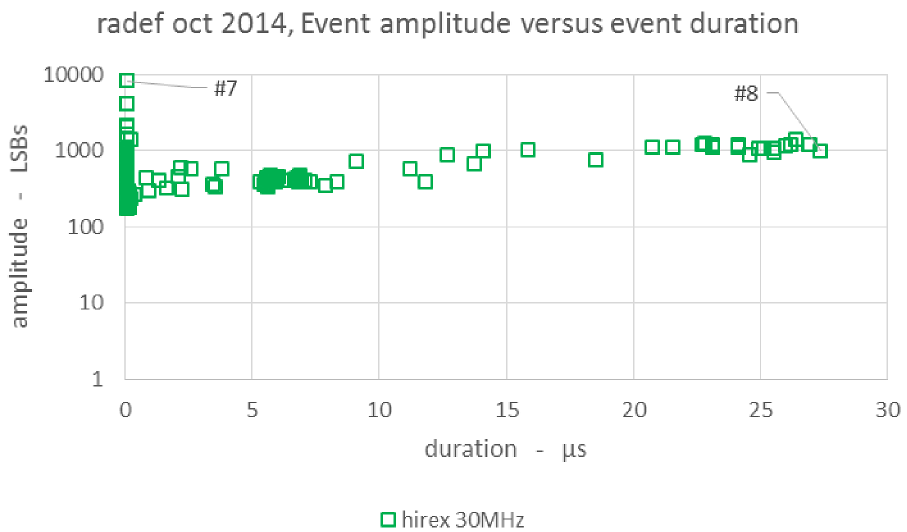




#numbers in the plots refer to event waves shown in the following pages

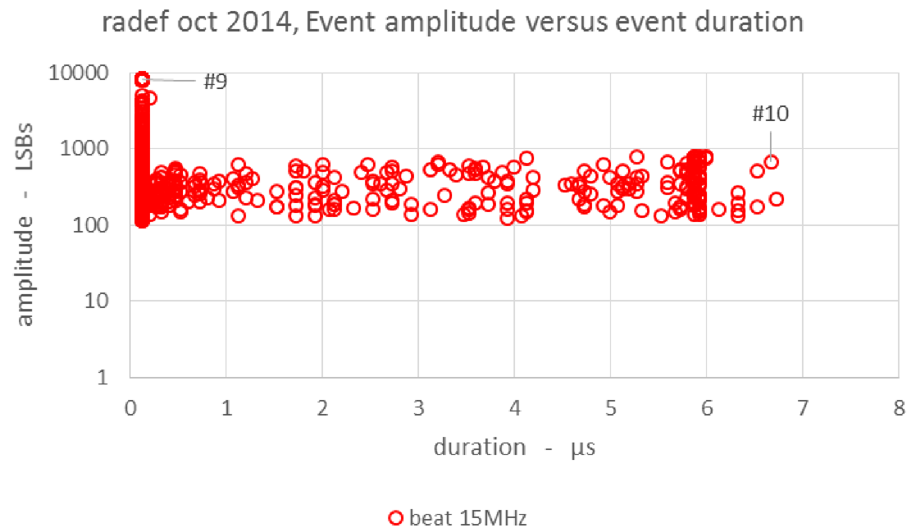
Figure 19 – RADEF, Oct 2014, RHF1401 events distribution, 4 points method, 15MHz and 30MHz frequency conversion





#numbers in the plots refer to event waves shown in the following pages

Figure 20 – RADEF, Oct 2014, RHF1401 events distribution, hirex method, 15MHz and 30MHz frequency conversion



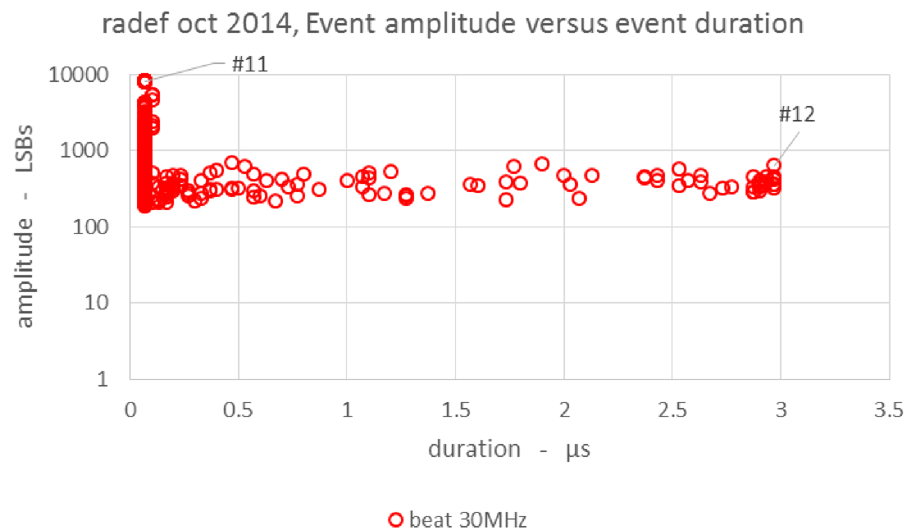


Figure 21 – **RADEF, Oct 2014, RHF1401 events distribution, beat frequency, 15MHz and 30MHz frequency conversion**

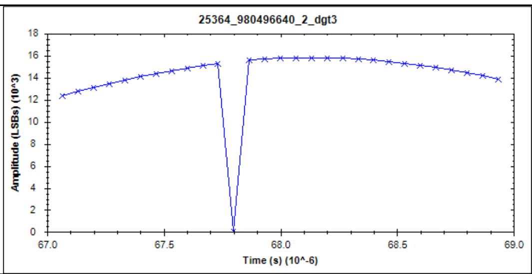
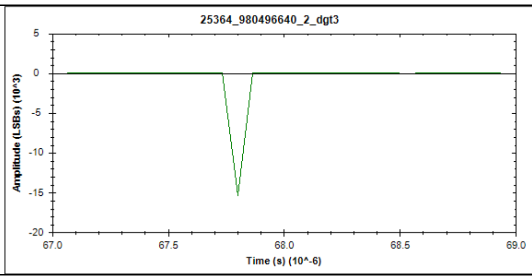
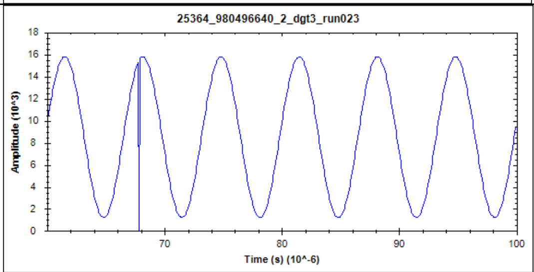
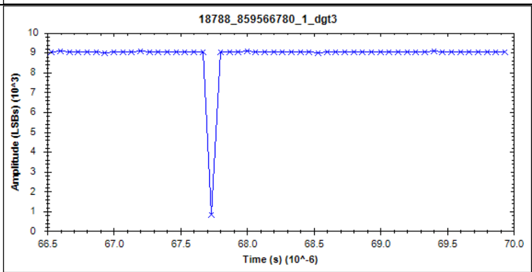
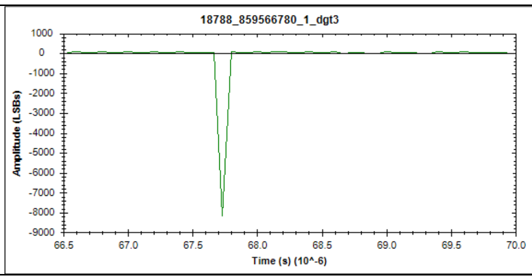
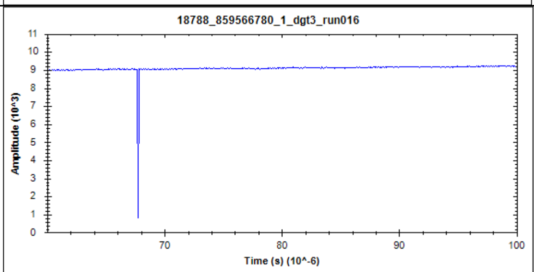
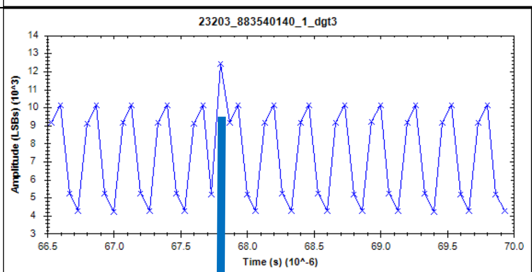
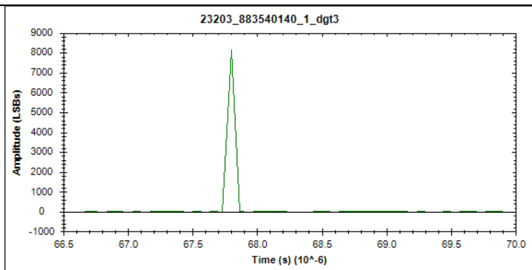
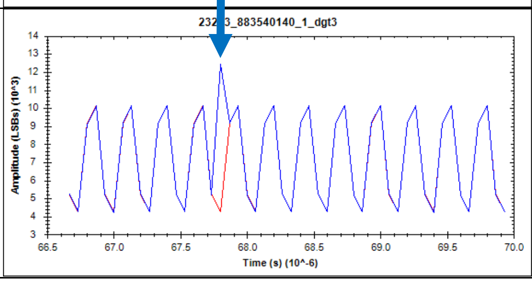
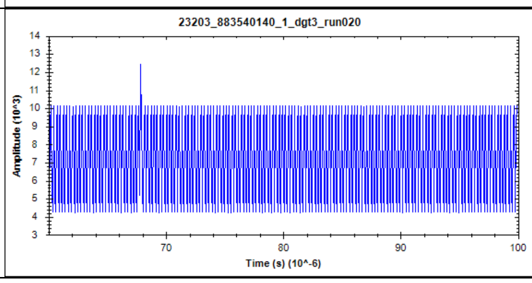
#5 RUN023 stampdate: 25364.98049664 **Hirex method** Xenon Amplitude: 15388 tester LSBs Duration: 0.13µs		
		
#9 RUN016 stampdate: 18788.859566780 **Beat frequency** Xenon Amplitude: 8267 tester LSBs Duration: 0.13µs		
		
#1 RUN020 stampdate: 23203.883540140 **4 points** Xenon Amplitude: 8215 tester LSBs Duration: 0.13µs		
		

Figure 22 – RADEF, October 2014, SET events examples, high amplitude small duration

Blue curve is with the event
Red curve is without the event

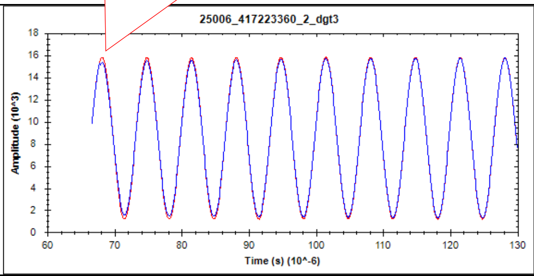
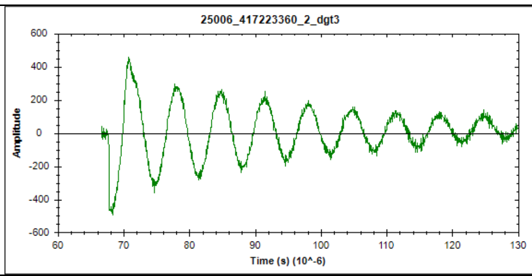
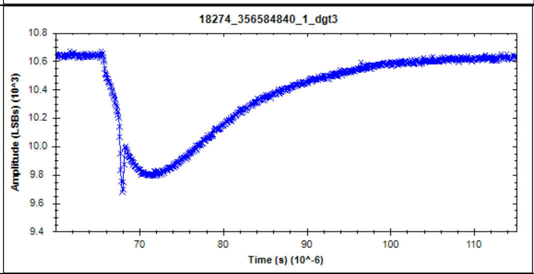
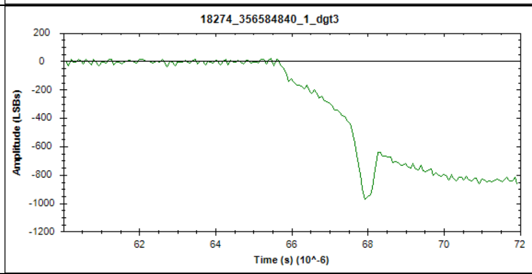
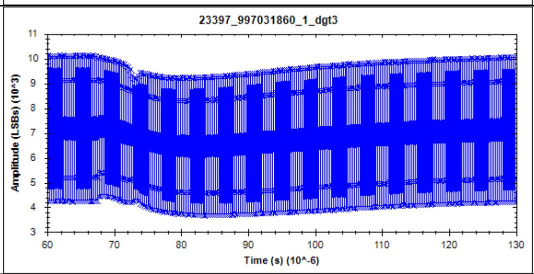
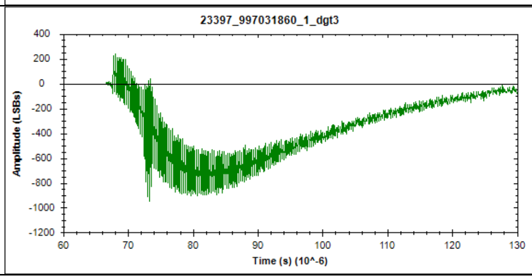
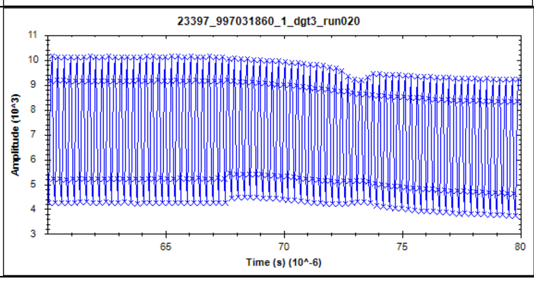
#6 RUN023 stampdate: 25006.41722336 **Hirex method** Xenon Amplitude: 951 tester LSBs Duration: 64.53µs		
#10 RUN016 stampdate: 18788.859566780 **Beat frequency** Xenon Amplitude: 675 tester LSBs Duration: 6.67µs		
#2 RUN020 stampdate: 23397.997031860 **4 points** Xenon Amplitude: 1185 tester LSBs Duration: 57.33µs		
		

Figure 23 – RADEF, October 2014, SET events examples, large duration

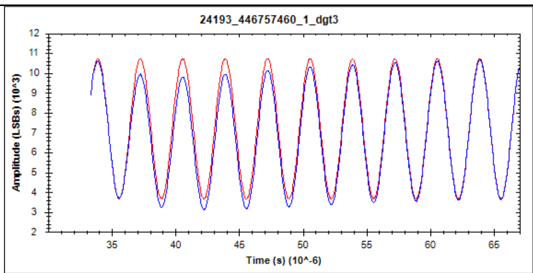
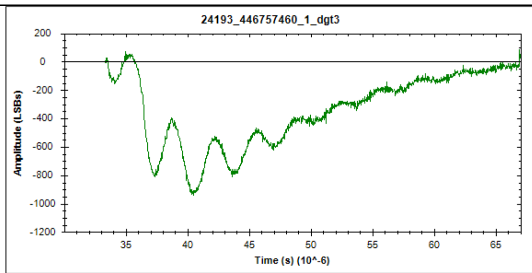
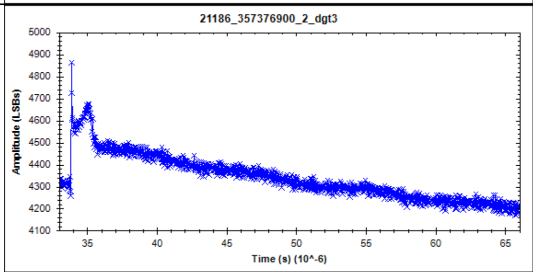
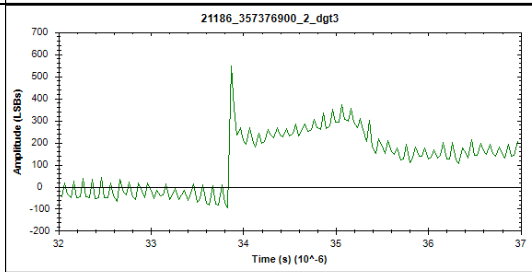
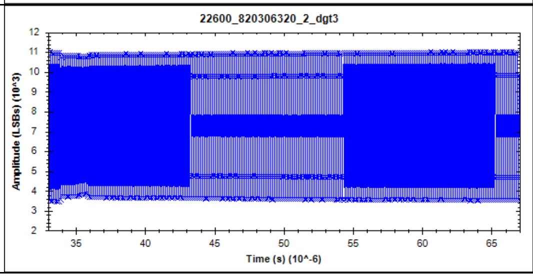
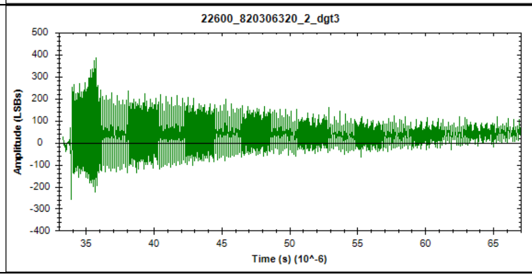
#8 RUN022 stampdate: 24193.44675746 **Hirex method** Xenon Amplitude: 1007 tester LSBs Duration: 27.37µs		
#12 RUN018 stampdate: 1186.357376900 **Beat frequency** Xenon Amplitude: 644 tester LSBs Duration: 2.97µs		
#4 RUN019 stampdate: 22600.820306320 **4 points** Xenon Amplitude: 643 tester LSBs Duration: 32.7µs		

Figure 24 – RADEF, October 2014, SET events examples, medium amplitude

10.4 SEL

During both test campaigns, no latchup has been detected for any run with LETs up to 60MeV/(mg/cm²)
As an example, Figure 25 show the recorded supply current plots recorded for 1 DUT under exposure with Xenon (LET =60).

Figure 25 – radef, October 2014 (W44), RHF1401, hirex run016, Xenon, dut1 supply currents

10.5 Conclusion

Three test methods, hirex method, 4 points method and beat frequency method have been implemented and give similar results in term of event detection and event SET cross-section curve as a function of LET.
For the three methods, 2 event populations are observed:
A first population of 1 to 2 conversion errors events with a maximum amplitude that could be quite significative and a second population of large events up to several hundred of successive conversions in error but with a much reduced error amplitude.
With the 4 points and hirex methods, it is possible to compare the output signal and the event signal with a large period (1000), it is then easier to evaluate the event duration. For the beat frequency in October 2014, as the conversions recorded do not cover a full input signal period, the comparison introduce an amplitude error. In August 2014, the input frequency was adjusted manually and it comes that the input change was much lower than 1 LSB at each consecutive conversion. This explained why in that case, a period of 1000 was possible to apply for comparison as the output signal is practically constant over the recorded period.