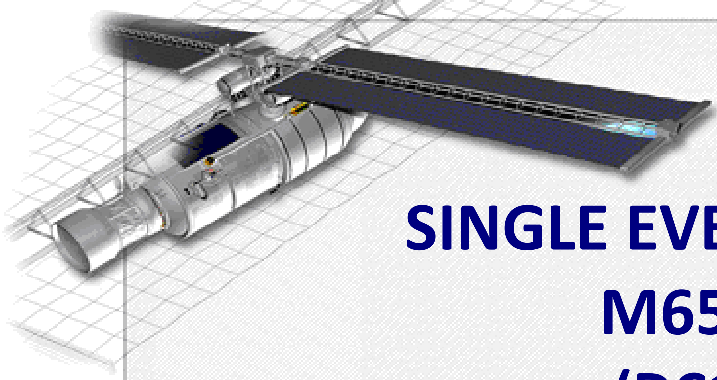
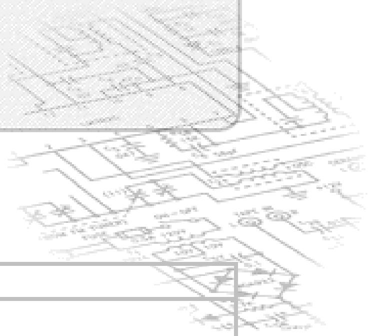
PROTON and HEAVY ION TEST REPORT



SINGLE EVENT EFFECTS
M65609E
(DC1028)
Rad. Hard. 128k x 8, 3.3-Volt SRAM
From
ATMEL



TRAD/TPTI/M65609E/BV/1312 Rev2		Labège, March 18th, 2014
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Revision: 2		
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CONTENTS

FIGURES

TABLES

1. Introduction

This report includes the test results of the proton and heavy ion Single Event Effects (SEEs) test sequence carried out on the **M65609E**, a **Rad. Hard. 128k x 8 bit CMOS SRAM** from **ATMEL**.

This test was performed for the **European Space Agency** on the **M65609E** susceptible to show Single Event Upset (**SEU**) and Multiple Bit Upset (**MBU**) induced by protons and heavy ions.

2. Documents

2.1. Applicable documents

SoW TEC-QEC/CP/SOW/2013-9

2.2. Reference documents

Basic specification: ESCC No. 25100 Issue 1, October 2002.
Data Sheet: M65609E, Rad. Hard. 128Kx8, 3.3-volt, Very Low Power, CMOS SRAM, Rev. 4158I–AERO–07/07

3. Organization of Activities

The relevant company has performed the following tasks during this evaluation:

1	Procurement of Test Samples	ESA
2	Preparation of Test Samples (delidding)	TRAD
3	Preparation of Test Hardware and Test Program	TRAD
4	Samples Check out	TRAD
5	Accelerator Test	ESA/TRAD
6	Proton and Heavy Ion Test Report	TRAD

Table 1: Organization of activities

4. Parts information

4.1. Device description

The M65609E is a very low power CMOS static RAM organized as 131072 x 8 bits. Utilizing an array of six transistors (6T) memory cells, the M65609E combines an extremely low standby supply current with a fast access time at 40 ns. The high stability of the 6T cell provides excellent protection against soft errors due to noise. The M65609E is processed according to the methods of the latest revision of the MIL PRF 38535 or ESCC 9000.

4.2. Identification

Type:	M65609E
Manufacturer:	ATMEL
Function:	Rad. Hard. 128k x 8 bit CMOS SRAM

4.3. Procurement information

Packaging:	FP32
Date Code:	1028
FR No.:	T8871-1B
Sample size:	10 parts provided by ESA.

4.4. Sample Preparation

Six parts were delidded by TRAD. A functional test sequence was performed on delidded samples to check if devices were degraded by the delidding operation. One sample was damaged during the delidding operation.

4.5. Sample pictures

4.5.1. External view

Figure 1: package marking

4.5.2. Internal view

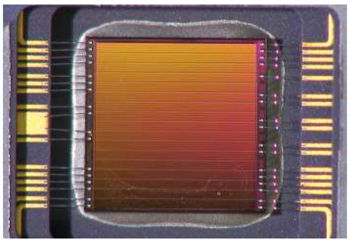


Figure 2: Internal overall view

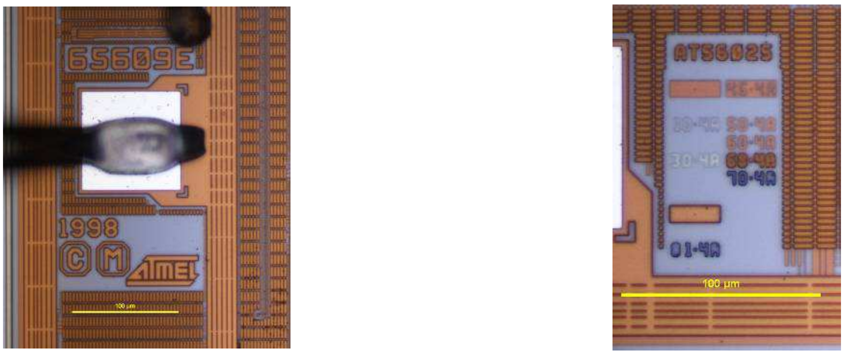
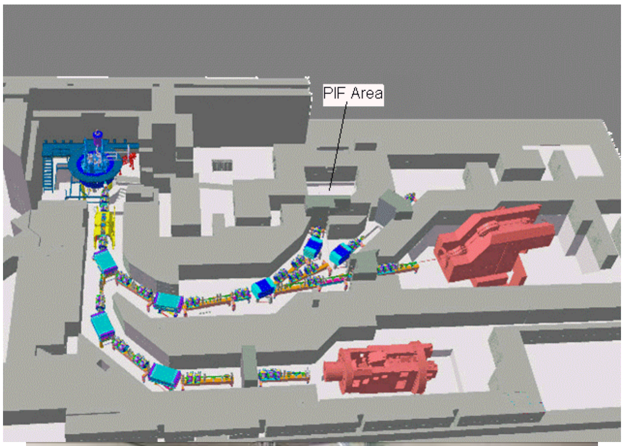


Figure 3: Die marking

5. Irradiation Facility for Proton beam

The test was performed at PSI (Paul Scherrer Institute) on December 1st, 2013. 4 samples were irradiated.

5.1. PSI Proton Test Facility (Paul Scherrer Institute - Switzerland)



PIF (Proton Irradiation Facility).

The initial proton beam for PIF is delivered from the PROSCAN accelerator with the help of the primary energy degrader, which allows setting the initial beam energy from 230 MeV down to 74 MeV.
The beam is subsequently guided to the Experimental Area where PIF facility is located.
The PIF experimental set-up consists of the local PIF energy degrader, beam collimating and monitoring devices.
According to the experience and user requirements, the monitor detectors are selected for each experiment individually: ionization chambers, Si-detectors, plastic scintillators.
Beam flux values are monitored through a set of counters and a PC-based data acquisition system. The system monitors proton flux and dose rate, calculates the total deposited dose and controls beam focus parameters. It also allows for setting the beam energy with the help of the PIF local energy degrader. Irradiations are usually carried out in air.

5.2. PIF Main features

- Initial proton energies: 230, 200, 150, 100 and 74 MeV.
- Energies available using the PIF degrader: quasi continuously from 6 MeV up to 230 MeV
- Maximum flux at 230 MeV for the focused beam: ~ $2*10^9$ protons/sec/cm^2
- Beam profiles are of Gaussian-form with standard (typical) : FWHM=10 cm
- Irradiations take place in air
- The maximum diameter of the irradiated area: f 9 cm
- The accuracy of the flux/dose determination: 5%
- Neutron background: less than 10^{-4} neutrons/proton/cm^2
- Irradiations, devices and sample positioning are supervised by the computer
- Data acquisition system allows automatic runs with user pre-defined irradiation criteria

5.3. Beam characteristics

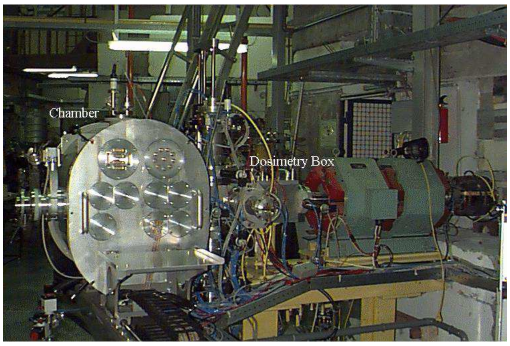
The beam flux was set between 4.46E+06 and 3.14E+07 protons/cm²/s based on the device sensitivity. Proton energies used were 230 MeV, 200 MeV, 151 MeV, 101 MeV, 75 MeV, 39 MeV and 23 MeV. Initial energy was 230 MeV and rest of energies was obtained with set of degraders.

6. Irradiation Facility for Heavy Ion beam

The test was performed at U.C.L (Université Catholique de Louvain) on December 11th and 14th 2013. Three delidded samples were irradiated.

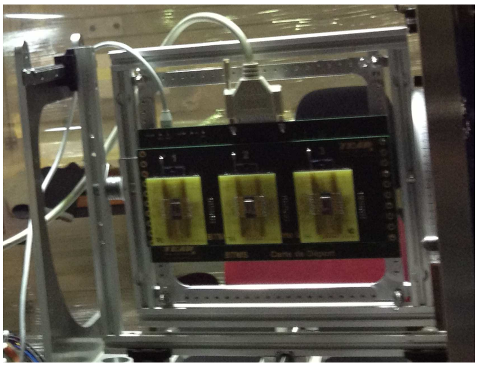
6.1. UCL Heavy Ion Test Facility (Université Catholique de Louvain - Belgique)

The CYClotron of LOuvain la NEuve (CYCLONE) is a multi-particle, variable energy, cyclotron capable of accelerating protons (up to 85 MeV), alpha particles and heavy ions.
For the heavy ions, the covered LET range is between 1.2 MeV.cm².mg^{-1} and 67.7 MeV.cm².mg^{-1}. Heavy ions available are separated in two “Ion Cocktails” named M/Q=5 and M/Q=3.3.



One of the main advantages of the UCL Heavy Ion Test Facility is the fast changing of ion species. Within the same cocktail, it takes only a few minutes to change from one ion to another.

The chamber has the shape of a barrel stretched vertically; its internal dimensions are 71 cm in height, 54 cm in width and 76 cm in depth. One side flange is used to support the board frame (25 X 25 cm) and user connectors.
The chamber is equipped with a vacuum system.



6.2. Dosimetry

To control and monitor the beam parameters, a dosimetry box is placed in front of the chamber.
It contains a faraday cup, 2 Parallel Plate Avalanche Counters (PPAC).
Two additional surface barrier detectors are placed in the test chamber.
The faraday cup is used during beam preparation at high intensity.
A beam uniformity measurement is performed with a collimated surface barrier detector. This detector is placed on a X and Y movement. The final profile is drawn and the ± 10 % width is calculated. The Homogeneity is ± 10 % on a 25 mm diameter.
During the irradiation, the flux is integrated in order to give the delivered total fluence (particule.cm^{-2}) on the device.

6.3. Beam characteristics

The beam flux can vary between a few particles s^{-1}cm^{-2} and $1.8{\cdot}10^{4}$s^{-1}cm^{-2} depending on the device sensitivity.

Heavy ion beam characteristics are listed in the following tables:

Ion	Energie (MeV)	Range (µm(Si))	LET (MeV.cm².mg^{-1})
$^{15}N^{3+}$	60	59	3.3
$^{20}Ne^{4+}$	78	45	6.4
$^{40}Ar^{8+}$	151	40	15.9
$^{84}Kr^{17+}$	305	39	40.4
$^{124}Xe^{25+}$	420	37	67.7

Table 2 : UCL cocktail M/Q=5

Ion	Energie (MeV)	Range (µm(Si))	LET (MeV.cm².mg^{-1})
$^{13}C^{4+}$	131	292	1.1
$^{22}Ne^{7+}$	235	216	3
$^{40}Ar^{12+}$	372	117	10.2
$^{58}Ni^{18+}$	567	100	20.4
$^{83}Kr^{25+}$	756	92	32.6

Table 3 : UCL cocktail M/Q=3.3

The highlighted ion species in the table above were used to perform this SEE test.

7. Test Procedure and Setup

7.1. Test procedure

7.1.1. Description of the test method

Runs were performed up to a fluence of 1.0E+10 Protons/cm^2 and 1.0E+6 Ions/cm^2 for the proton test and heavy ion test, respectively.

During the irradiation, the M65609E was continuously read for error detection. Write cycles were only applied in case of SEU or MBU identification in order to verify the ability of the memory to be written back to its initial state after an upset (test conditions summarized in table 4).

This test method was applied to verify the SEU and MBU sensitivity of the device.

The test was terminated when the maximum fluence was reached or when enough events (several thousands) were recorded to be statistically representative of the part behaviour.

7.2. Test bench description

7.2.1. Preparation of test hardware and program

The test bench consists of a Labview-based software, laboratory equipment, and electronic board as part of the hardware. It allows the testing of parts under low or high energy beam by giving the possibility to separate test boards from the irradiated board charged with Units Under Test (UUT). A direct plug between the irradiated board and the other test boards (low energy beam configuration) shortens the access paths and reduces response times in the test procedure. On the other hand, a remote communication between the irradiated board and the other test boards protects all electronic parts constituting the latter from the irradiation of the high energy beam if that configuration is needed.
Figures 4 & 5 give a synoptic view in high and low energy beam configurations, respectively. Figure 6 shows the Remote board and the FPGA development board of the test bench.

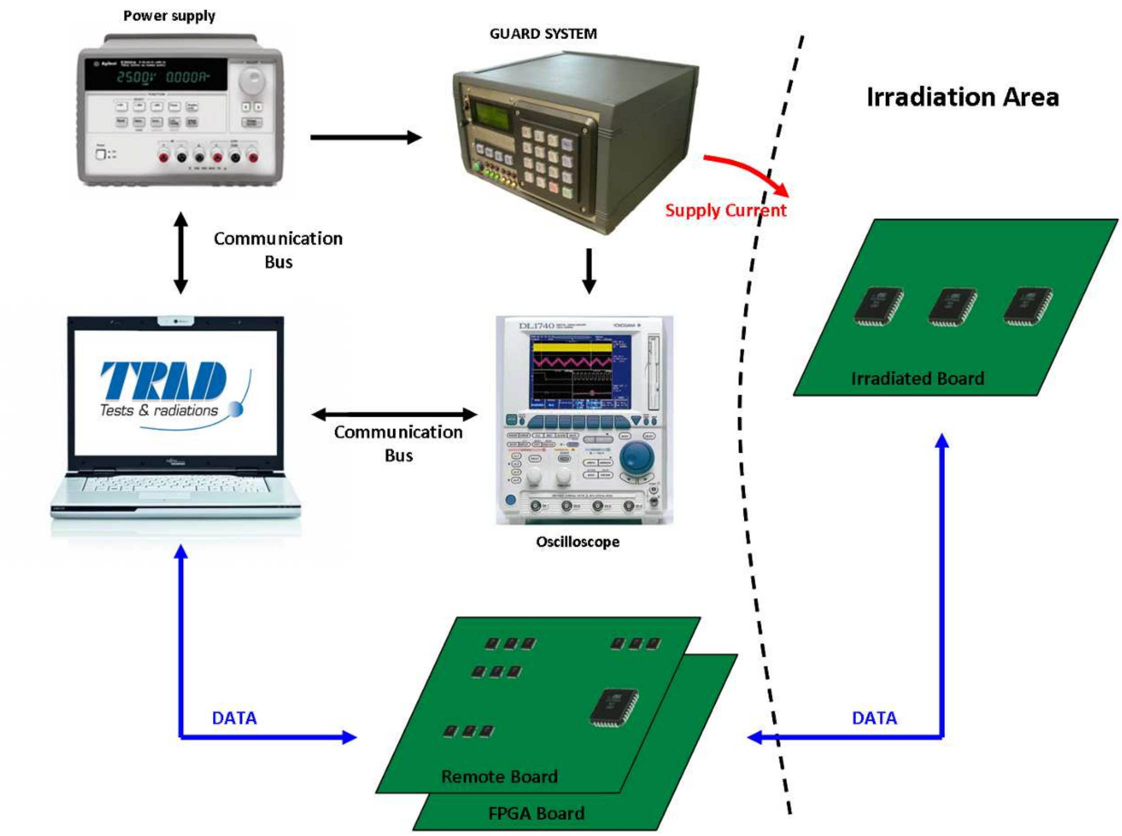


Figure 4 : Synoptic view of the test bench for high energy tests.

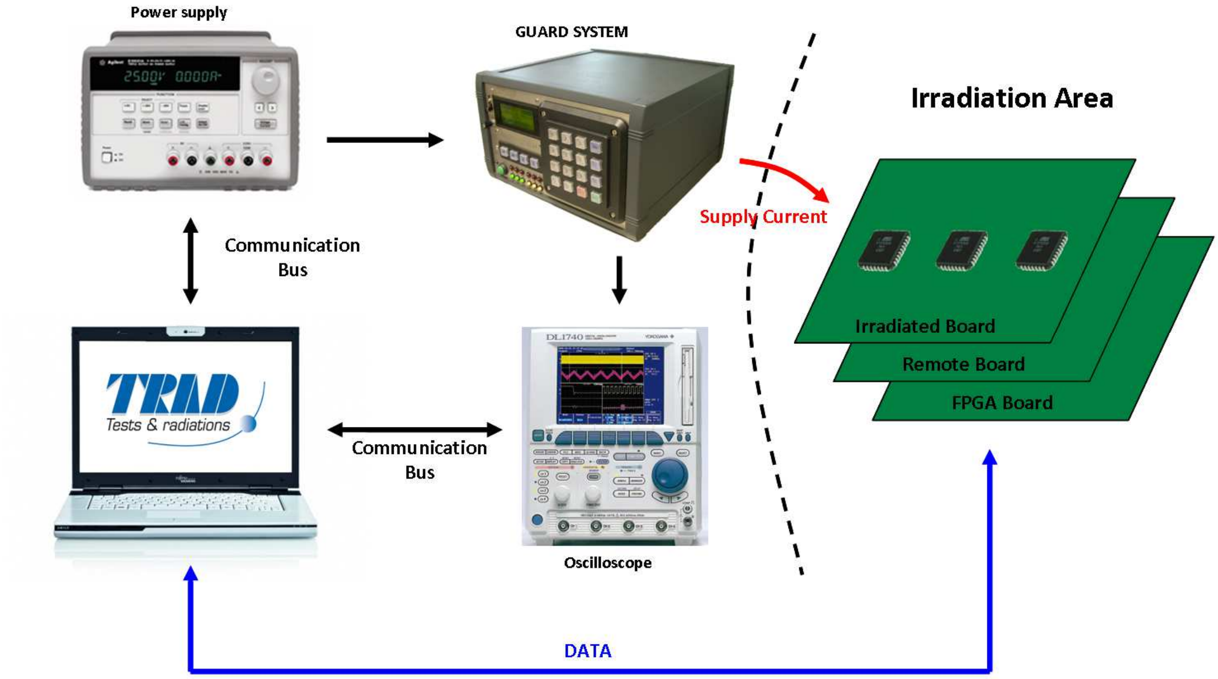


Figure 5 : Synoptic view of the test bench for low energy tests.

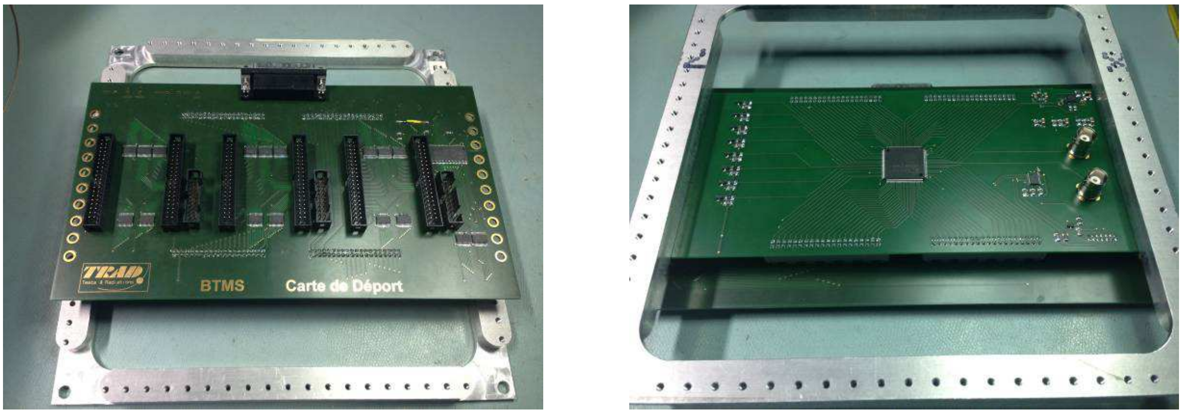


Figure 6 : Remote and FPGA Development Boards

Figure 7 : test bench pictures at PSI

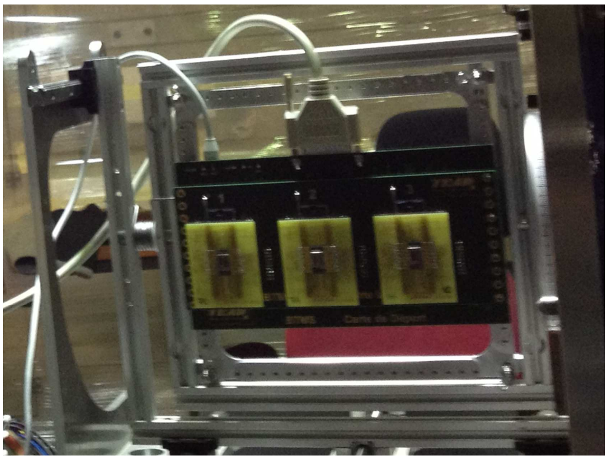


Figure 8 : test bench pictures at UCL

7.2.2. Software description

The software is designed as a user interface that drives the hardware and manages all the data flow for storage and visualization in real-time during the experiment. It also ensures the communication with laboratory equipment, then gathering all the necessary functions for the operator to drive the experiment from a single interface.

Considering a software-module based approach, the following figure describes the test bench software:

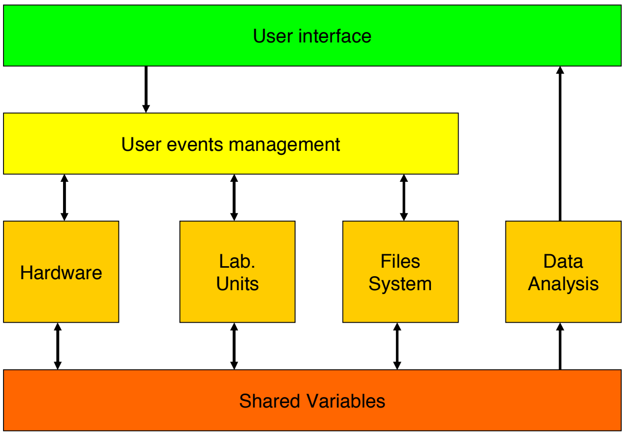
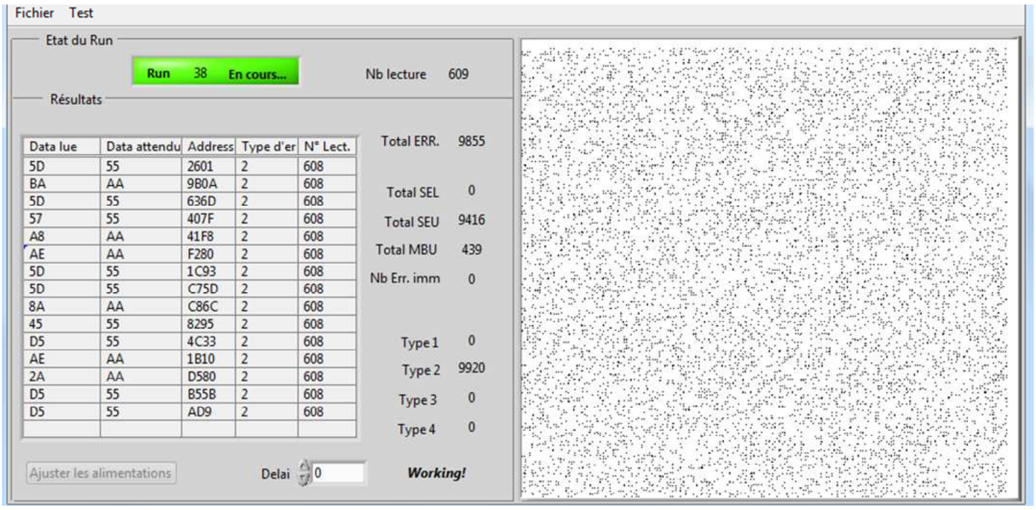


Figure 9 : Test bench software architecture

Each functional block of the software has been designed to run independently, sharing common variables, and all of them are driven by the "User events management" block. This architecture provides good stability by using a small amount of CPU charge and keeping the physical memory available at all times, to avoid a system crash during an experiment.



Run 38 En cours...

Nb lecture 609

Data lue	Data attendu	Address	Type d'er	N° Lect.
5D	55	2601	2	608
BA	AA	9B0A	2	608
5D	55	636D	2	608
57	55	407F	2	608
A8	AA	41F8	2	608
AE	AA	F280	2	608
5D	55	1C93	2	608
5D	55	C75D	2	608
8A	AA	C86C	2	608
45	55	8295	2	608
D5	55	4C33	2	608
AE	AA	1B10	2	608
2A	AA	D580	2	608
D5	55	B55B	2	608
D5	55	AD9	2	608

Total ERR. 9855
Total SEL 0
Total SEU 9416
Total MBU 439
Nb Err. imm 0
Type 1 0
Type 2 9920
Type 3 0
Type 4 0

Delai 0

Figure 10 : Test bench software screenshot

7.2.3. Hardware description

The hardware is designed around an FPGA to provide an efficient way to manage the required design flexibility combined with a robust architecture. Then, by reconfiguration of the memory controller, the test bench can address any SRAM for testing purposes up to 1.048.576 * 16 bits-words (20 address bits).

The power supply delivers the current for the UUT through the GUARD System, a specific unit designed by TRAD that monitors the supply current and protects the UUT against latchups. Each event detected by the GUARD system triggers the oscilloscope for latchup visualization.

Figure 11 is a global view of the Test Bench with its three boards represented.

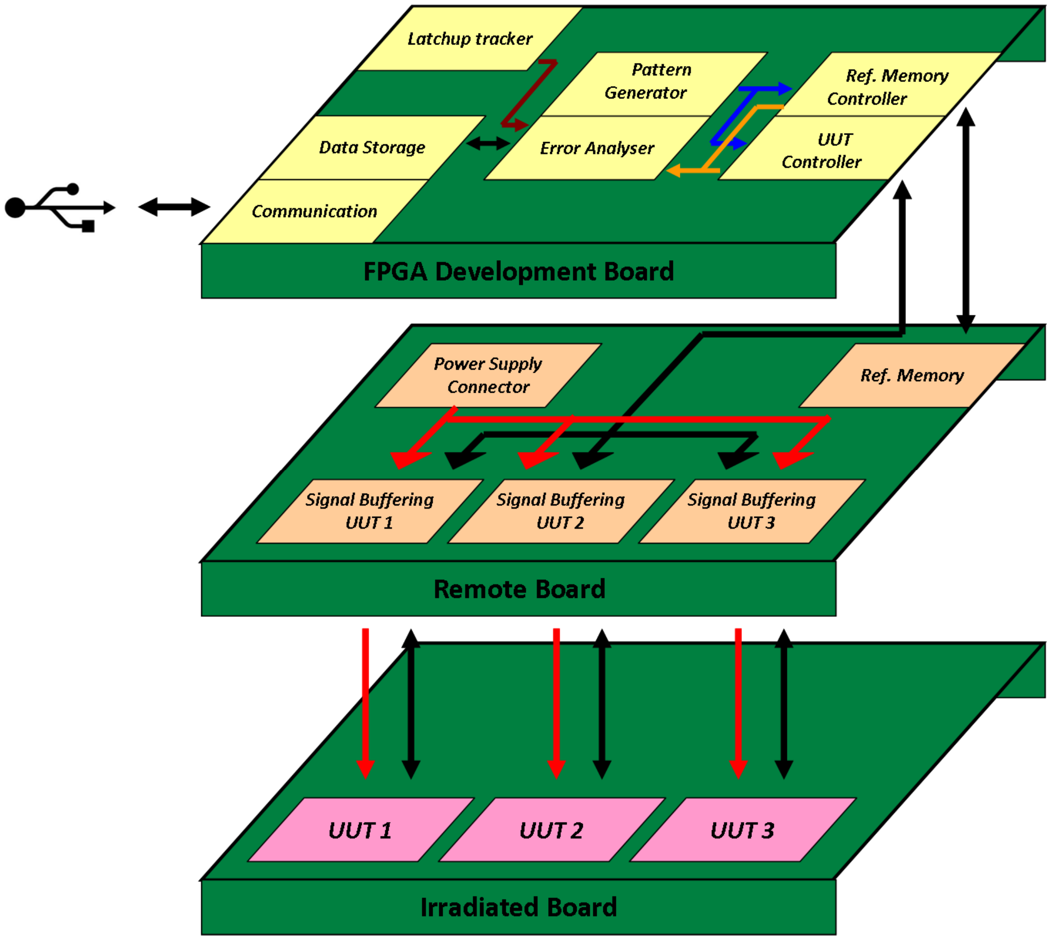


Figure 11 : Global view of the test bench hardware

7.2.4. Test Bench operation

Before each run, the reference memory and the UUT are filled with a checker-board pattern (e.g 10101010 at even addresses and 01010101 at odd addresses) from address 0 up to the maximum address of the UUT. A first verification of their contents is performed off beam.

During irradiation, the test bench reads both memories and compares their contents one address at a time. When the last address is reached, the FPGA sends a command to the Labview software to indicate the end of the read/compare cycle. Depending on the user setting options, a new read/compare order is immediately sent back to the FPGA or an additional delay can be inserted before. If there is no event during the cycle, this operation is performed at the maximum system speed (test conditions summarized in table 4).

However, if the data read from the UUT doesn't fit the data from the reference memory, a sequence of operation is launched to determine the error type. This sequence is summarized in Figure 12.

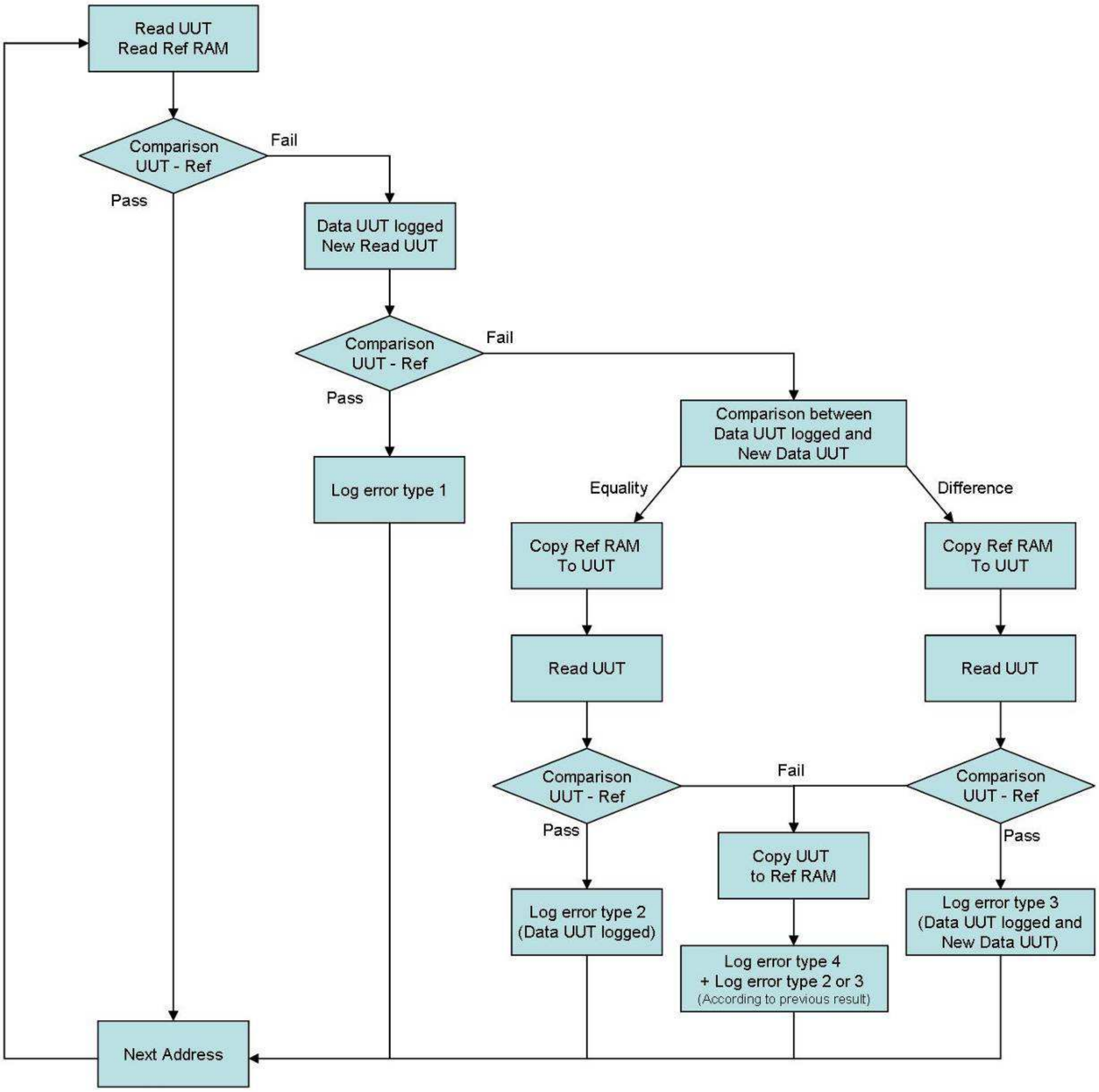


Figure 12 : Test bench operation

An error logged as "Type 1" is considered to be an SET (Single Event Transient) present on the output bus when it has been sampled. If the data from the UUT is correct after a second read cycle delayed by 1µs, it means that the storage element itself contains the expected value.
In the case of an upset in a storage element, the data from the UUT won't match the expected data (from the reference memory) after a second read cycle. This eliminates the possibility of a transient event. If the two read cycles give the same erroneous data, the error is logged as "Type 2". In case of a

difference between these two data, the error is logged as “Type 3”. In order to determine if the event is actually an SEU or a stuck bit, a write cycle is performed with the expected data, followed by a read cycle. The result of this third comparison determines the final error type. Either the data is correct again and an SEU is recorded (Type 2 or 3) or the memory cell can’t be written back to its initialization state and therefore the event is a stuck bit (Type 4).

All the events detected by the error analyser are sent to the Labview software through the communication module for real-time analysis and storage. Thus, an illustration of the memory area can be calculated and plotted in a three-dimensional image in which the first plane is representative of the memory area in address term and the third dimension gives the upset occurrence per address. This graphical view allows to verify the beam uniformity and to make sure that all the memory area is tested.

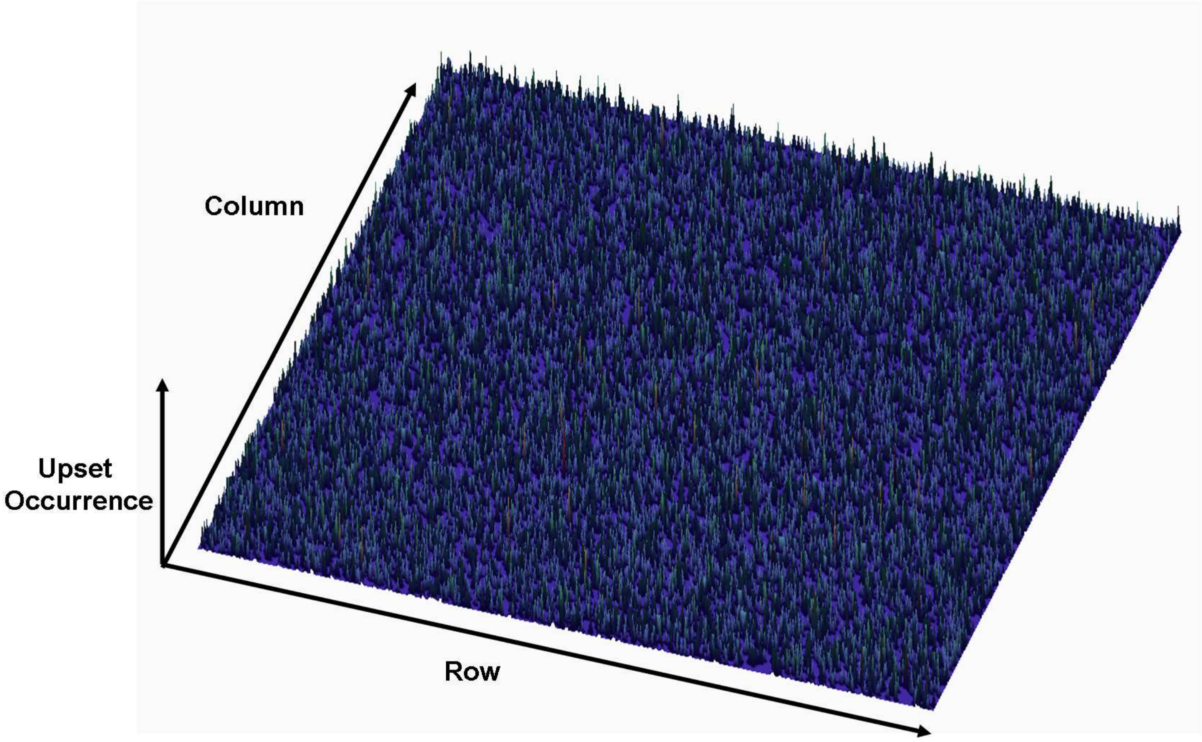


Figure 13 : Three-dimensional image of the memory tested.

7.2.5. Test equipment identification

The tests were carried out with the following list of equipment.

COMPUTER	MI-OP-40
REF. TEST BOARD	AGIS II - BTMS carte de déport - BTMS Carte UUT
EQUIPMENT	ME-54 – GR-51
TEST PROGRAM	BTMS_BV_1311_rev3.vi

7.2.6. Device setup and Test conditions

The device setup used to perform the proton and heavy ion SEE test is given in the following table:

Vcc	3.3V
Number of Address tested	131 072
Data mask	8 bits width data tested (no mask)
Delay between full device read cycles (note 1)	0s
Delay after 1st error detection (note 2)	1µs
Read Cycle time of the full memory (note 3)	32.768ms (without error)
Pattern used	Checker board (xAA/x55)
Temperature	25°C (Room temperature)

Table 4: M65609E Test Conditions

Note 1: When the last address is reached, an exposure delay can be inserted before initiating a new comparison cycle.

Note 2: During a comparison cycle, if the data read from the UUT is wrong, a short delay is inserted before initiating a second read cycle (same address) to eliminate the possibility of a transient on the IO of the UUT during sampling.

Note 3: If no error occurs on the memory, each address is read and compared with its previous value (stored in the reference memory) every 250ns:

- 200ns needed for the “READ” command (this command is simultaneously sent to the reference memory controller and the UUT memory controller thanks to the natural ability of FPGA to process tasks in parallel), and
- 50ns needed for the data comparison itself and the address management (increment or back to zero).

If errors occur on the memory, each address is read and compared with its previous value on average every 2µs depending on the error type (See flowchart, figure 12). The number of machine cycles needed to determine the error type depends on the error type itself. Moreover, an additional delay may be required if the storage unit is full before moving to the next address.

8. Non conformance

Test sequence, test and measurement conditions were nominal.

9. RESULTS

The results presented in the following pages were obtained after a post-treatment of the raw data collected during irradiation campaigns. Indeed, the test bench records all events, and determines their type depending on several criteria. Particularly, the distinction between SEU and MBU is based upon the number of bit upset inside a single data byte. That is, if more than one bit differs from the expected data, an MBU is counted.

Actually, an MBU should be considered only if two adjacent bits are upset due to a single particle strike. So, the physical distribution of the memory cells inside the device must be correlated with the test results to extract the real number of MBU for each run.

TRAD obtained the information about the physical distribution of memory cells from the manufacturer ATMEL, and then, a specific analysis was performed to separate real MBU from multiple upsets. In fact, in some worst cases, approximately half of the MBU initially detected have been discarded because their upset cells were non-adjacent cells.

This differentiation had a heavy impact on the results. For example, with the physical distribution unknown, MBU were found under a 100MeV proton beam. The detailed results in the following pages show that is was not the case.

The following table is an example of the results obtained after the MBU detection was performed. According to the manufacturer, the physical distribution of the memory cells inside the device is the interleaving of two bytes, A and B, selected thanks to A12. Their bits have the following pattern:

A1, A5, B1, A6, A2, B5, B2, B6, B3, B7, B4, B8, A3, A7, A4, A8.

An MBU is considered if two upset bits are adjacent. So, the couples of bits that form MBU are:
(A1-A5), (A6-A2), (A3-A7), (A7-A4), (A4-A8), (B5-B2), (B2-B6), (B6-B3), (B3-B7), (B7-B4), B4-B8).

Read Data	Expected Data	bit upset	Adrress	A12	Event Type
'E2	'AA	'01001000	'1CDF4	0	True MBU (A7-A4)
'E2	'AA	'01001000	'1FA9E	1	True MBU (B7-B4)
'B8	'AA	'00010010	'10E36	0	Multiple SEU (A2-A5)
'E2	'AA	'01001000	'7E8E	1	True MBU (B7-B4)
'E2	'AA	'01001000	'17068	1	True MBU (B7-B4)
'E2	'AA	'01001000	'165C4	0	True MBU (A7-A4)
'E2	'AA	'01001000	'15862	1	True MBU (B7-B4)
'E2	'AA	'01001000	'B578	1	True MBU (B7-B4)
'E2	'AA	'01001000	'13CF6	1	True MBU (B7-B4)
'71	'55	'00100100	'1E705	0	Multiple SEU (A3-A6)
'E2	'AA	'01001000	'D0DC	1	True MBU (B7-B4)
'B8	'AA	'00010010	'8F20	0	Multiple SEU (A2-A5)
'E2	'AA	'01001000	'C792	0	True MBU (A7-A4)
'E2	'AA	'01001000	'136E2	1	True MBU (B7-B4)
'B8	'AA	'00010010	'1E410	0	Multiple SEU (A2-A5)
'E2	'AA	'01001000	'2E12	0	True MBU (A7-A4)
'B8	'AA	'00010010	'1EA68	0	Multiple SEU (A2-A5)
'E2	'AA	'01001000	'2B8C	0	True MBU (A7-A4)
'B8	'AA	'00010010	'1E8CC	0	Multiple SEU (A2-A5)
'E2	'AA	'01001000	'1E148	0	True MBU (A7-A4)
'E2	'AA	'01001000	'9ED8	1	True MBU (B7-B4)
'E2	'AA	'01001000	'10B48	0	True MBU (A7-A4)
'E2	'AA	'01001000	'308A	1	True MBU (B7-B4)
'E2	'AA	'01001000	'B488	1	True MBU (B7-B4)
'71	'55	'00100100	'AB33	0	Multiple SEU (A3-A6)
'71	'55	'00100100	'2017	0	Multiple SEU (A3-A6)
'71	'55	'00100100	'18807	0	Multiple SEU (A3-A6)
'6A	'AA	'11000000	'1F6D4	1	Multiple SEU (B7-B8)
'B8	'AA	'00010010	'AEE2	0	Multiple SEU (A2-A5)
'71	'55	'00100100	'14323	0	Multiple SEU (A3-A6)
'E2	'AA	'01001000	'29AC	0	True MBU (A7-A4)
'B8	'AA	'00010010	'12B2C	0	Multiple SEU (A2-A5)
'E2	'AA	'01001000	'9048	1	True MBU (B7-B4)
'E2	'AA	'01001000	'21B0	0	True MBU (A7-A4)
'71	'55	'00100100	'1C54F	0	Multiple SEU (A3-A6)
'E2	'AA	'01001000	'1D18A	1	True MBU (B7-B4)
'B8	'AA	'00010010	'12E22	0	Multiple SEU (A2-A5)
'E2	'AA	'01001000	'1AC7C	0	True MBU (A7-A4)
'B8	'AA	'00010010	'18006	0	Multiple SEU (A2-A5)
'71	'55	'00100100	'89B1	0	Multiple SEU (A3-A6)
'71	'55	'00100100	'1A27D	0	Multiple SEU (A3-A6)
'B8	'AA	'00010010	'A6FC	0	Multiple SEU (A2-A5)
'E2	'AA	'01001000	'16A36	0	True MBU (A7-A4)
'E2	'AA	'01001000	'BBCE	1	True MBU (B7-B4)

Table 5: MBU differentiation - Run N°24 - part 74 - LET 14.42MeV Heavy ion beam

The mapping outputs with the identified SEU and MBU events for both proton and heavy ion tests are shown in the Appendix section.

9.1. Proton Test Results

9.1.1. Summary of runs

Test results are presented hereafter. For both SEU and MBU “initial events” are the events measured during the test campaign and “true events” are the events defined after the prost-processing procedure where the memory physical architecture was taken into account.

M65609E VCC = 3.3V								SEU			MBU			Comments
RUN	Part	Energie (Mev)	Flux (p/cm2/s)	Time (s)	Fluence	Run Dose (krad)	Cumulated Dose (krad)	Initial events	True Events	Cross section	Initial events	True Events	Cross section	
1	79	230	8.94E+06	1119	1.00E+10	0.534	0.534	339	339	3.39E-08	2	2	2.00E-10	
2	79	200	3.00E+06	171	9.80E+08	0.057	0.591	31	31	3.16E-08	0	0	<1.00E-10	Run Canceled
3	79	200	5.66E+06	1768	1.00E+10	0.581	1.172	319	319	3.19E-08	0	0	<1.00E-10	
4	79	151	6.94E+06	1441	1.00E+10	0.703	1.875	323	323	3.23E-08	0	0	<1.00E-10	
5	79	101	7.56E+06	1323	1.00E+10	0.929	2.804	317	319	3.19E-08	1	0	<1.00E-10	
6	79	75	6.99E+06	1431	1.00E+10	1.156	3.96	338	338	3.38E-08	0	0	<1.00E-10	
7	79	230	4.46E+06	2244	1.00E+10	0.534	4.494	367	373	3.73E-08	3	0	<1.00E-10	Flux dependency check
8	78	230	4.69E+06	2132	1.00E+10	0.534	0.534	366	368	3.68E-08	3	2	2.00E-10	
9	78	151	7.43E+06	1346	1.00E+10	0.703	1.237	312	314	3.14E-08	1	0	<1.00E-10	
10	78	75	1.05E+07	951	1.00E+10	1.16	2.397	289	289	2.89E-08	0	0	<1.00E-10	
22	72	75	1.83E+07	546	1.00E+10	1.16	1.16	261	261	2.61E-08	0	0	<1.00E-10	sensitivity check
23	72	39	2.18E+07	458	1.00E+10	1.913	3.073	201	201	2.01E-08	0	0	<1.00E-10	
24	72	23	2.13E+07	469	1.00E+10	2.903	5.976	198	198	1.98E-08	0	0	<1.00E-10	
25	71	39	3.14E+07	318	1.00E+10	1.92	1.92	213	213	2.13E-08	0	0	<1.00E-10	
26	71	23	2.14E+07	468	1.00E+10	2.9	4.82	194	194	1.94E-08	0	0	<1.00E-10	

Table 6: M65609E test results

Both SEU and MBU events were detected during this test.
SEU and MBU tests results are described hereafter.
From the 22nd run, parts irradiated were undelidded (part 72 & 71) – Run 22 (sensitivity check) was performed to ensure that the SEU sensitivity was similar on delidded and undelidded samples at 75 MeV.

9.1.2. SEU tests results

The SEU test was performed at 25°C (Room temperature).

SEUs were observed down to the lowest test energy of 23 MeV.

SEU Cross sections

M65609E - SEU Cross Section (cm²)				
Energy (MeV)	79	78	72	71
230	3.39E-08	3.68E-08		
200	3.19E-08			
151	3.23E-08	3.14E-08		
101	3.19E-08			
75	3.38E-08	2.89E-08	2.61E-08	
39			2.01E-08	2.13E-08
23			1.98E-08	1.94E-08

Table 7: SEU cross section results

The following figures present the cross section of the SEU event on the **M65609E** part.

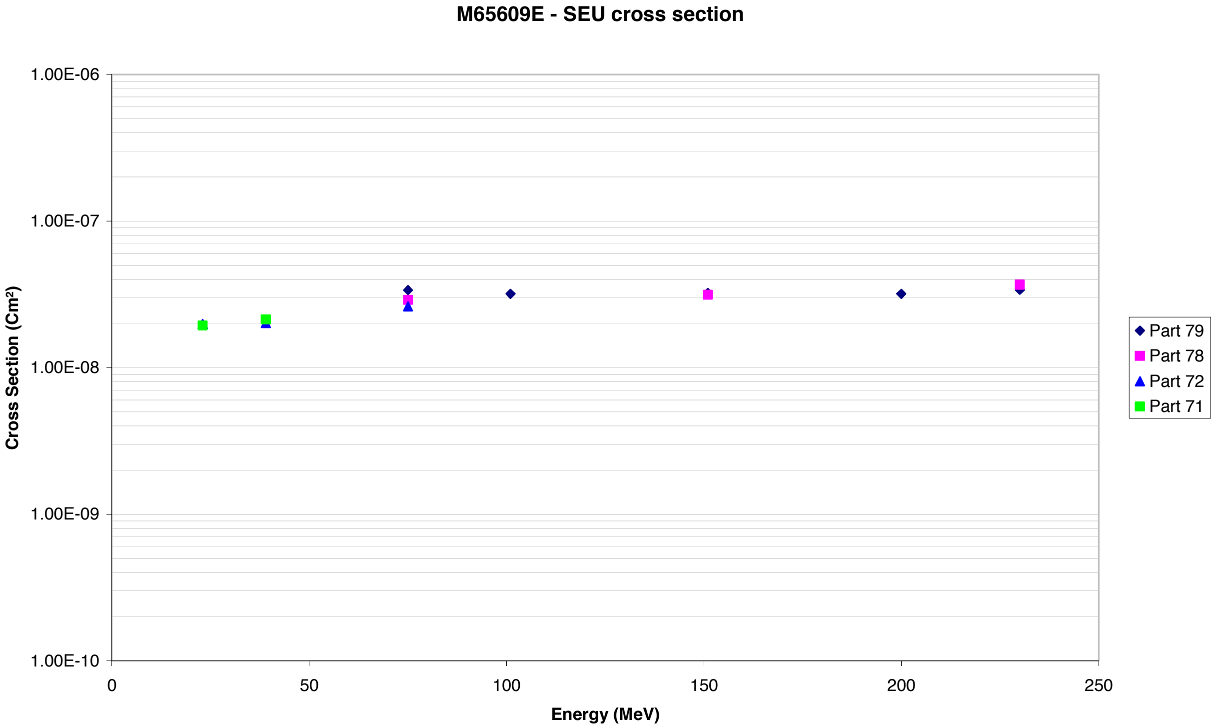


Figure 14: SEU cross section curve for M65609E

9.1.3. MBU tests results

The MBU test was performed at 25°C (Room temperature).

MBUs were observed under proton beam at 230MeV only.

MBU Cross sections

M65609E - MBU Cross Section (cm²)		
Energy (MeV)	79	78
230	2.00E-10	2.00E-10
200	<1.00E-10	<1.00E-10
151	<1.00E-10	<1.00E-10
101	<1.00E-10	<1.00E-10
75	<1.00E-10	<1.00E-10

Table 8: MBU cross section results

The following figure presents the cross section of the MBU events on the **M65609E** parts.

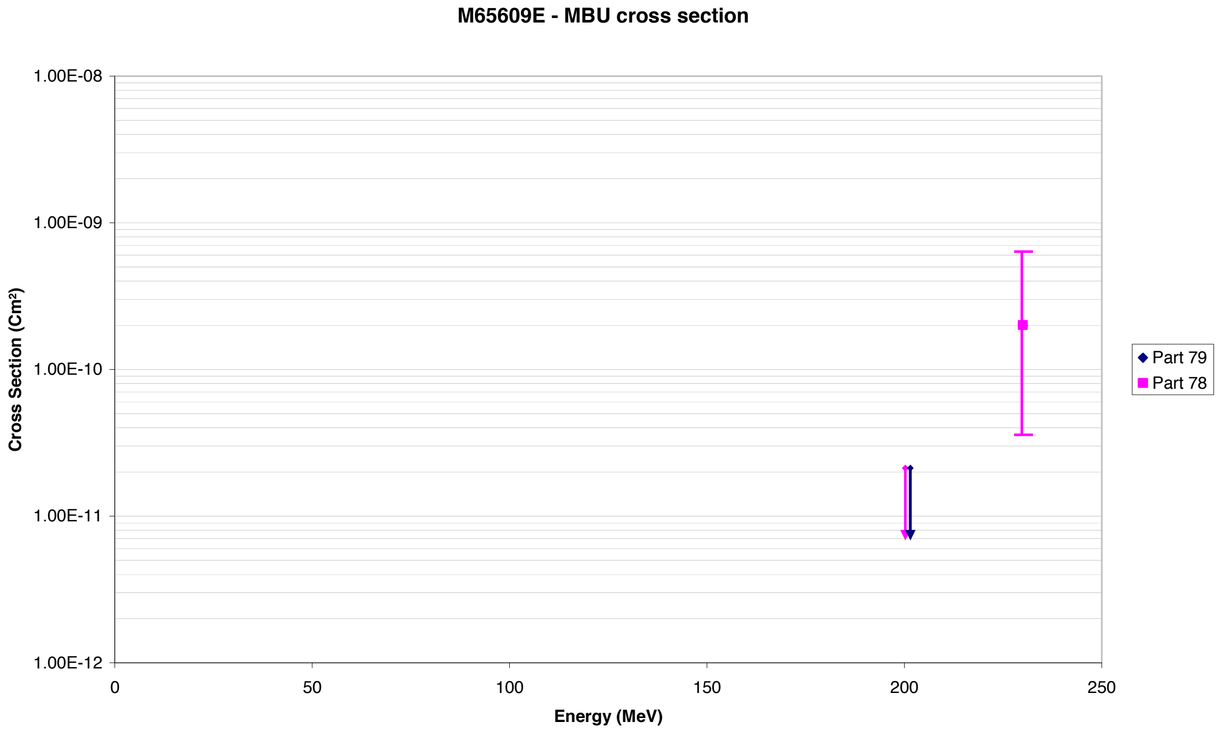


Figure 15: MBU cross section curve for M65609E

9.1.4. Complementary test result analysis – Proton test

	SEU	MBU-2	MBU-3	MBU-4	MBU-5	MBU-6	MBU-7	MBU-8	Total events
Run N° 0001	339	2	0	0	0	0	0	0	341
Run N° 0003	319	0	0	0	0	0	0	0	319
Run N° 0004	323	0	0	0	0	0	0	0	323
Run N° 0005	319	0	0	0	0	0	0	0	319
Run N° 0006	338	0	0	0	0	0	0	0	338
Run N° 0007	373	0	0	0	0	0	0	0	373
Run N° 0008	368	2	0	0	0	0	0	0	370
Run N° 0009	314	0	0	0	0	0	0	0	314
Run N° 0010	289	0	0	0	0	0	0	0	289
Run N° 0022	261	0	0	0	0	0	0	0	261
Run N° 0023	201	0	0	0	0	0	0	0	201
Run N° 0024	198	0	0	0	0	0	0	0	198
Run N° 0025	213	0	0	0	0	0	0	0	213
Run N° 0026	194	0	0	0	0	0	0	0	194

Table 9: SEU & MBU distribution – according to number of bits upseted – Proton test

	Err. Type 1	Err. Type 2	Err. Type 3	Err. Type 4	Total events
Run N° 0001	0	341	0	0	341
Run N° 0003	0	319	0	0	319
Run N° 0004	0	323	0	0	323
Run N° 0005	0	319	0	0	319
Run N° 0006	0	338	0	0	338
Run N° 0007	0	373	0	0	373
Run N° 0008	0	370	0	0	370
Run N° 0009	0	314	0	0	314
Run N° 0010	0	289	0	0	289
Run N° 0022	0	261	0	0	261
Run N° 0023	0	201	0	0	201
Run N° 0024	0	198	0	0	198
Run N° 0025	0	213	0	0	213
Run N° 0026	0	194	0	0	194

Table 10: Error types distribution – Proton test

	0 ---> 1	1 --->0	Total events*
Run N° 0001	186	157	341
Run N° 0003	160	159	319
Run N° 0004	149	174	323
Run N° 0005	160	159	318
Run N° 0006	154	184	338
Run N° 0007	183	190	370
Run N° 0008	176	196	369
Run N° 0009	148	166	313
Run N° 0010	145	144	289
Run N° 0022	136	125	261
Run N° 0023	106	95	201
Run N° 0024	101	97	198
Run N° 0025	116	97	213
Run N° 0026	92	102	194

Table 11: Transition ‘0’ to ‘1’ and ‘1’ to ‘0’ distribution – Proton test

	Bit0	Bit1	Bit2	Bit3	Bit4	Bit5	Bit6	Bit7	Total events*
Run N° 0001	49	39	43	48	45	43	40	36	341
Run N° 0003	48	47	41	31	35	23	50	44	319
Run N° 0004	35	39	38	38	47	45	38	43	323
Run N° 0005	40	39	42	40	41	39	38	40	318
Run N° 0006	42	40	46	45	42	33	47	43	338
Run N° 0007	39	42	43	53	63	53	37	43	370
Run N° 0008	42	50	51	45	48	53	42	41	369
Run N° 0009	31	41	37	43	40	37	45	40	313
Run N° 0010	45	38	41	31	27	29	33	45	289
Run N° 0022	36	38	27	32	29	23	41	35	261
Run N° 0023	26	26	32	20	23	30	24	20	201
Run N° 0024	25	18	23	29	26	29	23	25	198
Run N° 0025	26	17	31	27	23	27	33	29	213
Run N° 0026	28	24	23	21	27	34	16	21	194

Table 12: Upsets per bit distribution – Proton test

*: On tables 10 and 11, the column Total events corresponds to the number of SEU and MBU detected during the run and not to the sum of all upsets detected. As an MBU is composed of 2 upsets minimum, those two totals are different.

9.2. Heavy Ion Test Results

9.2.1. Summary of runs.

Test results are presented hereafter. For both SEU and MBU “initial events” are the events measured during the test campaign and “true events” are the events defined after the prost-processing procedure where the memory physical architecture was taken into account.

M65609E														SEU			MBU			COMMENTS
RUN	Part	Ion	Energy (MeV)	Range (µm)	LET (MeV.cm²/mg)	Tilt (°)	Temp (°)	Eff. LET (MeV.cm²/mg)	Eff. Range (µm Si)	Flux (φ) (cm^{-2}.s^{-1})	Time (s)	Run Fluence (Φ) (cm^{-2})	Run Dose (krad)	Cumulated Dose (krad)	Initial Events	True Events	Cross Section	Initial Events	True Events	Cross Section	
High LET M/Q=5																				
1	70	124Xe 25+	420	37	67.7	0	25	67.70	37.0	5.73E+02	139	7.96E+04	0.086	0.086		NA	-		NA	-	Handling Settings
2	74	124Xe 25+	420	37	67.7	0	25	67.70	37.0	2.63E+03	166	4.37E+05	0.474	0.474		NA	-		NA	-	Handling Settings
3	74	124Xe 25+	420	37	67.7	0	25	67.70	37.0	4.16E+02	3	1.25E+03	0.001	0.475	92	No data	-	2	No data	-	Handling Settings
4	70	124Xe 25+	420	37	67.7	0	25	67.70	37.0	6.04E+02	1660	1.00E+06	1.085	1.172	36481	No data	-	1708	No data	-	Half memory tested (adress bit stuck due to a hardware problem)
5	74	124Xe 25+	420	37	67.7	0	25	67.70	37.0	1.06E+03	948	1.00E+06	1.084	1.559	36922	No data	-	23065	No data	-	Investigation to find the adress bit stuck
6	76	124Xe 25+	420	37	67.7	0	25	67.70	37.0	1.07E+03	939	1.00E+06	1.085	1.085	35967	No data	-	1640	No data	-	Investigation to find the adress bit stuck
7	74	124Xe 25+	420	37	67.7	0	25	67.70	37.0	1.06E+03	941	1.00E+06	1.085	2.644	36111	No data	-	1651	No data	-	Investigation to find the adress bit stuck
8	70	124Xe 25+	420	37	67.7	0	25	67.70	37.0	9.25E+02	1083	1.00E+06	1.085	2.256	74320	77662	7.75E-02	3419	1748	1.75E-03	Investigation OK, A8 stuck to '0'. All the memory is now tested
9	74	124Xe 25+	420	37	67.7	0	25	67.70	37.0	1.00E+03	1001	1.00E+06	1.085	3.729	73175	76619	7.65E-02	3430	1708	1.70E-03	
High Range M/Q=3.3																				
10	70	83 Kr 25+	756	92	32.6	0	25	32.60	92.0	4.78E+02	909	4.34E+05	0.226	2.483	13921	No data	-	383	No data	-	Handling Settings
11	70	83 Kr 25+	756	92	32.6	0	25	32.60	92.0	5.14E+02	32	1.65E+04	0.009	2.492	2805	No data	-	2351	No data	-	Handling Settings
12	70	83 Kr 25+	756	92	32.6	0	25	32.60	92.0	4.69E+02	52	2.44E+04	0.013	2.504	971	No data	-	20	No data	-	Handling Settings
13	70	83 Kr 25+	756	92	32.6	0	25	32.60	92.0	4.65E+02	77	3.58E+04	0.019	2.523	771	No data	-	18	No data	-	Handling Settings
14	70	83 Kr 25+	756	92	32.6	0	25	32.60	92.0	1.01E+03	993	1.00E+06	0.522	3.045	44233	45327	4.53E-02	1133	586	5.85E-04	
15	74	83 Kr 25+	756	92	32.6	0	25	32.60	92.0	1.01E+03	995	1.00E+06	0.523	4.252	44016	45072	4.50E-02	1122	594	5.93E-04	
16	74	83 Kr 25+	756	92	32.6	45	25	46.10	65.1	6.79E+02	1474	1.00E+06	0.739	4.991	57955	59541	5.95E-02	1518	725	7.24E-04	
17	70	83 Kr 25+	756	92	32.6	45	25	46.10	65.1	6.80E+02	1473	1.00E+06	0.739	3.784	58804	60390	6.03E-02	1601	808	8.07E-04	
18	70	58 Ni 18+	567	100	20.4	0	25	20.40	100.0	1.01E+03	995	1.00E+06	0.327	4.111	35110	35612	3.55E-02	511	260	2.59E-04	
19	74	58 Ni 18+	567	100	20.4	0	25	20.40	100.0	1.01E+03	996	1.00E+06	0.327	5.318	34974	35478	3.54E-02	473	221	2.21E-04	
20	74	58 Ni 18+	567	100	20.4	45	25	28.85	70.7	7.98E+02	1255	1.00E+06	0.462	5.780	44851	45619	4.55E-02	779	395	3.94E-04	
21	70	58 Ni 18+	567	100	20.4	45	25	28.85	70.7	1.04E+03	965	1.00E+06	0.462	4.573	44989	45821	4.58E-02	818	402	4.02E-04	
22	70	40 Ar 12+	372	117	10.2	0	25	10.20	117.0	1.01E+03	995	1.00E+06	0.164	4.736	18920	18922	1.89E-02	3	2	2.00E-06	
23	74	40 Ar 12+	372	117	10.2	0	25	10.20	117.0	1.09E+03	915	1.00E+06	0.163	5.943	18798	18802	1.88E-02	5	3	3.00E-06	
24	74	40 Ar 12+	372	117	10.2	45	25	14.42	82.7	1.15E+03	871	1.00E+06	0.231	6.175	26737	26775	2.67E-02	44	25	2.49E-05	
25	70	40 Ar 12+	372	117	10.2	45	25	14.42	82.7	1.47E+03	683	1.00E+06	0.231	4.968	26970	27002	2.70E-02	36	20	2.00E-05	
26	70	22 Ne 7+	235	216	3	0	25	3.00	216.0	3.74E+03	270	1.01E+06	0.048	5.016	53	53	5.25E-05	0	0	<1.E-06	
27	74	22 Ne 7+	235	216	3	0	25	3.00	216.0	5.18E+03	194	1.01E+06	0.048	6.223	54	54	5.37E-05	0	0	<1.E-06	
28	74	22 Ne 7+	235	216	3	45	25	4.24	152.7	3.75E+03	268	1.00E+06	0.068	6.291	127	127	1.26E-04	0	0	<1.E-06	
29	70	22 Ne 7+	235	216	3	45	25	4.24	152.7	3.89E+03	259	1.01E+06	0.068	5.085	190	190	1.89E-04	0	0	<1.E-06	
30	70	13 C 4+	131	292	1.1	0	25	1.10	292.0	5.47E+03	185	1.01E+06	0.018	5.102	3	3	2.97E-06	0	0	<1.E-06	
31	74	13 C 4+	131	292	1.1	0	25	1.10	292.0	7.60E+03	133	1.01E+06	0.018	6.309	1	1	9.90E-07	0	0	<1.E-06	
32	74	83 Kr 25+	756	92	32.6	60	25	65.20	46.0	5.25E+02	1907	1.00E+06	1.044	7.353	78985	81267	8.12E-02	2205	1064	1.06E-03	
33	70	83 Kr 25+	756	92	32.6	60	25	65.20	46.0	5.05E+02	1980	1.00E+06	1.044	6.146	79293	81249	8.12E-02	2184	1116	1.12E-03	

▨ **Invalided run for handling setting**

🟨 **Runs included in cross-section**

Table 13: M65609E test results

Both SEU and MBU events were detected during this test. SEU and MBU tests results are described hereafter.

Runs 1 to 3 (Table 13) served to validate the test bed operation during irradiation. These runs are named "Handling Settings". After these runs, the test started. Results obtained during runs 4 to 7 were compared to previous tests on this memory and an important difference was observed (counted events were two times less than expected events). The card was removed and the physical problem was investigated. A dust (metallic) was in contact between the address line A8 and the ground. The problem was fixed and the test started again (RUN8). From this run (8), the results are correct.

Runs that are not included in the cross section curves have not been post-analysed to extract true MBU from the physical distribution, and this is why they appear with “No data” in the column entitled “True Events” of table 13.

9.2.2. SEU tests results

The SEU test was performed at 25°C (Room temperature). SEUs were observed during the irradiation for all tested LET, ranging from 1.1 MeV.cm^2.mg^{-1} to 67.7 MeV.cm^2.mg^{-1}.

SEU Cross sections

M65609E - SEU Cross Section (cm^2)			
LET Eff (MeV.cm^2.mg^{-1})	**Heavy Ion ; Tilt**	Part N°70	Part N°74
67.7	**$^{124}Xe^{25+}$; 0°**	7.75E-02	7.65E-02
65.2	**$^{83}Kr^{25+}$; 60°**	8.12E-02	8.12E-02
46.1	**$^{83}Kr^{25+}$; 45°**	6.03E-02	5.95E-02
32.6	**$^{83}Kr^{25+}$; 0°**	4.53E-02	4.50E-02
28.85	**$^{58}Ni^{18+}$; 45°**	4.58E-02	4.55E-02
20.4	**$^{58}Ni^{18+}$; 0°**	3.55E-02	3.54E-02
14.42	**$^{40}Ar^{12+}$; 45°**	2.70E-02	2.67E-02
10.2	**$^{40}Ar^{12+}$; 0°**	1.89E-02	1.88E-02
4.24	**$^{22}Ne^{7+}$; 45°**	1.89E-04	1.26E-04
3	**$^{22}Ne^{7+}$; 0°**	5.25E-05	5.37E-05
1.1	**$^{13}C^{4+}$; 0°**	2.97E-06	9.90E-07

Table 14: SEU cross section results

The following figures present the cross section of the SEU events on the **M65609E** parts.

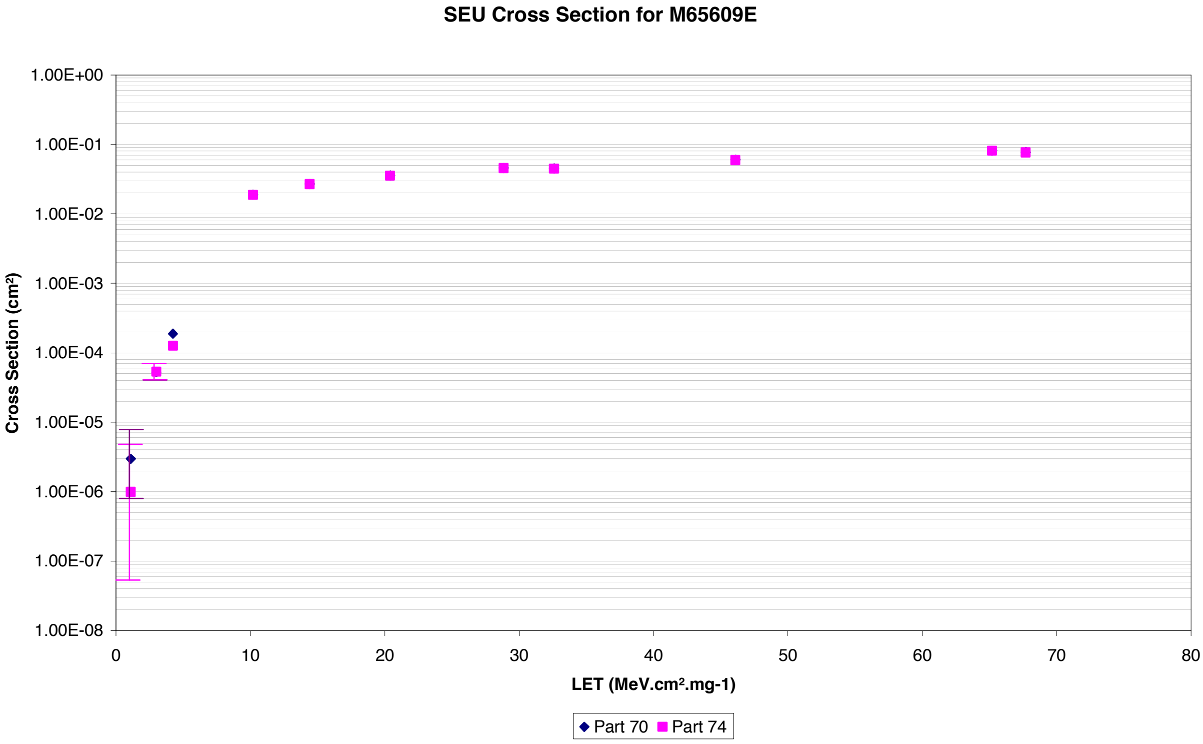


Figure 16: SEU cross section curve for M65609E

9.2.3. MBU tests results

The MBU test was performed at 25°C (Room temperature). MBUs were observed during the irradiation for LET ranging from 10.2 MeV.cm^2.mg^{-1} to 67.7 MeV.cm^2.mg^{-1}.

MBU Cross sections

M65609E - MBU Cross Section (cm^2)			
LET Eff (MeV.cm².mg^{-1})	Heavy Ion ; Tilt	Part N°70	Part N°74
67.7	**^{124}Xe^{25+} ; 0°**	1.75E-03	1.70E-03
65.2	**^{83}Kr^{25+} ; 60°**	1.12E-03	1.06E-03
46.1	**^{83}Kr^{25+} ; 45°**	8.07E-04	7.24E-04
32.6	**^{83}Kr^{25+} ; 0°**	5.85E-04	5.93E-04
28.85	**^{58}Ni^{18+} ; 45°**	4.02E-04	3.94E-04
20.4	**^{58}Ni^{18+} ; 0°**	2.59E-04	2.21E-04
14.42	**^{40}Ar^{12+} ; 45°**	2.00E-05	2.49E-05
10.2	**^{40}Ar^{12+} ; 0°**	2.00E-06	3.00E-06
4.24	**^{22}Ne^{7+} ; 45°**	<1.E-06	<1.E-06
3	**^{22}Ne^{7+} ; 0°**	<1.E-06	<1.E-06
1.1	**^{13}C^{4+} ; 0°**	<1.E-06	<1.E-06

Table 15: MBU cross section results

The following figures present the cross section of MBU events on the **M65609E** part.

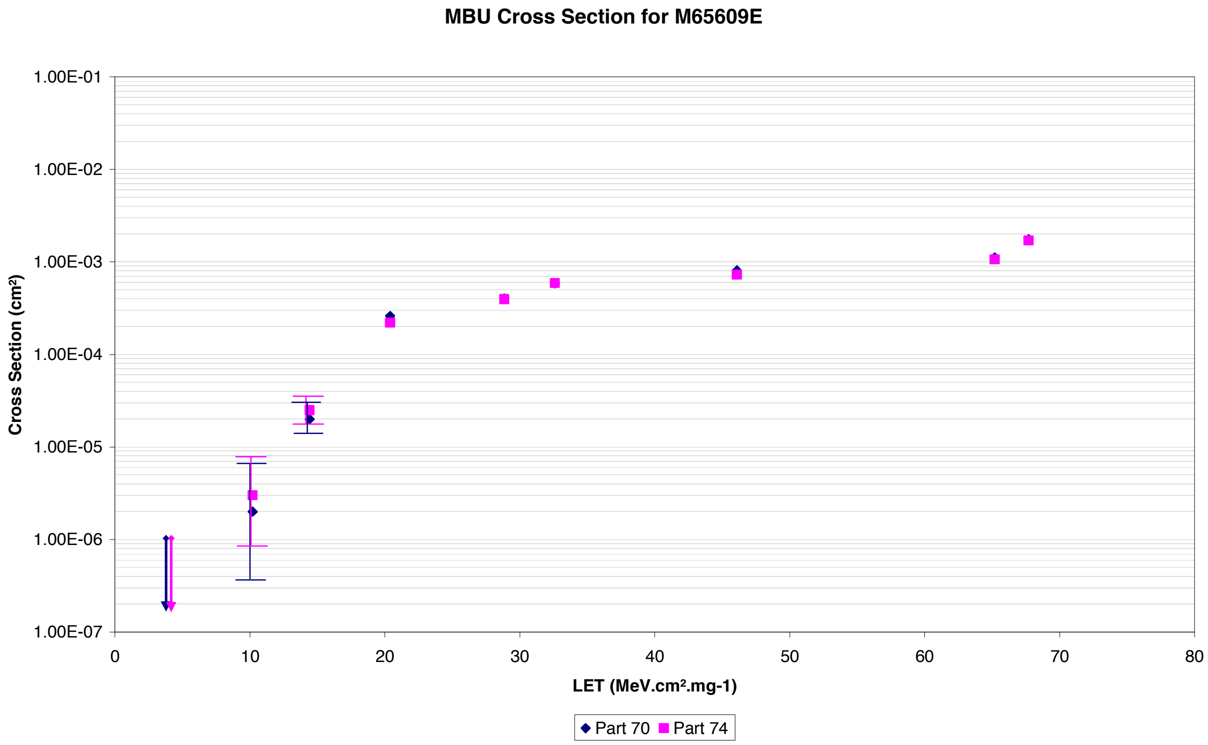


Figure 17: MBU cross section curve for M65609E

9.2.4. Complementary test result analysis – Heavy Ions test

	SEU	MBU-2	MBU-3	MBU-4	MBU-5	MBU-6	MBU-7	MBU-8	Total events
Run N° 0008	77662	1748	0	0	0	0	0	0	79410
Run N° 0009	76619	1708	0	0	0	0	0	0	78327
Run N° 0014	45327	586	0	0	0	0	0	0	45913
Run N° 0015	45072	594	0	0	0	0	0	0	45666
Run N° 0016	59541	725	0	0	0	0	0	0	60266
Run N° 0017	60390	808	0	0	0	0	0	0	61198
Run N° 0018	35612	260	0	0	0	0	0	0	35872
Run N° 0019	35478	221	0	0	0	0	0	0	35699
Run N° 0020	45619	395	0	0	0	0	0	0	46014
Run N° 0021	45821	402	0	0	0	0	0	0	46223
Run N° 0022	18922	2	0	0	0	0	0	0	18924
Run N° 0023	18802	3	0	0	0	0	0	0	18805
Run N° 0024	26775	25	0	0	0	0	0	0	26800
Run N° 0025	27002	20	0	0	0	0	0	0	27022
Run N° 0026	53	0	0	0	0	0	0	0	53
Run N° 0027	54	0	0	0	0	0	0	0	54
Run N° 0028	127	0	0	0	0	0	0	0	127
Run N° 0029	190	0	0	0	0	0	0	0	190
Run N° 0030	3	0	0	0	0	0	0	0	3
Run N° 0031	1	0	0	0	0	0	0	0	1
Run N° 0032	81267	1064	0	0	0	0	0	0	82331
Run N° 0033	81430	1116	0	0	0	0	0	0	82546

Table 16: SEU & MBU distribution – according to number of bits upseted – Heavy Ions test

	Err. Type 1	Err. Type 2	Err. Type 3	Err. Type 4	Total events
Run N° 0008	1	79409	0	0	79410
Run N° 0009	0	78327	0	0	78327
Run N° 0014	0	45913	0	0	45913
Run N° 0015	0	45666	0	0	45666
Run N° 0016	0	60266	0	0	60266
Run N° 0017	0	61198	0	0	61198
Run N° 0018	0	35872	0	0	35872
Run N° 0019	0	35699	0	0	35699
Run N° 0020	0	46014	0	0	46014
Run N° 0021	0	46223	0	0	46223
Run N° 0022	0	18924	0	0	18924
Run N° 0023	0	18805	0	0	18805
Run N° 0024	0	26800	0	0	26800
Run N° 0025	0	27022	0	0	27022
Run N° 0026	0	53	0	0	53
Run N° 0027	0	54	0	0	54
Run N° 0028	0	127	0	0	127
Run N° 0029	0	190	0	0	190
Run N° 0030	0	3	0	0	3
Run N° 0031	0	1	0	0	1
Run N° 0032	0	82331	0	0	82331
Run N° 0033	0	82546	0	0	82546

Table 17: Error types distribution – Heavy Ions test

	0 ---> 1	1 --->0	Total events*
Run N° 0008	40631	40527	79410
Run N° 0009	40081	39954	78327
Run N° 0014	23285	23214	45913
Run N° 0015	23312	22948	45666
Run N° 0016	30674	30317	60266
Run N° 0017	31234	30772	61198
Run N° 0018	18221	17911	35872
Run N° 0019	18243	17677	35699
Run N° 0020	23465	22944	46014
Run N° 0021	23446	23179	46223
Run N° 0022	9512	9414	18924
Run N° 0023	9474	9334	18805
Run N° 0024	13585	13240	26800
Run N° 0025	13691	13351	27022
Run N° 0026	30	23	53
Run N° 0027	30	24	54
Run N° 0028	61	66	127
Run N° 0029	82	108	190
Run N° 0030	1	2	3
Run N° 0031	1	0	1
Run N° 0032	41737	41658	82331
Run N° 0033	41901	41761	82546

Table 18: Transition '0' to '1' and '1' to '0' distribution – Heavy Ions test

c	Bit0	Bit1	Bit2	Bit3	Bit4	Bit5	Bit6	Bit7	Total events*
Run N° 0008	10051	10122	10141	10193	10028	10157	10241	10225	79410
Run N° 0009	10100	10059	9872	10075	10026	9987	9913	10003	78327
Run N° 0014	5816	5682	5936	5820	5734	5843	5892	5776	45913
Run N° 0015	5789	5804	5734	5749	5874	5782	5874	5654	45666
Run N° 0016	7611	7717	7582	7614	7723	7605	7583	7556	60266
Run N° 0017	7739	7767	7617	7831	7785	7754	7738	7775	61198
Run N° 0018	4486	4523	4512	4557	4557	4405	4582	4510	35872
Run N° 0019	4364	4491	4518	4428	4484	4561	4551	4523	35699
Run N° 0020	5857	5730	5900	5676	5796	5878	5849	5723	46014
Run N° 0021	5882	5766	5824	5805	5947	5835	5812	5754	46223
Run N° 0022	2277	2368	2375	2362	2409	2335	2414	2386	18924
Run N° 0023	2320	2372	2382	2279	2411	2422	2311	2311	18805
Run N° 0024	3262	3347	3373	3395	3359	3386	3412	3291	26800
Run N° 0025	3405	3344	3352	3336	3445	3318	3401	3441	27022
Run N° 0026	5	8	3	4	8	10	6	9	53
Run N° 0027	8	9	6	8	6	6	7	4	54
Run N° 0028	18	15	16	15	13	17	18	15	127
Run N° 0029	27	25	23	18	23	22	31	21	190
Run N° 0030	0	2	0	1	0	0	0	0	3
Run N° 0031	0	0	0	0	0	0	1	0	1
Run N° 0032	10589	10325	10515	10298	10467	10502	10232	10467	82331
Run N° 0033	10559	10326	10355	10613	10547	10226	10532	10504	82546

Table 19: Upsets per bit distribution – Heavy Ions test

*: On tables 17 and 18, the column Total events corresponds to the number of SEU and MBU detected during the run and not to the sum of all upsets detected. As an MBU is composed of 2 upsets minimum, those two totals are different.

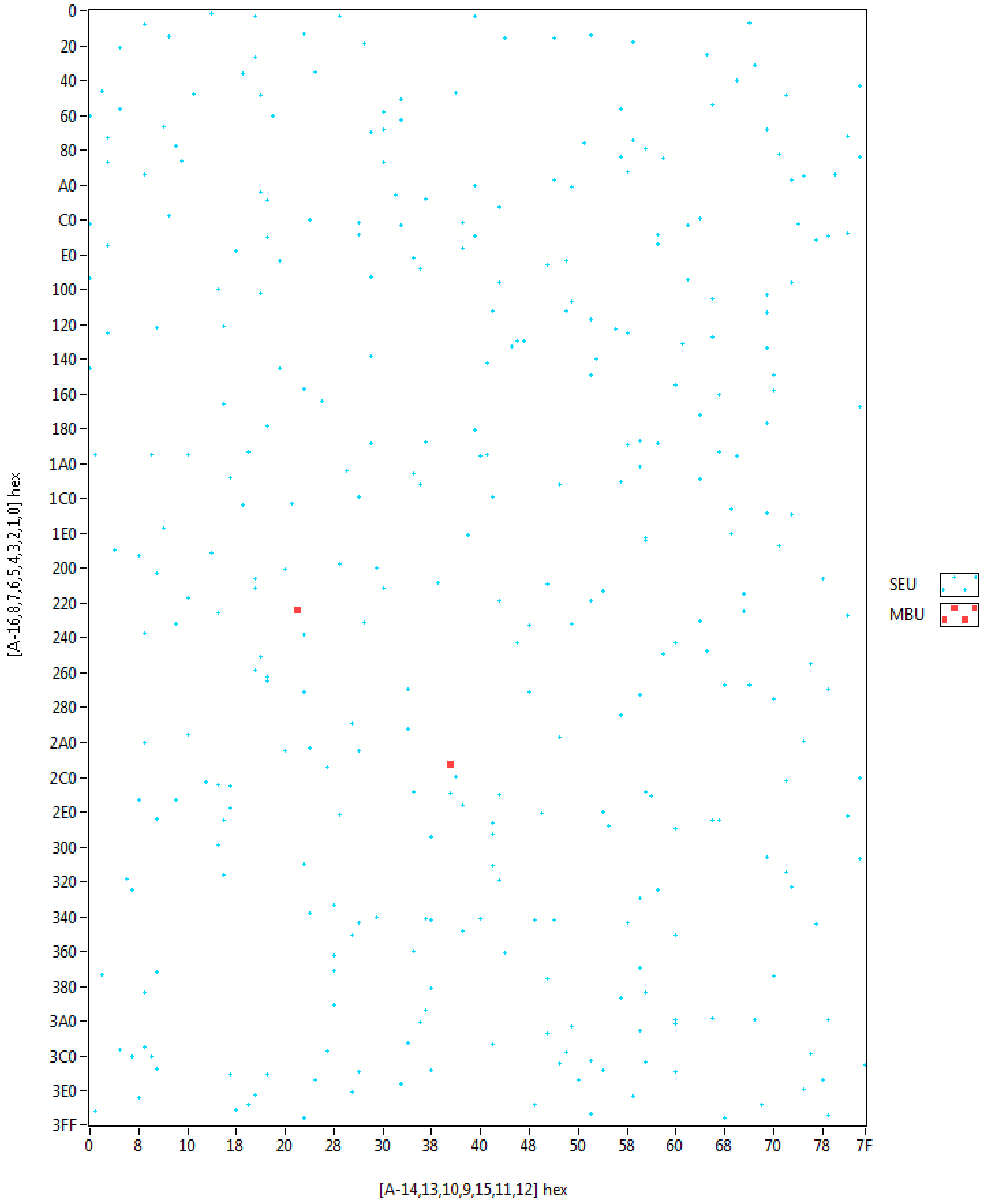
10. CONCLUSION

Proton and Heavy Ion SEE tests were performed on **M65609E**, a **Rad. Hard. 128k x 8 bit CMOS SRAM** from **ATMEL**. The aim of the test was to evaluate the sensitivity of the device versus **SEU** and **MBU**.

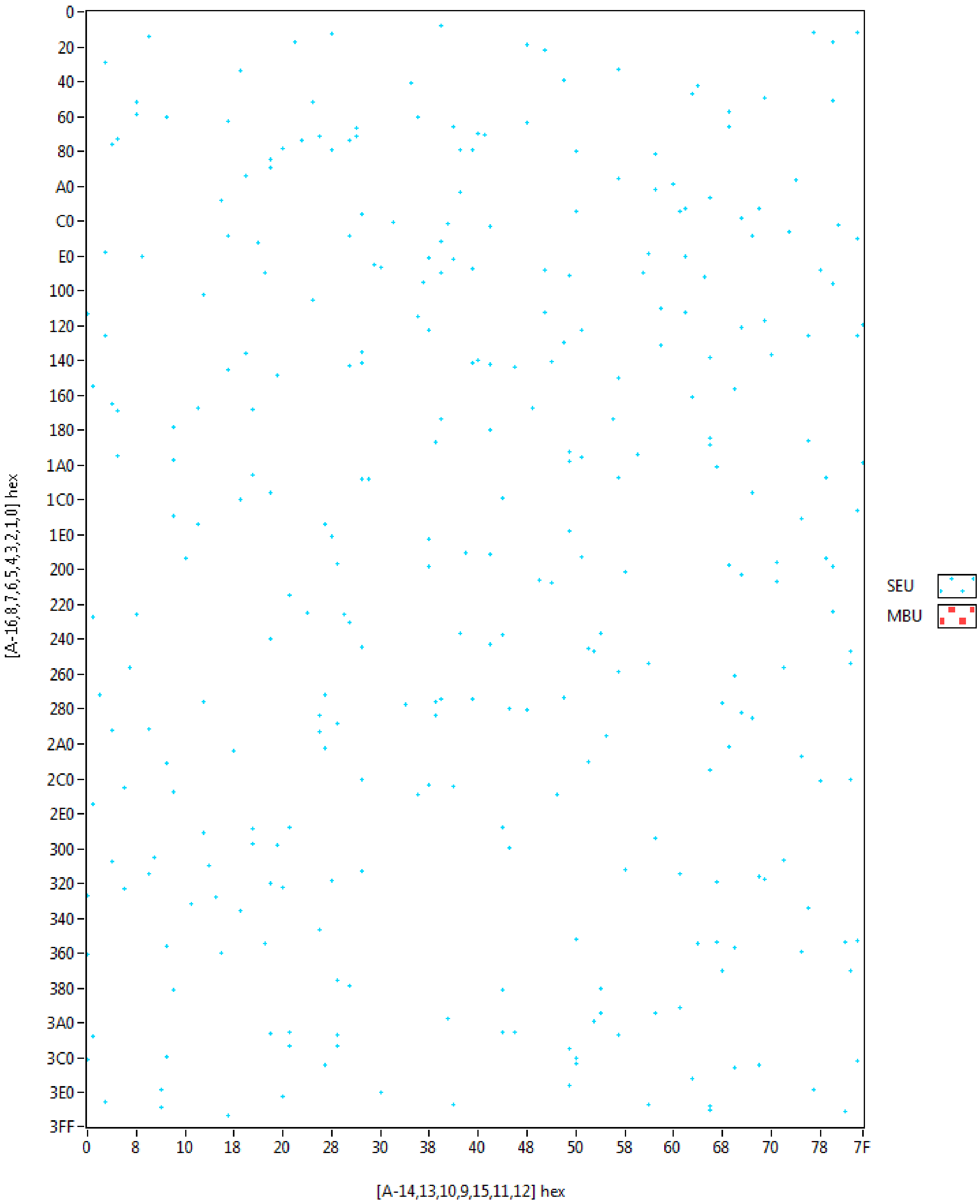
SEUs were observed on the M65609E down to the lowest proton test energy of 23 MeV and the lowest heavy ion test LET of 1.1 MeV.cm^2.mg^{-1}.
MBUs were observed on the M65609E at the maximum tested proton energy of 230 MeV and for a minimum heavy ion LET of 10.2 MeV.cm^2.mg^{-1}.

APPENDIX

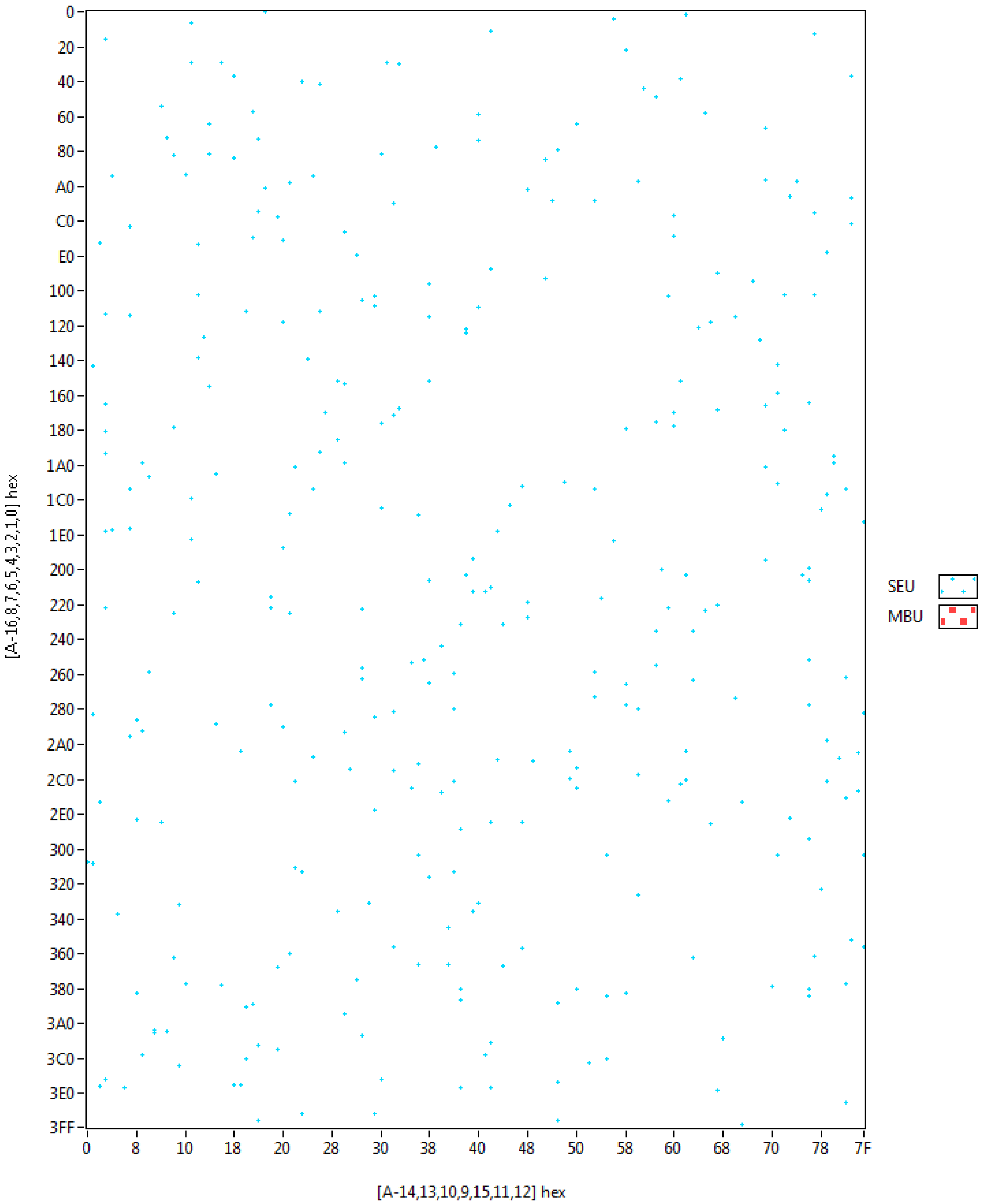
1. SEU vs MBU mapping – Proton test results



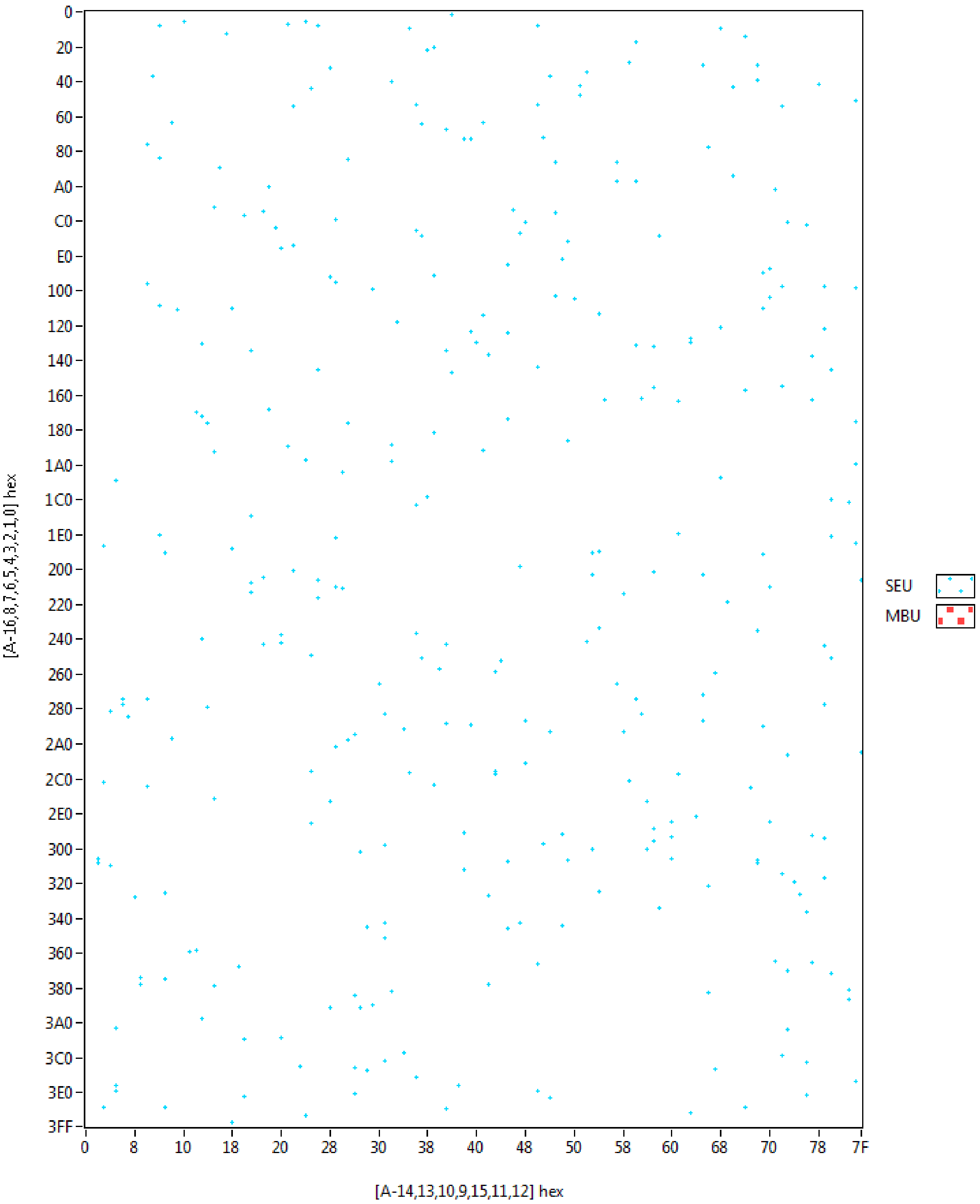
Run N°1 - part 79- 230MeV Proton beam.



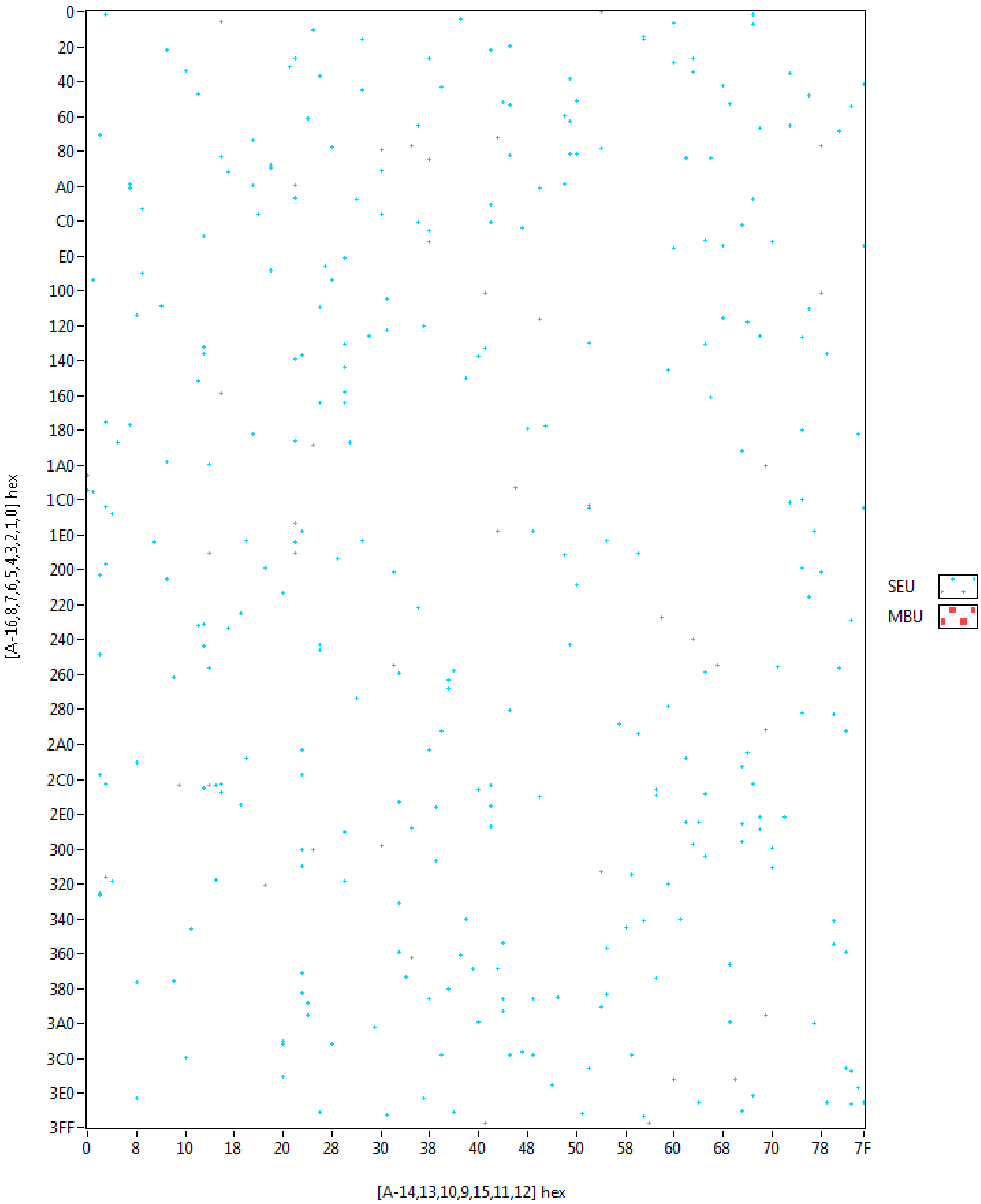
Run N°3 - part 79 - 200MeV Proton beam.



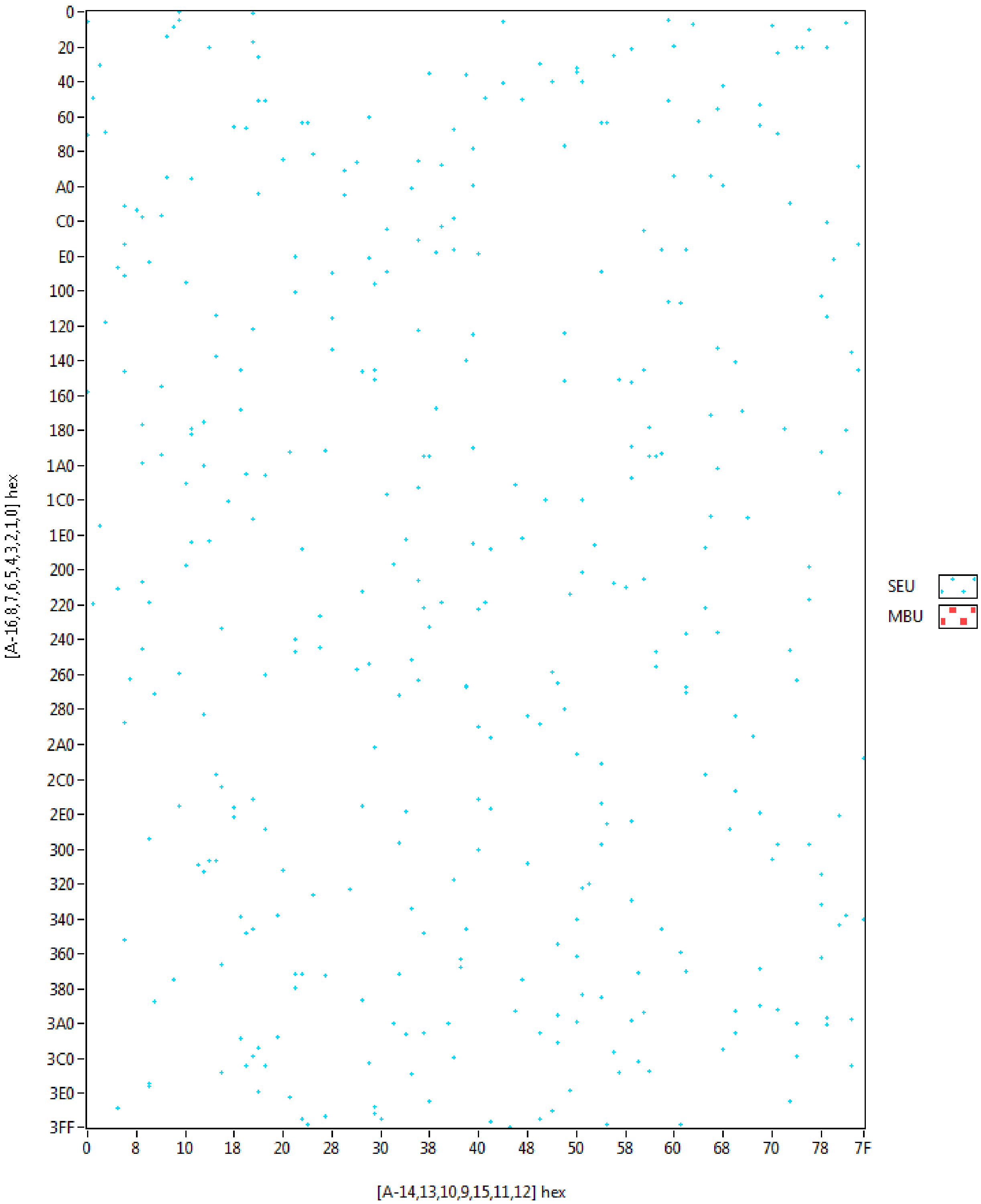
Run N°4 - part 79 - 151MeV Proton beam.



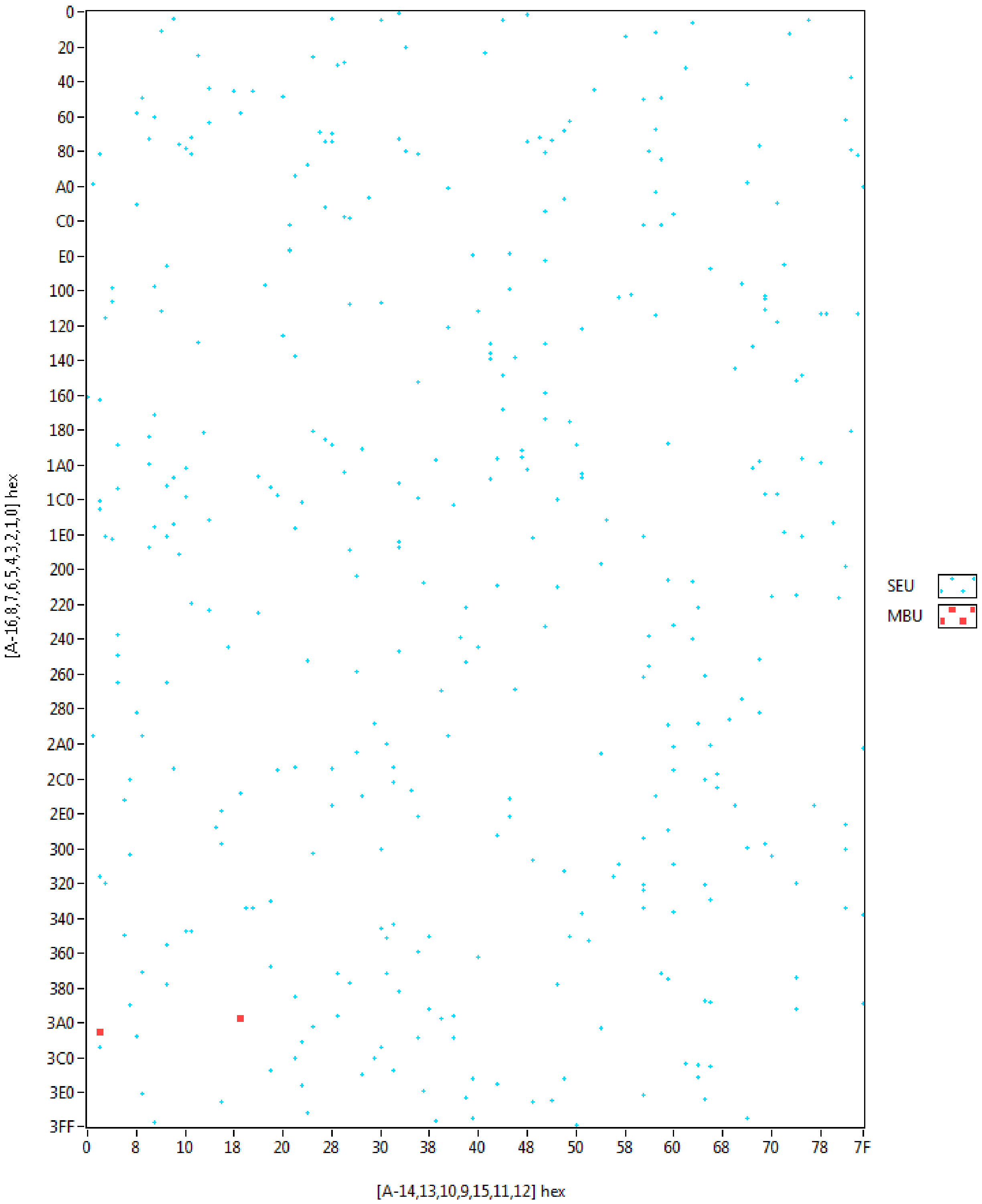
Run N°5 - part 79 - 101MeV Proton beam.



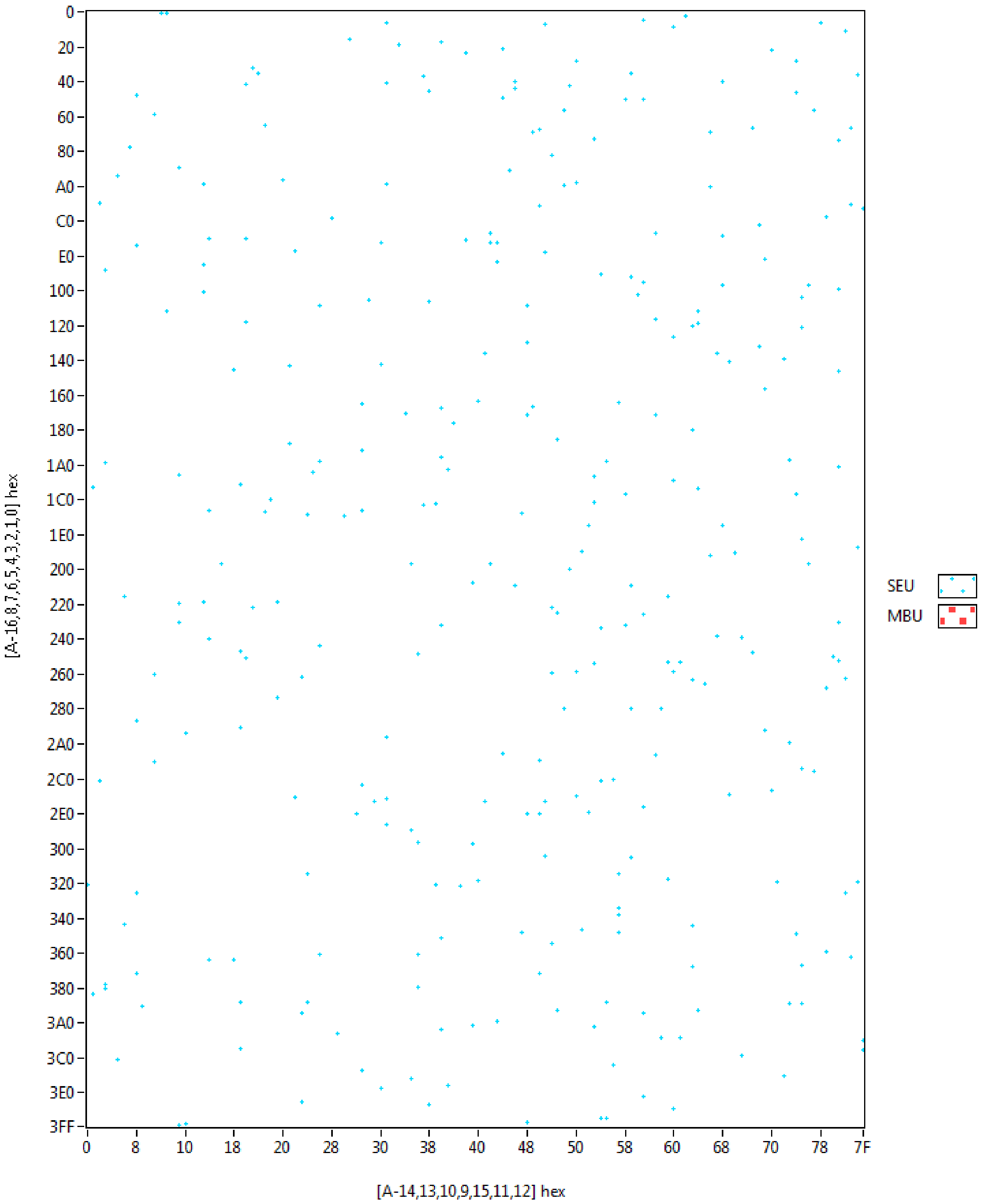
Run N°6 - part 79 - 75MeV Proton beam.



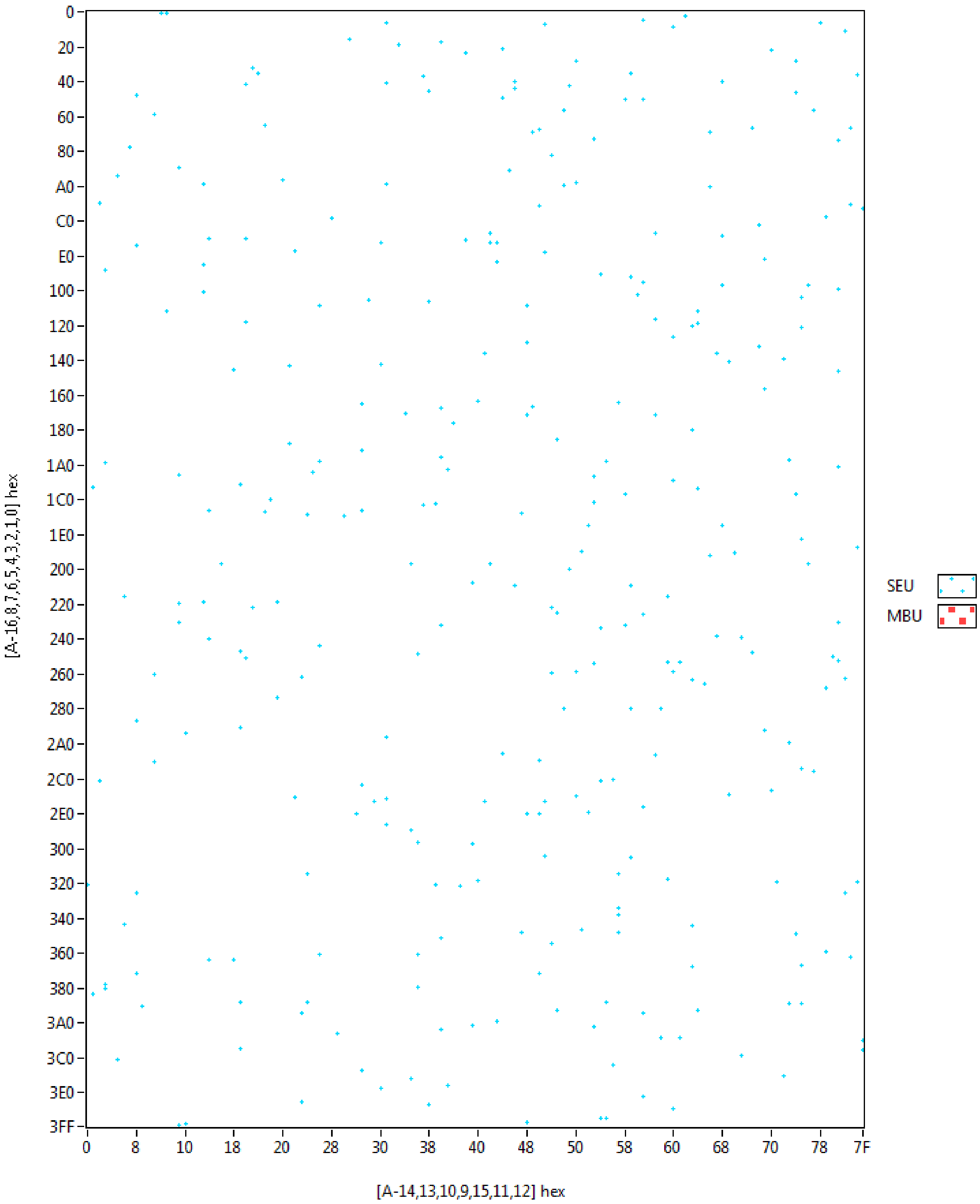
Run N°7 - part 79 - 230MeV Proton beam.



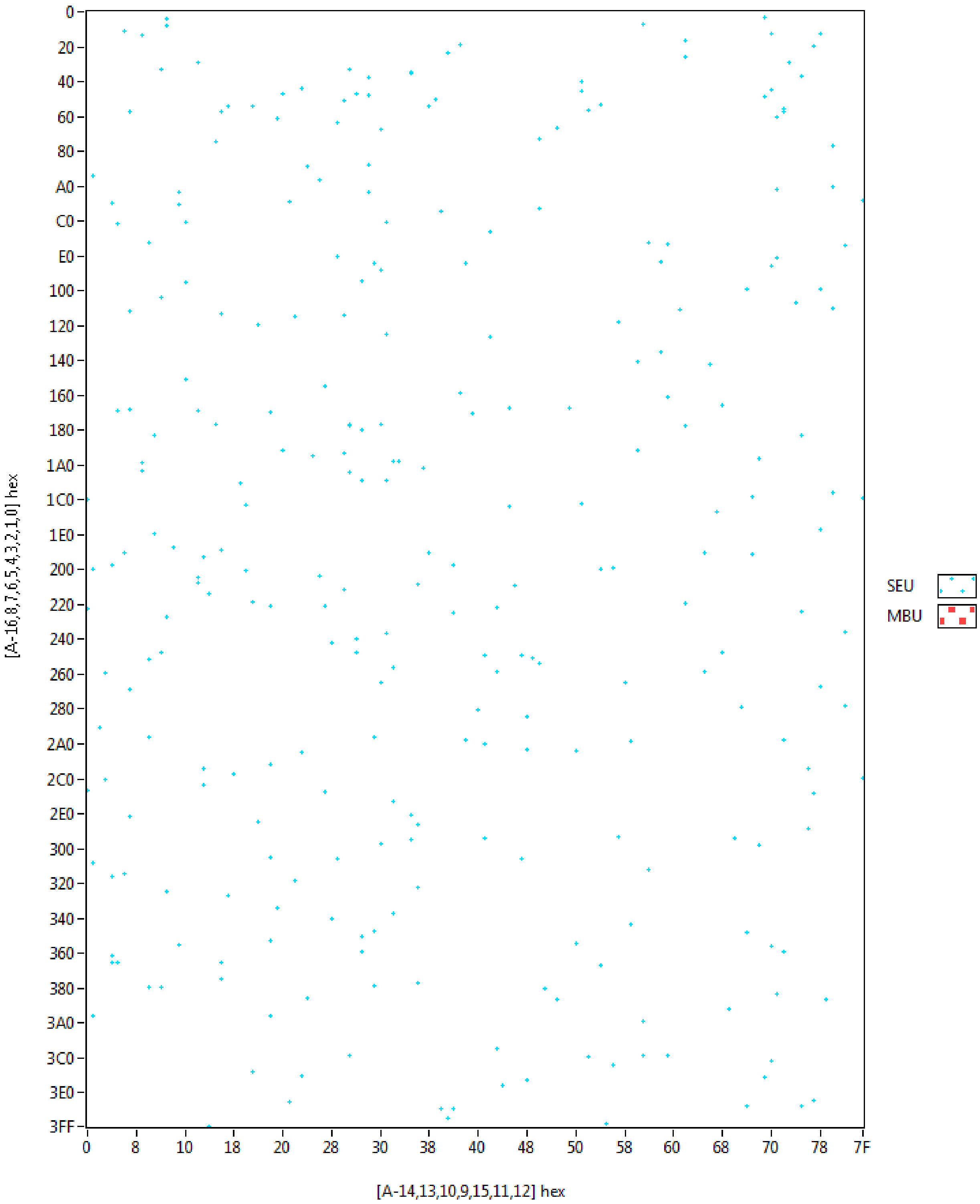
Run N°8 - part 78 - 230MeV Proton beam.



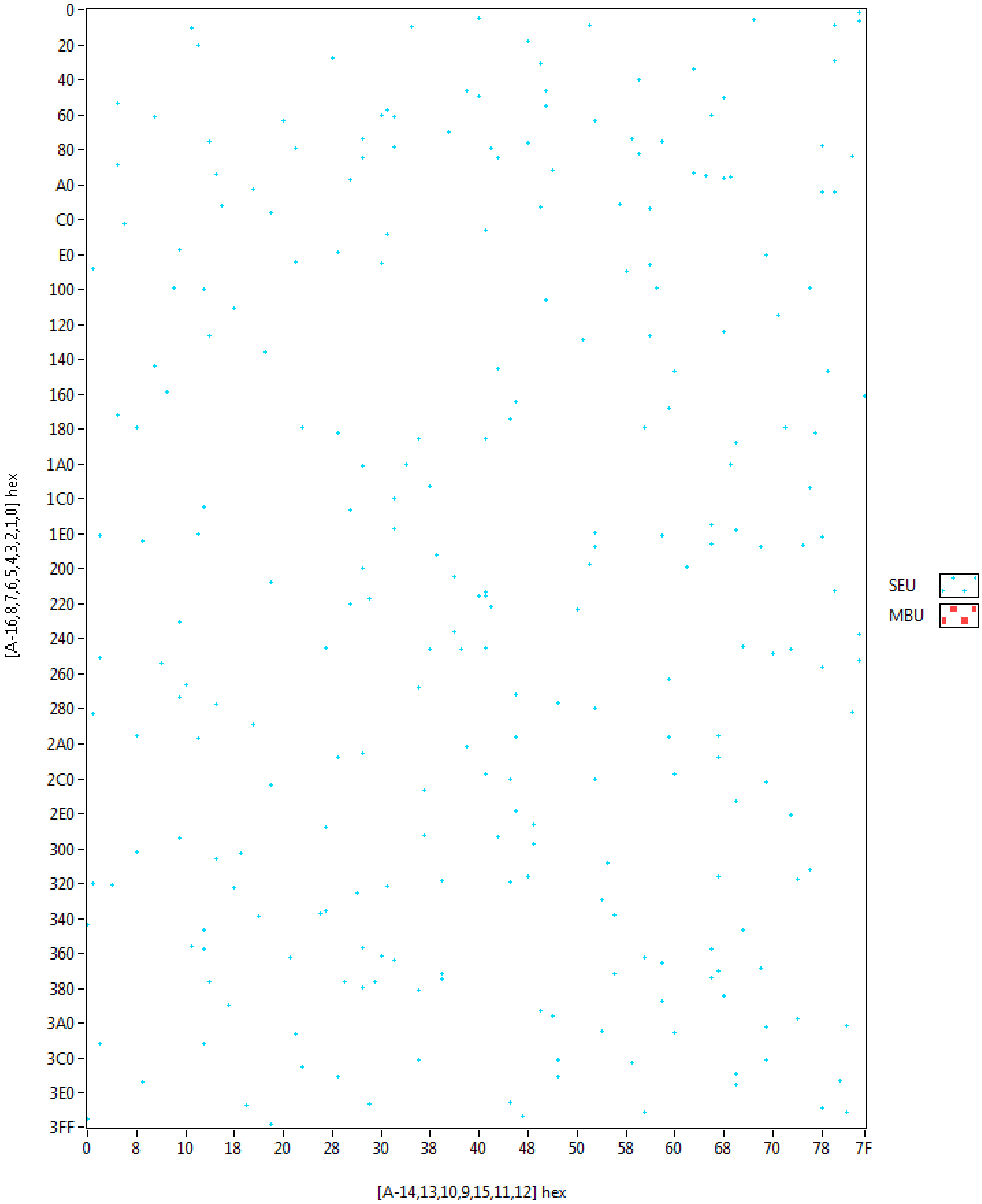
Run N°9 - part 78 - 151MeV Proton beam.



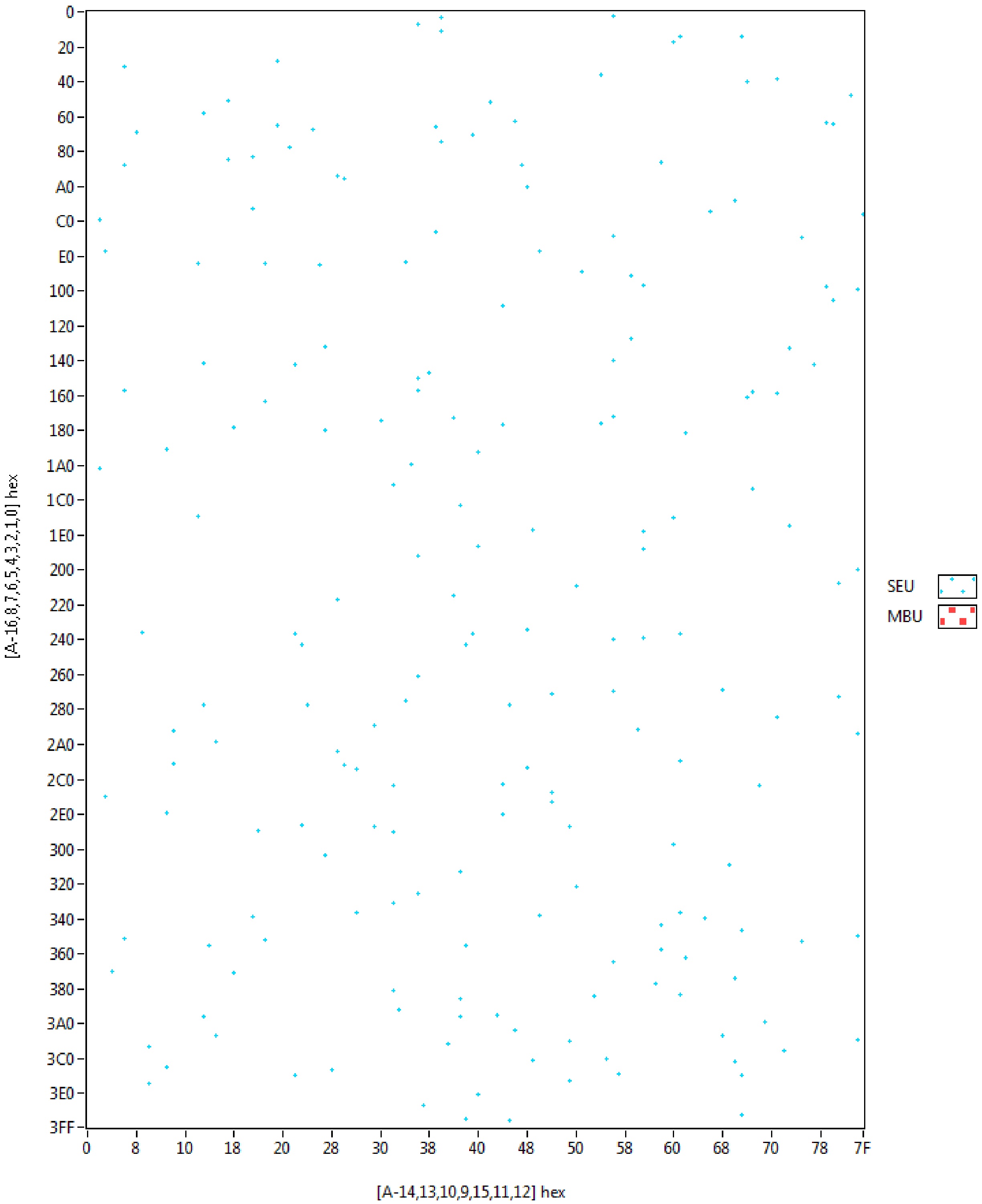
Run N°9 - part 78 - 151MeV Proton beam.



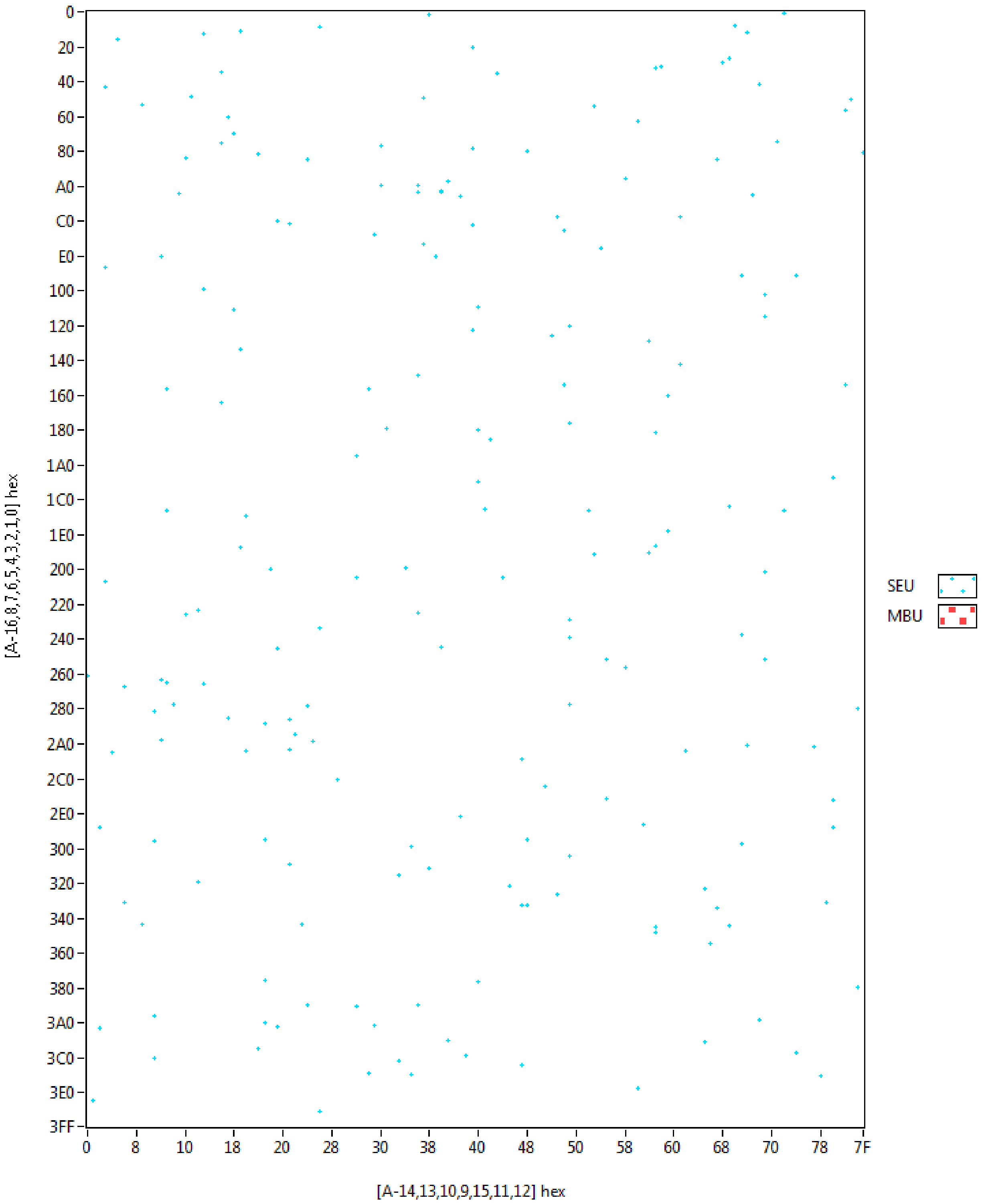
Run N°10 - part 78 - 75MeV Proton beam.



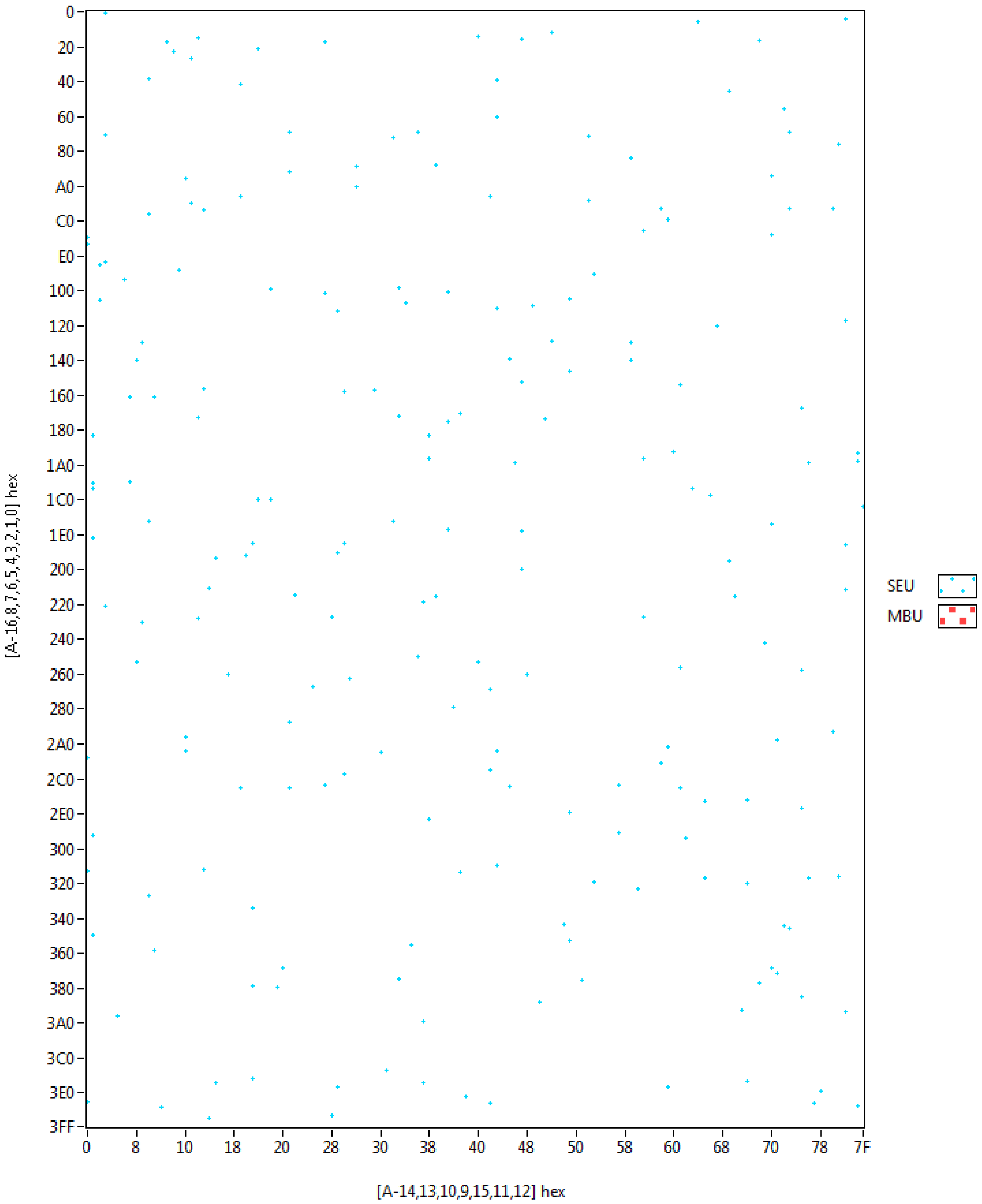
Run N°22 - part 72 - 75MeV Proton beam.



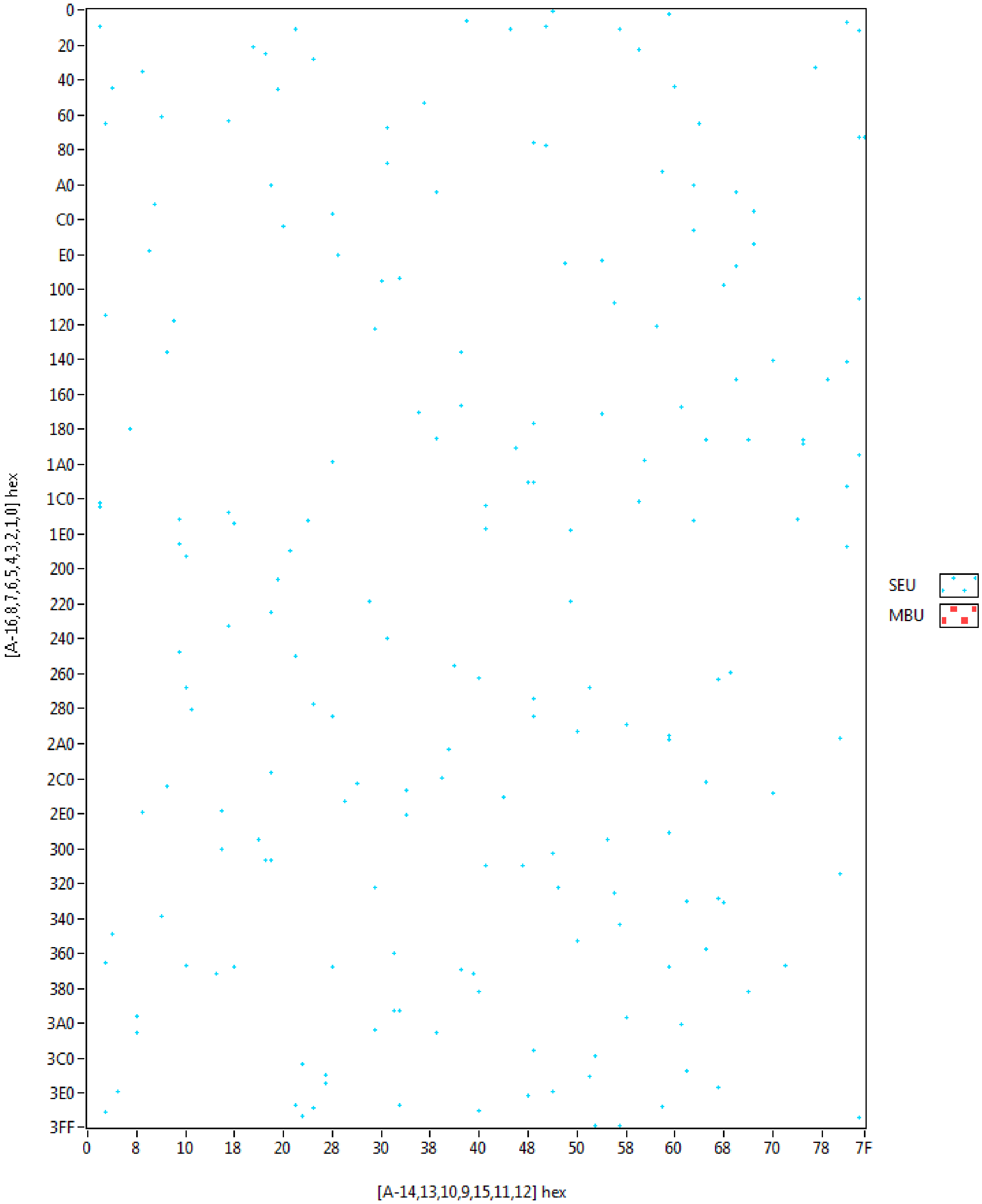
Run N°23 - part 72 - 39MeV Proton beam.



Run N°24 - part 72 - 23MeV Proton beam.

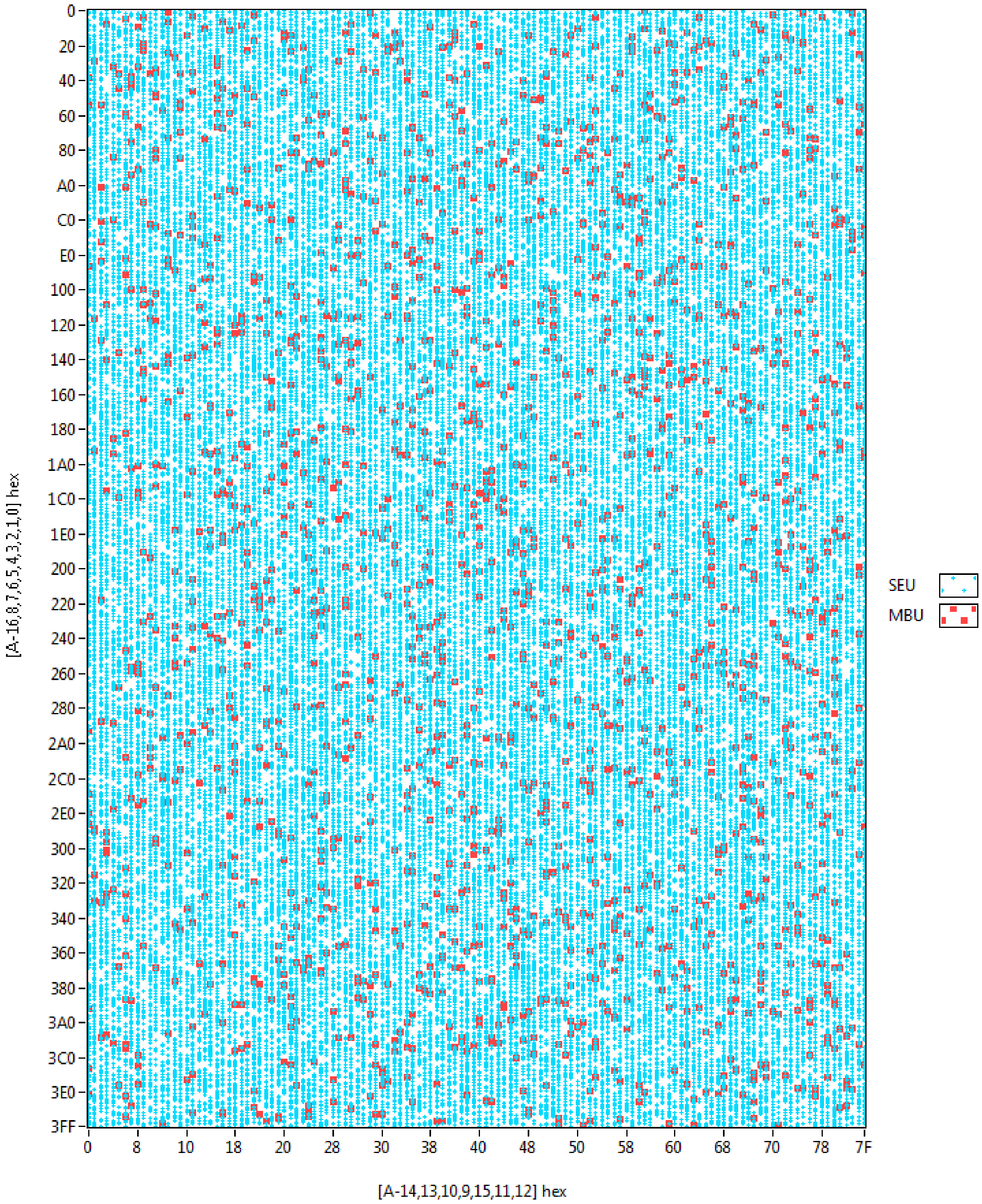


Run N°25 - part 71 - 39MeV Proton beam.

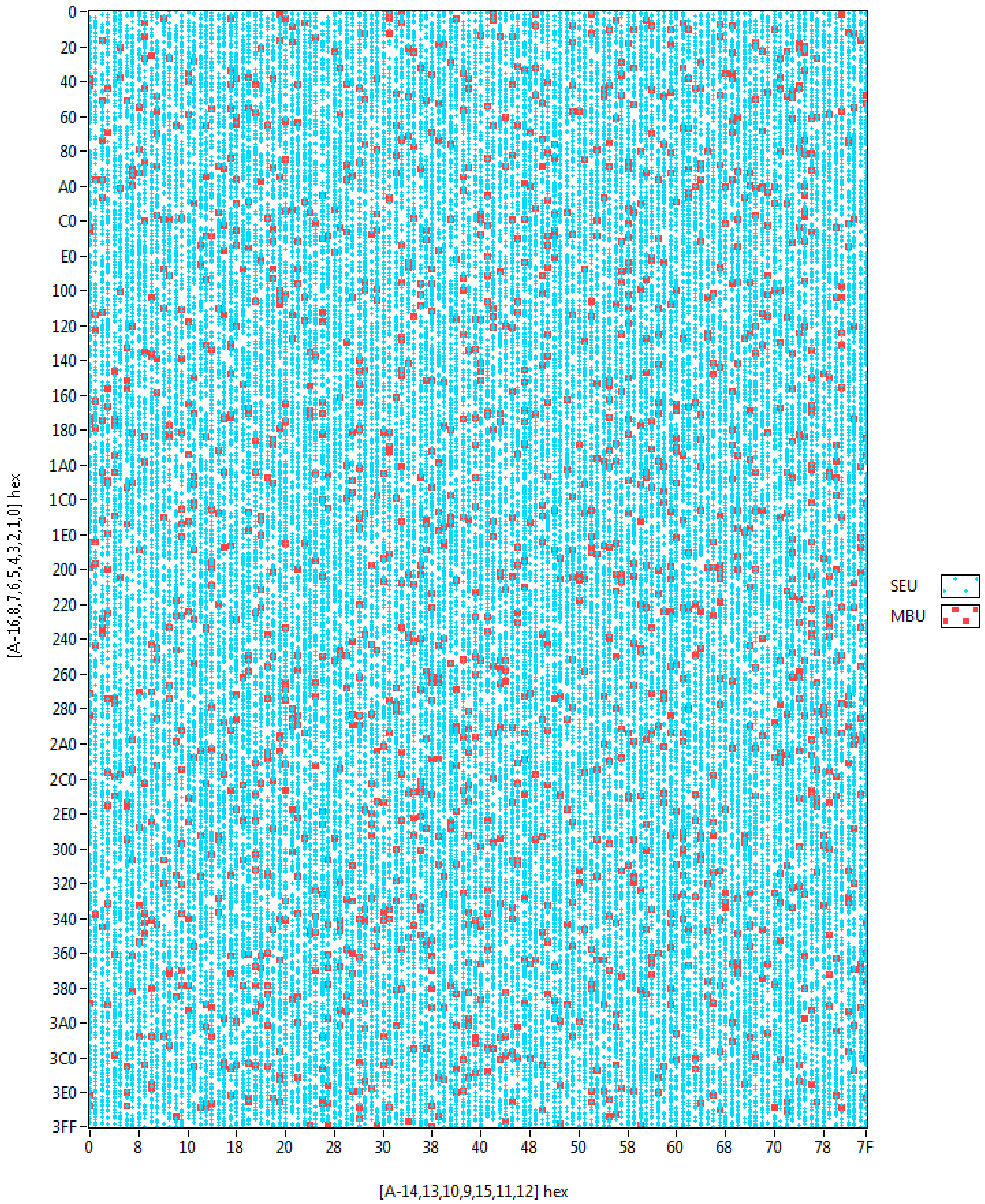


Run N°26 - part 71 - 23MeV Proton beam.

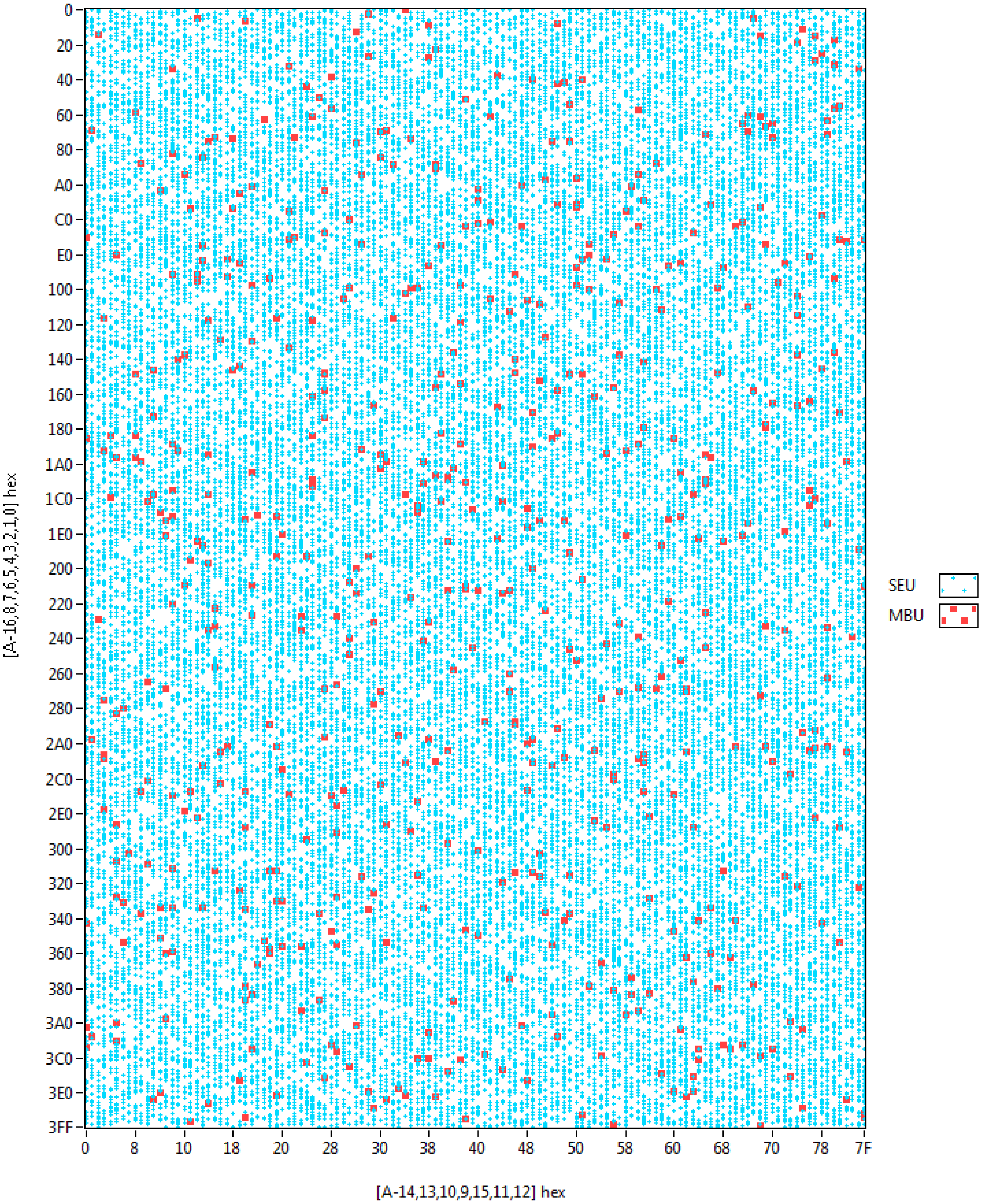
2. SEU vs MBU mapping – Heavy ion test results



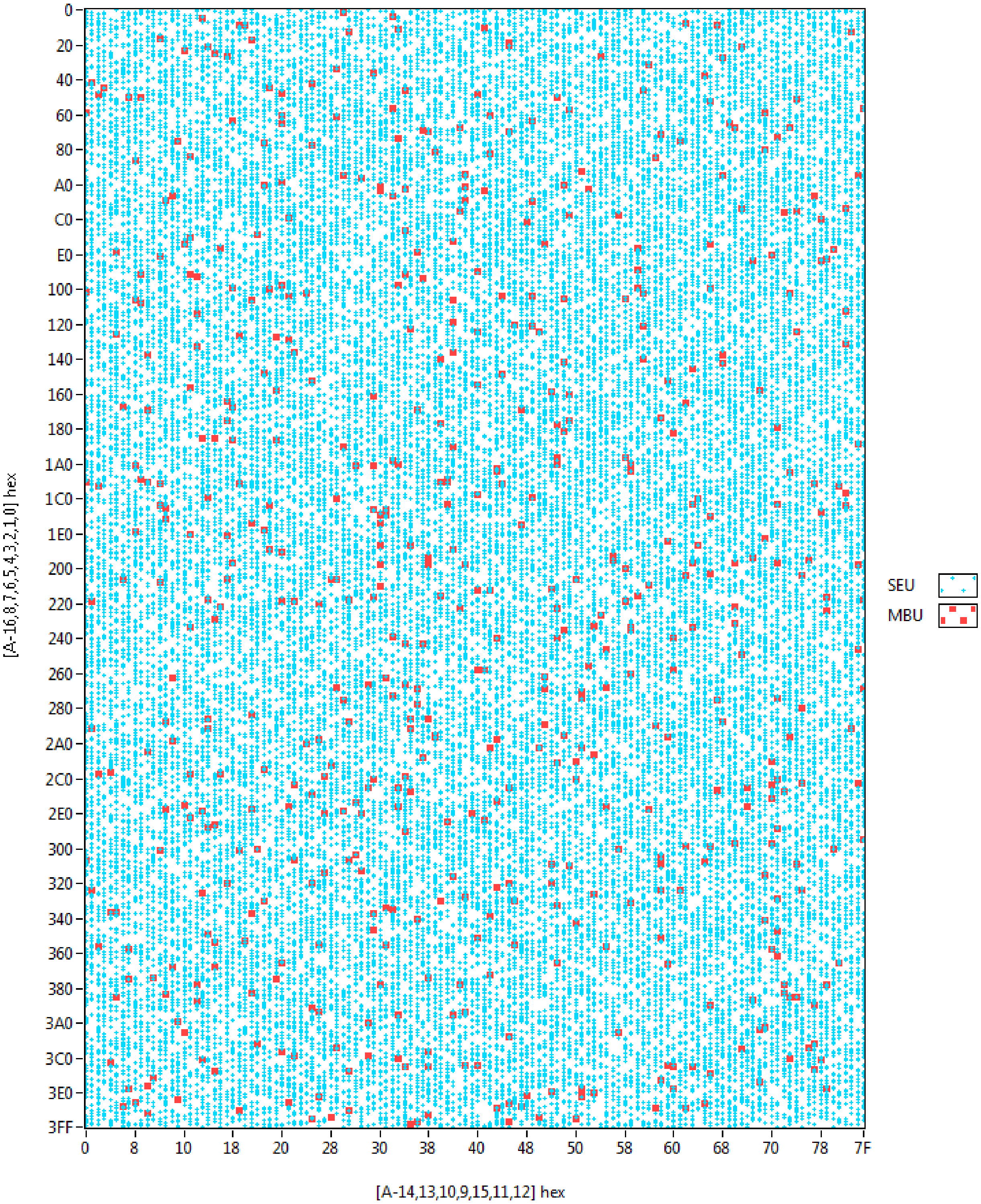
Run N°8 - part 70 - LET 67.7MeV Heavy ion beam.



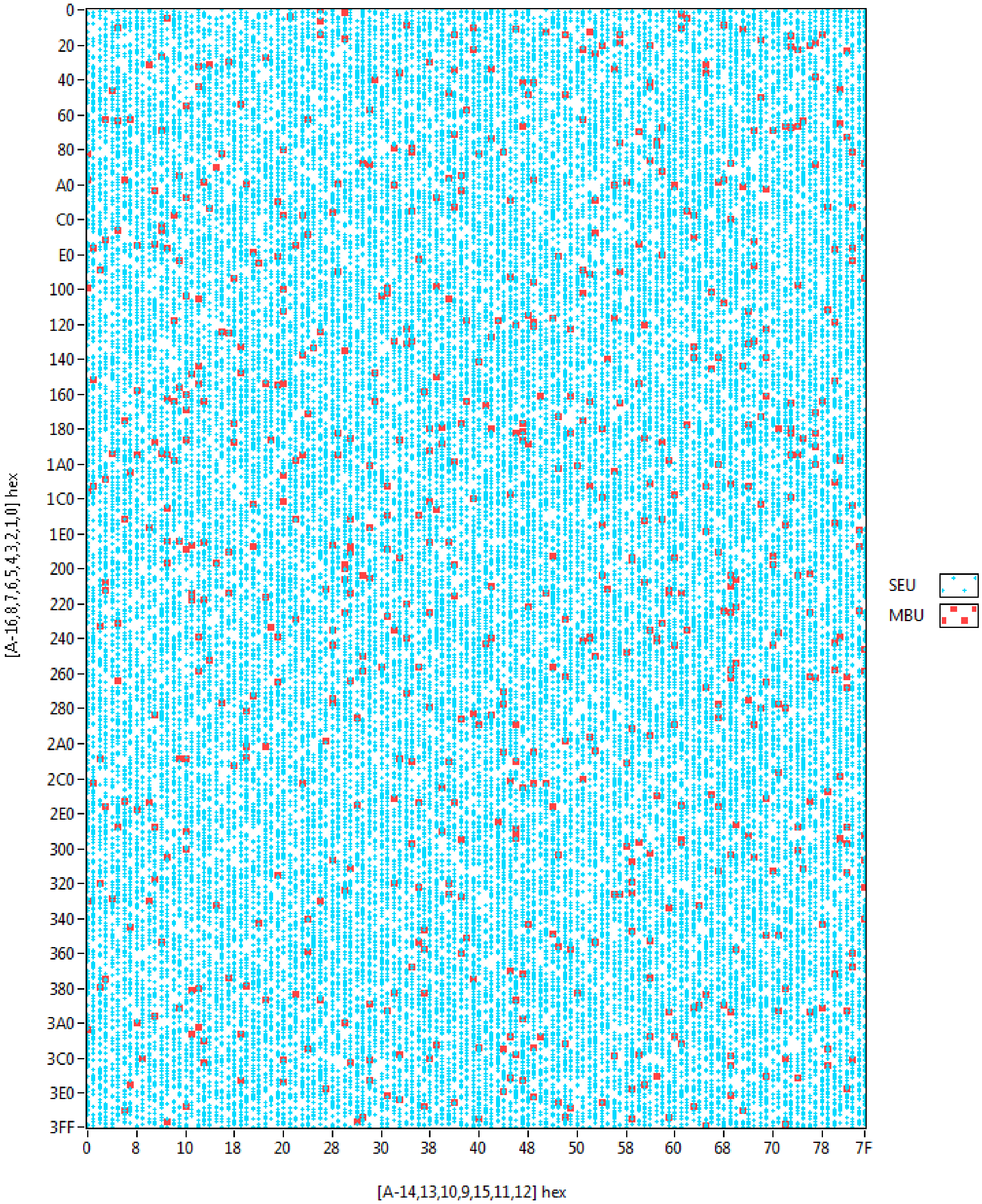
Run N°9 - part 74 - LET 67.7MeV Heavy ion beam.



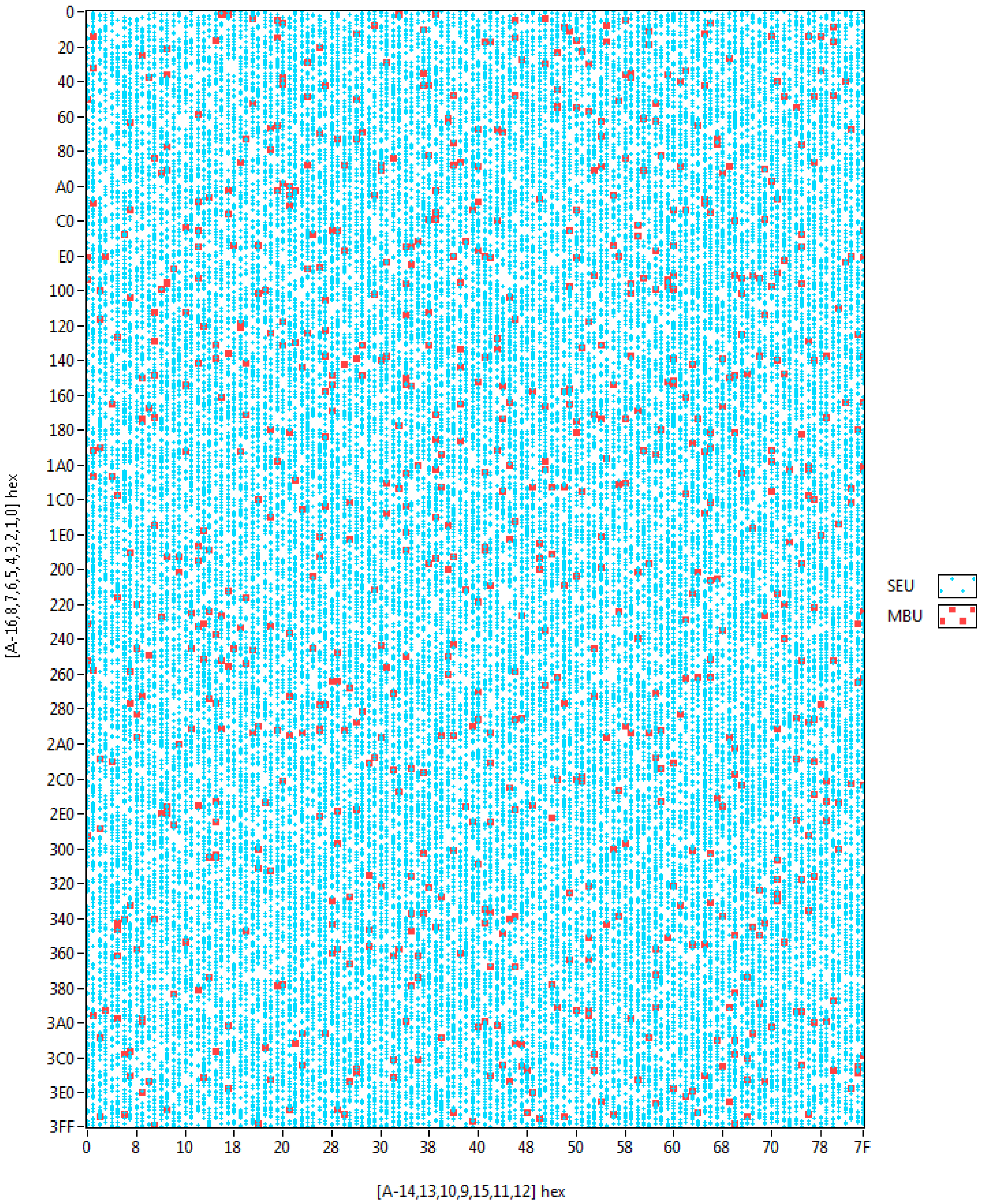
Run N°14 - part 70 - LET 32.6MeV Heavy ion beam.



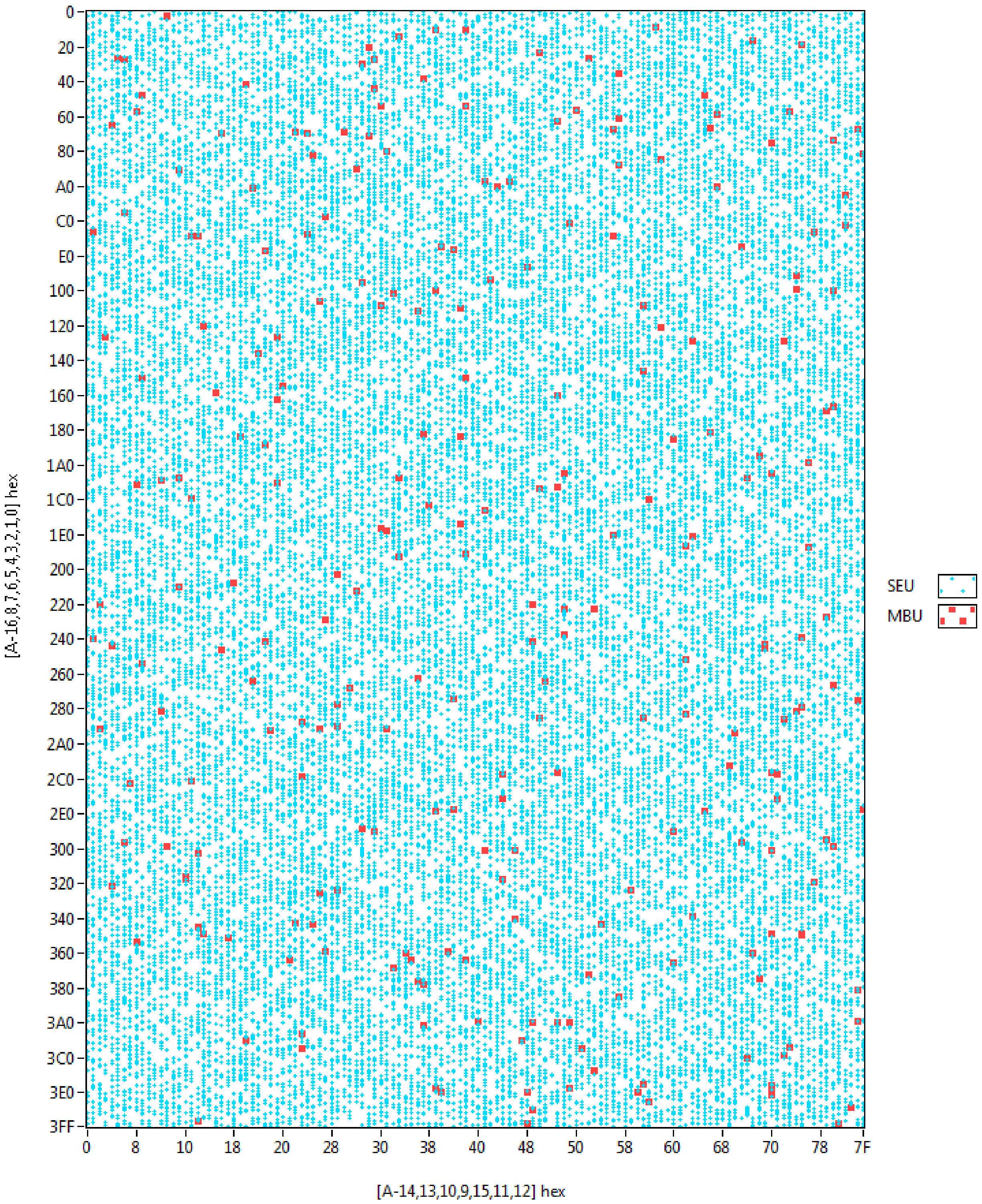
Run N°15 - part 74 - LET 32.6MeV Heavy ion beam.



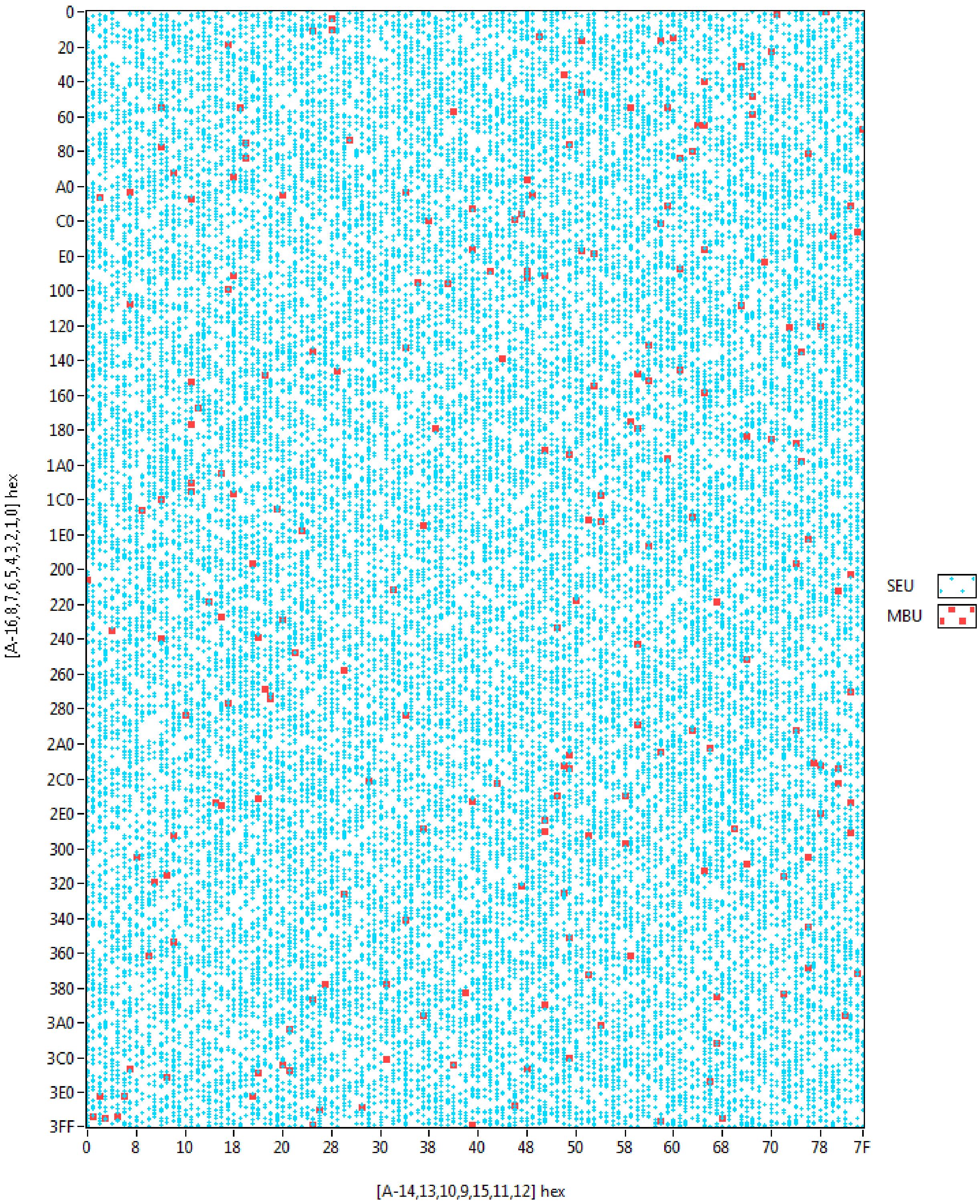
Run N°16 - part 74 - LET 46.1MeV Heavy ion beam.



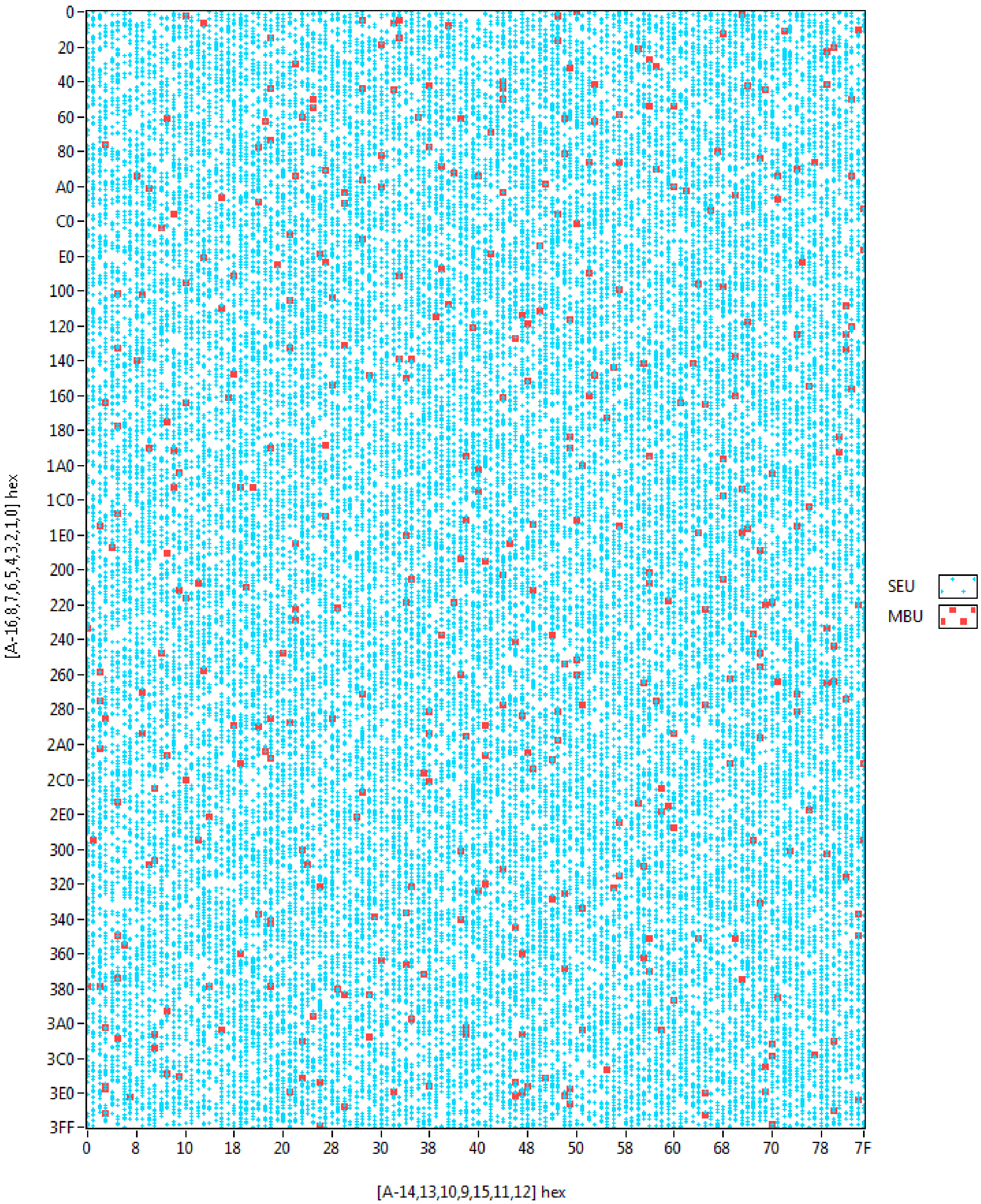
Run N°17 - part 70 - LET 46.1MeV Heavy ion beam.



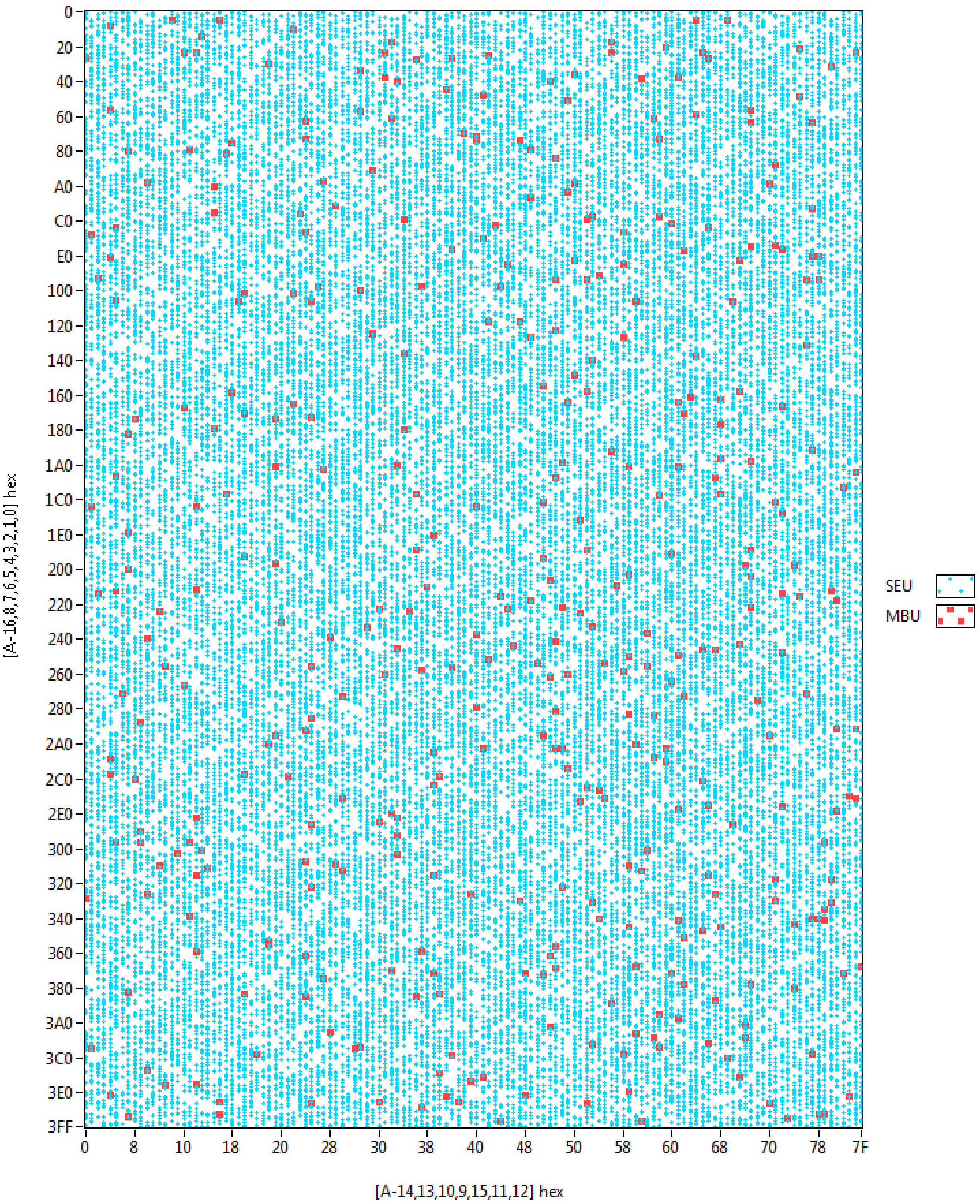
Run N°18 - part 70 - LET 20.4MeV Heavy ion beam.



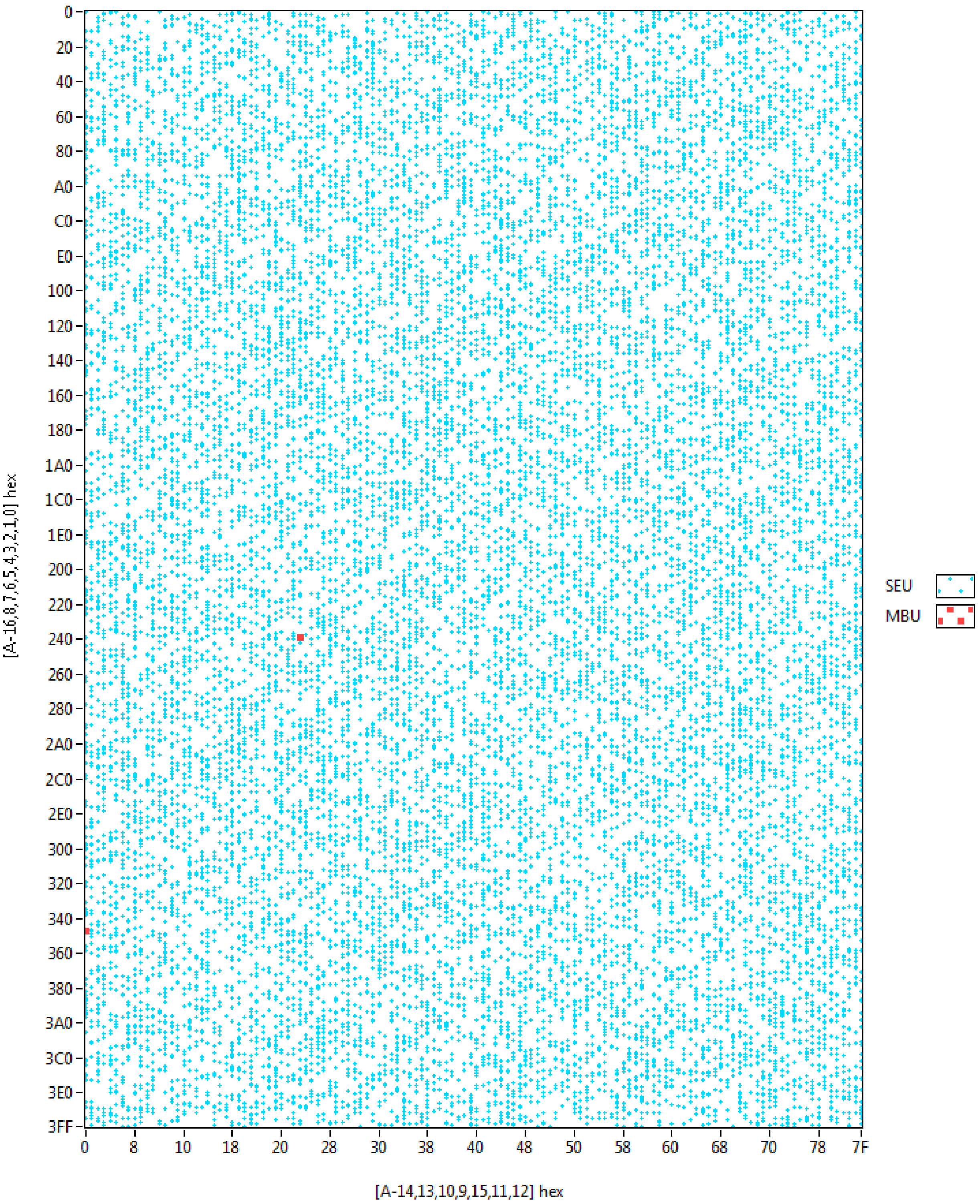
Run N°19 - part 74 - LET 20.4MeV Heavy ion beam.



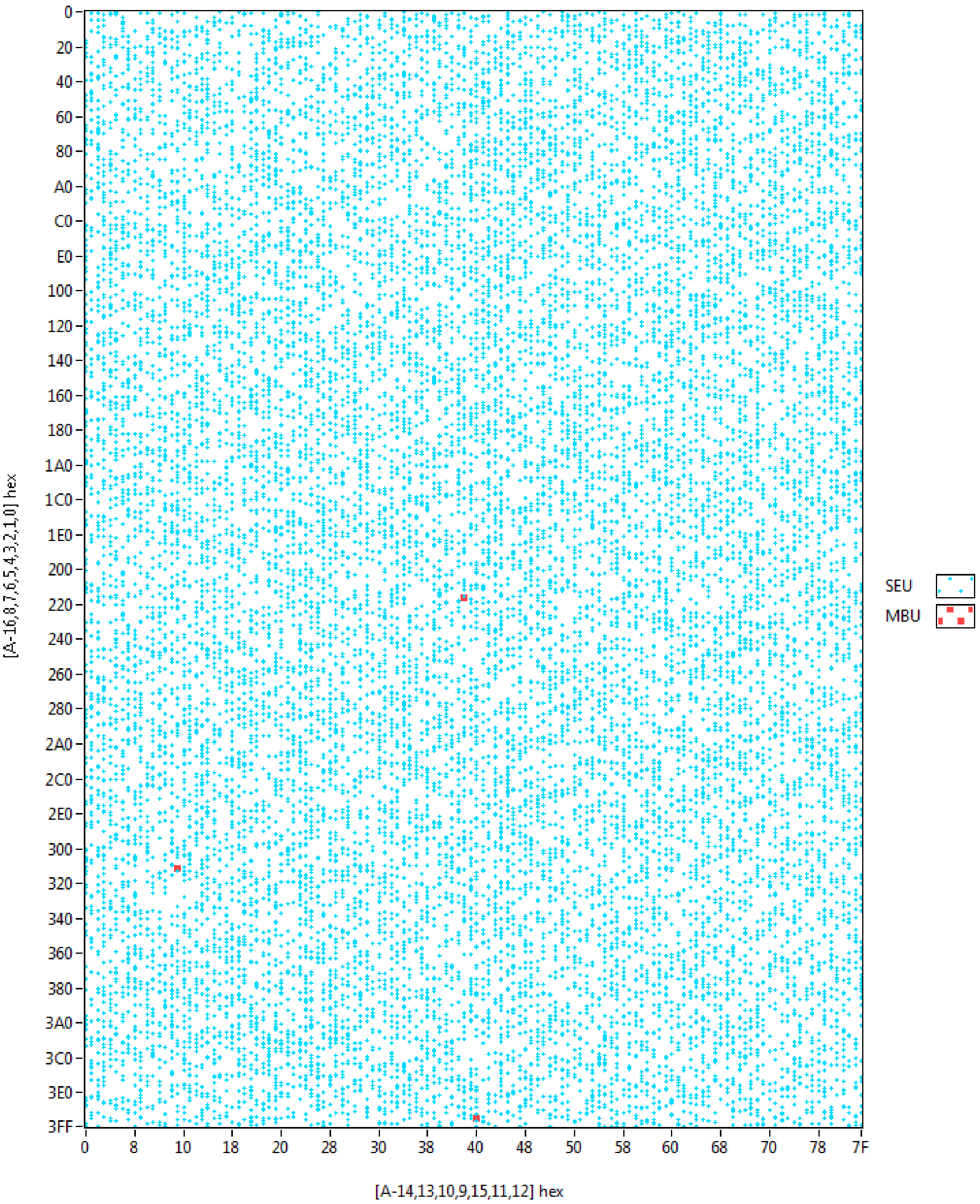
Run N°20 - part 74 - LET 28.85MeV Heavy ion beam.



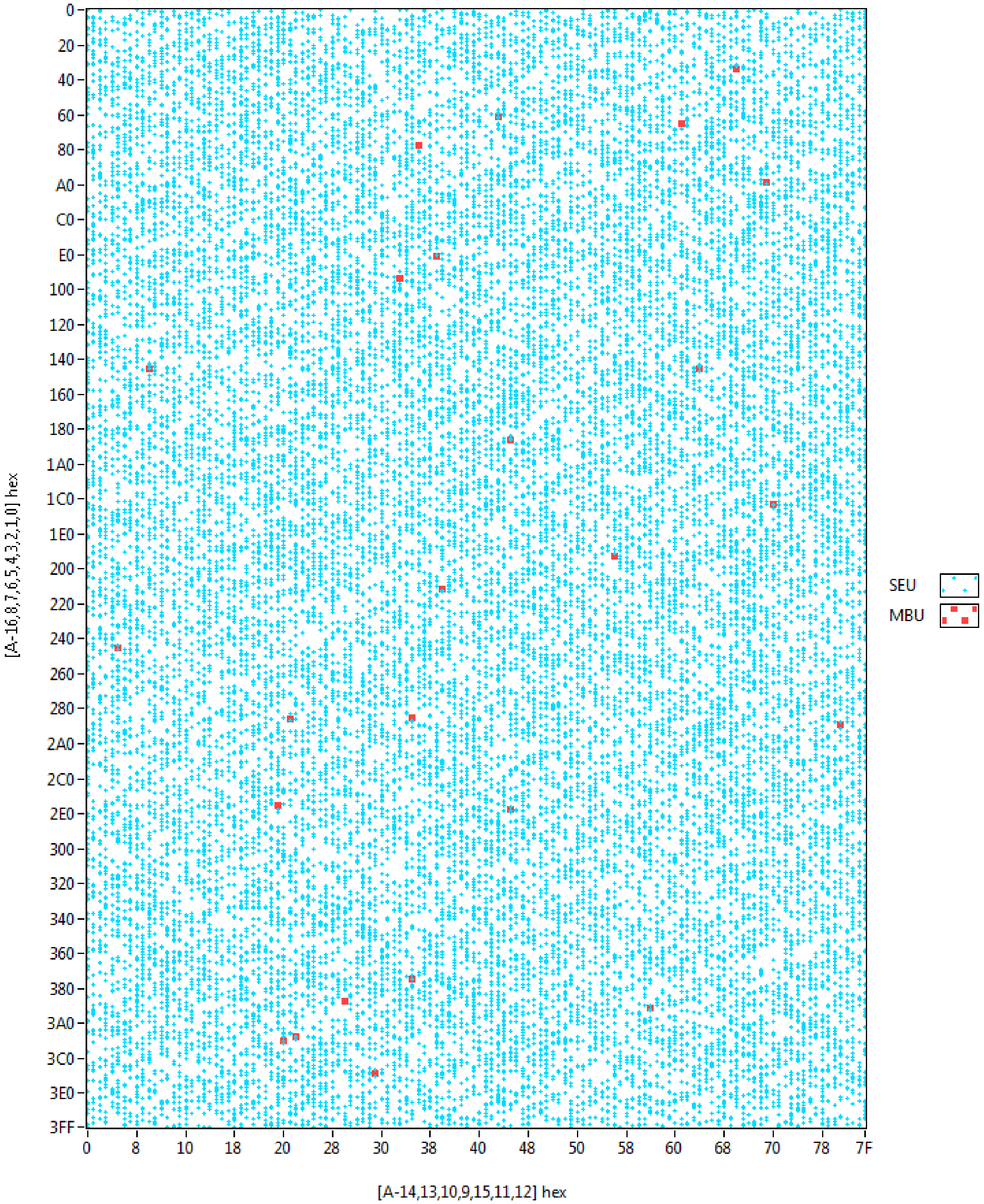
Run N°21 - part 70 - LET 28.85MeV Heavy ion beam.



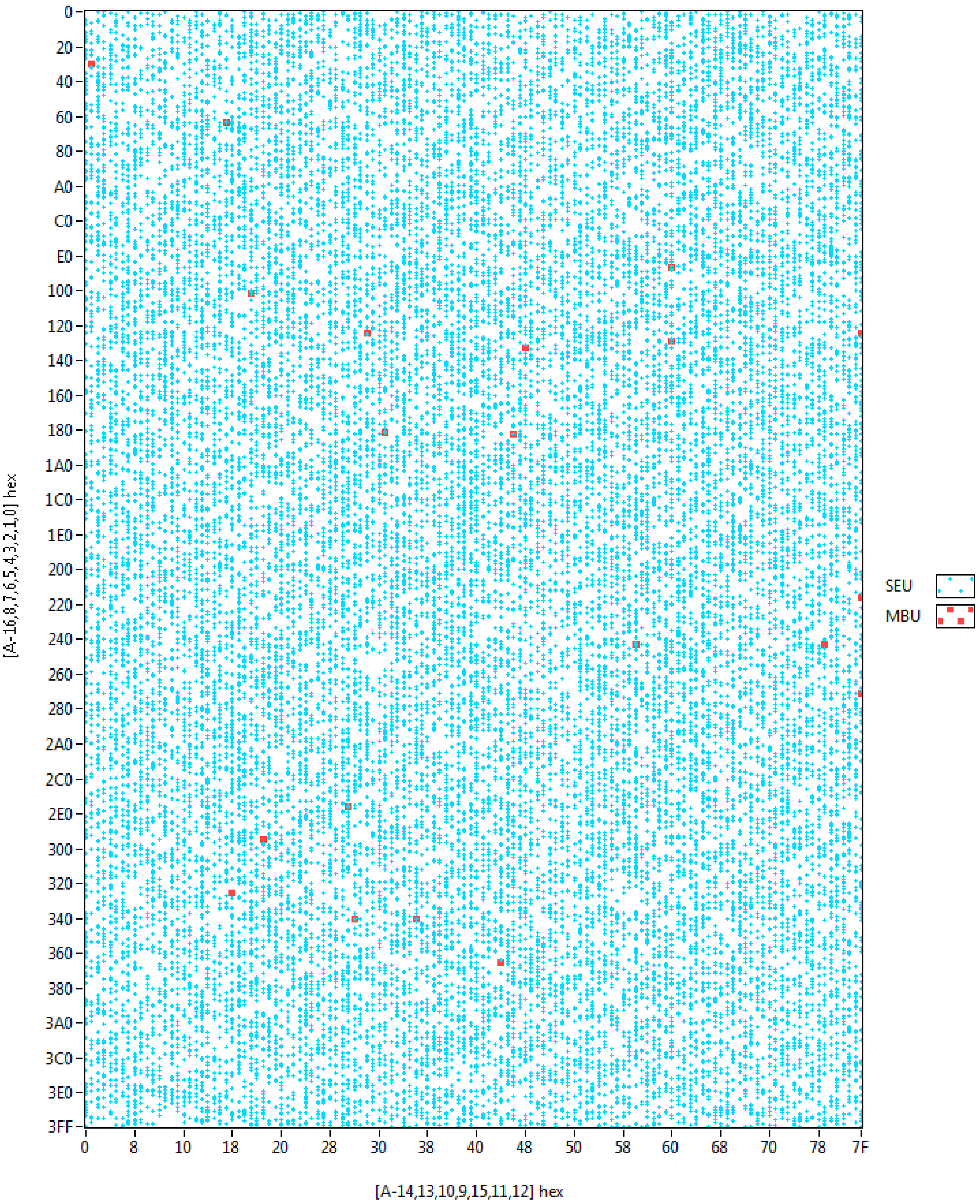
Run N°22 - part 70 - LET 10.2MeV Heavy ion beam.



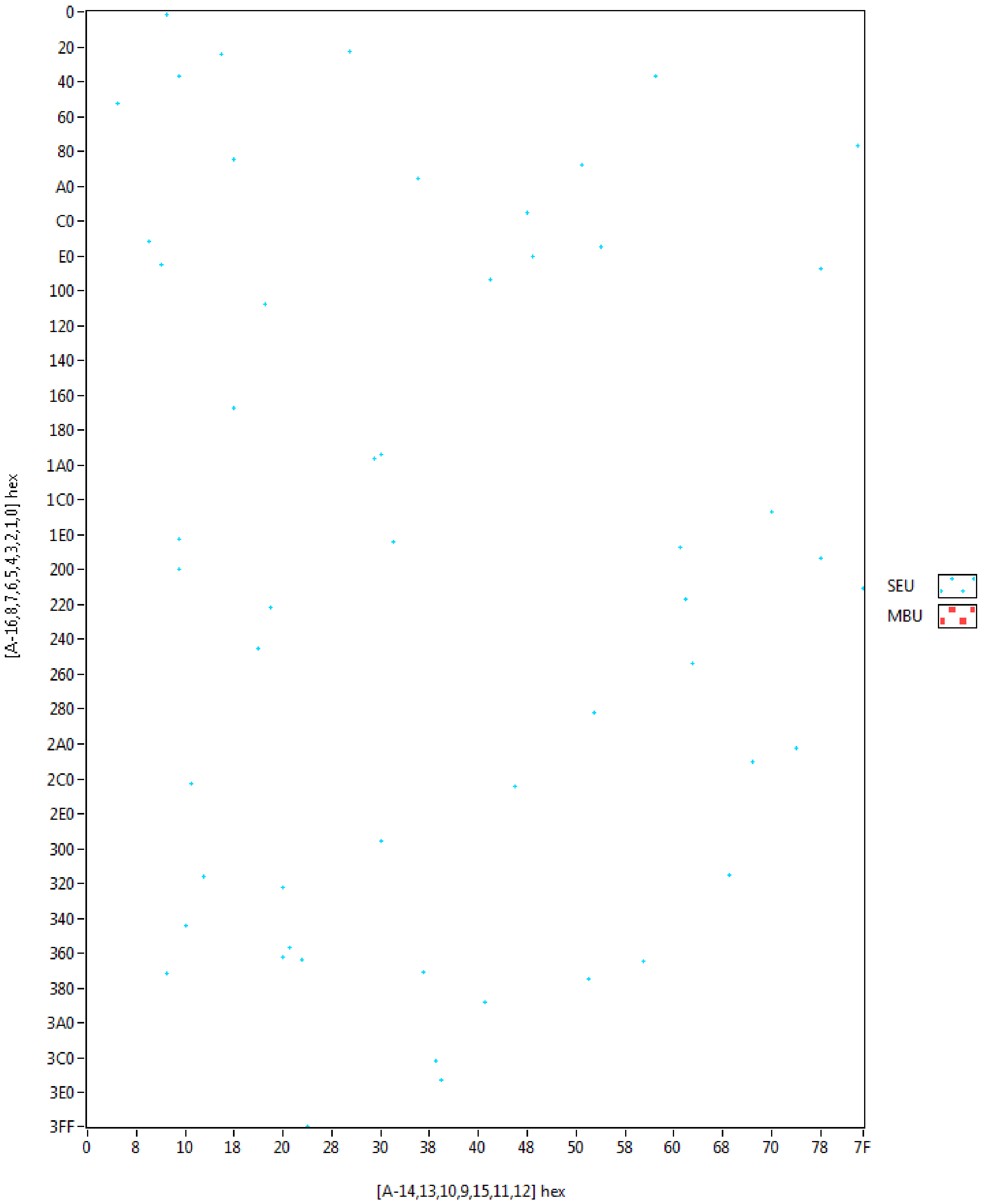
Run N°23 - part 74 - LET 10.2MeV Heavy ion beam.



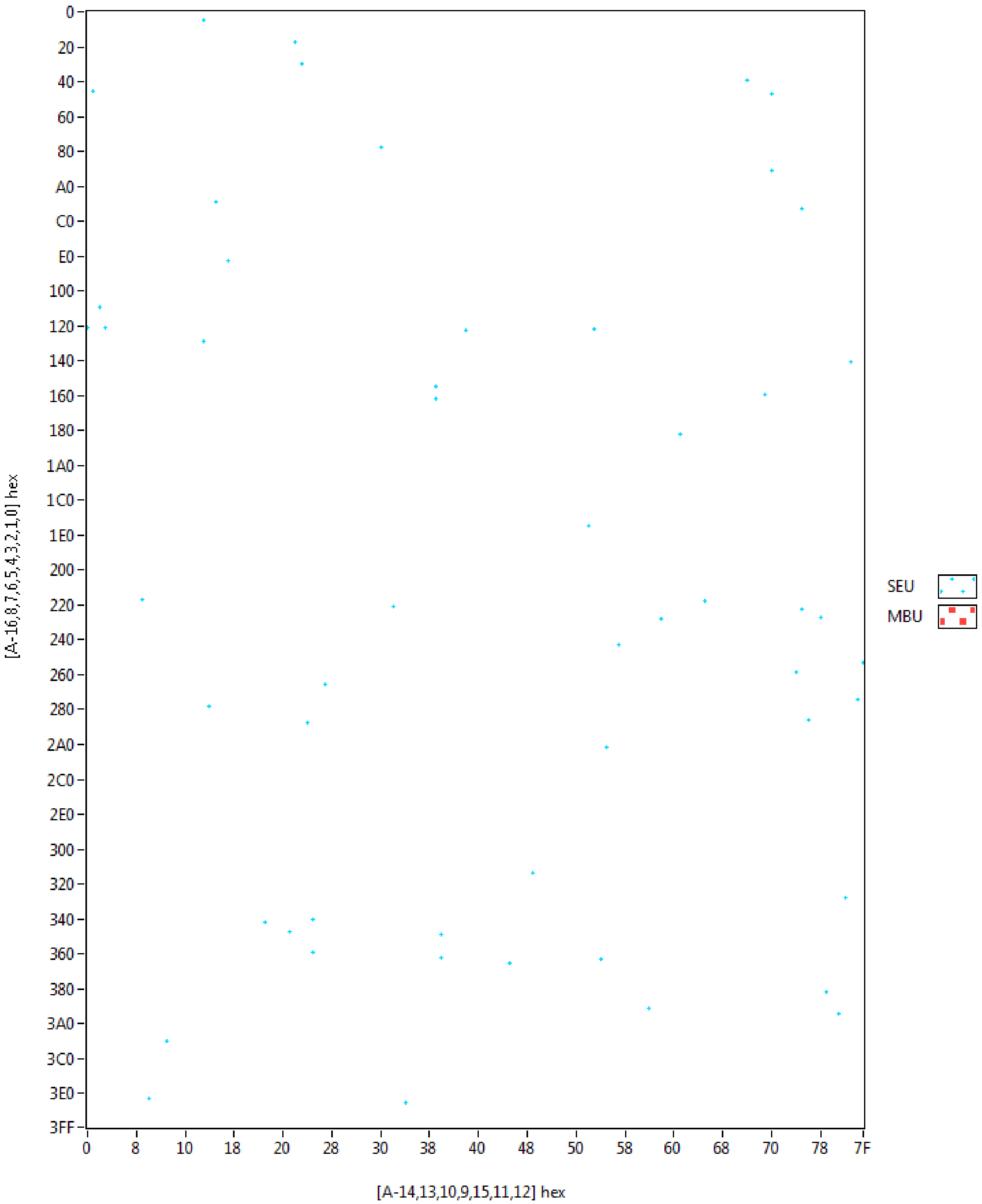
Run N°24 - part 74 - LET 14.42MeV Heavy ion beam.



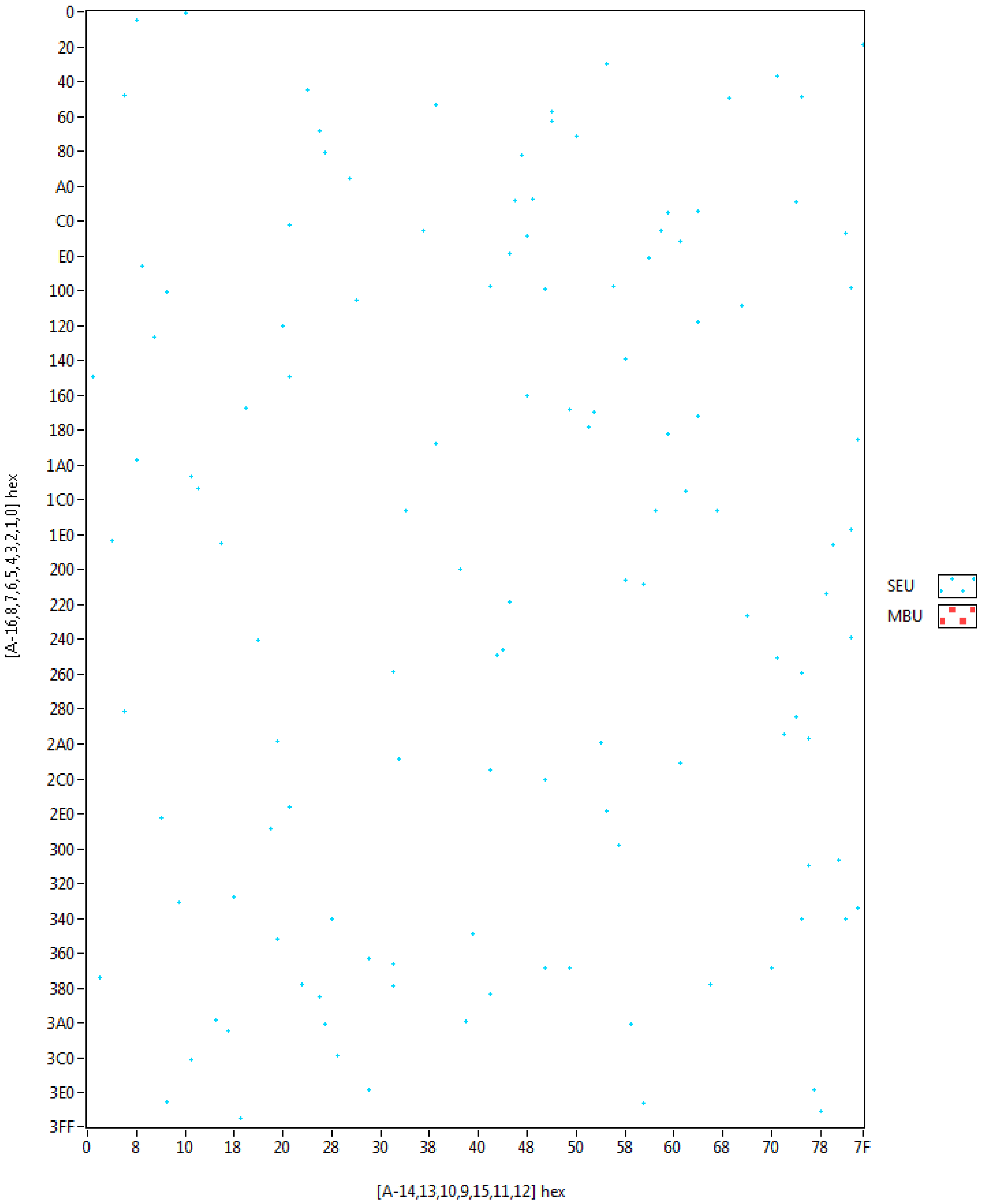
Run N°25 - part 70 - LET 14.42MeV Heavy ion beam.



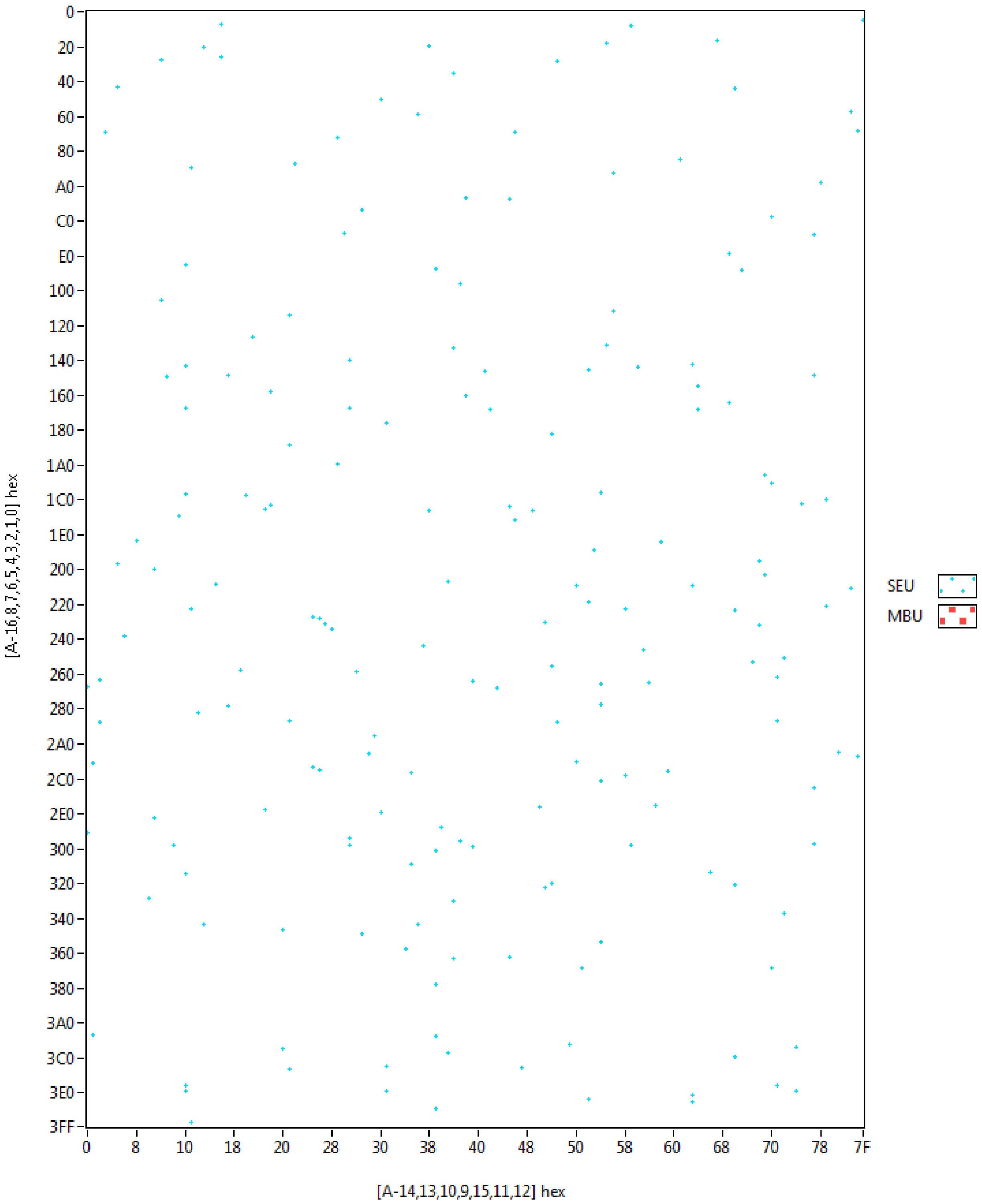
Run N°26 - part 70 - LET 3MeV Heavy ion beam.



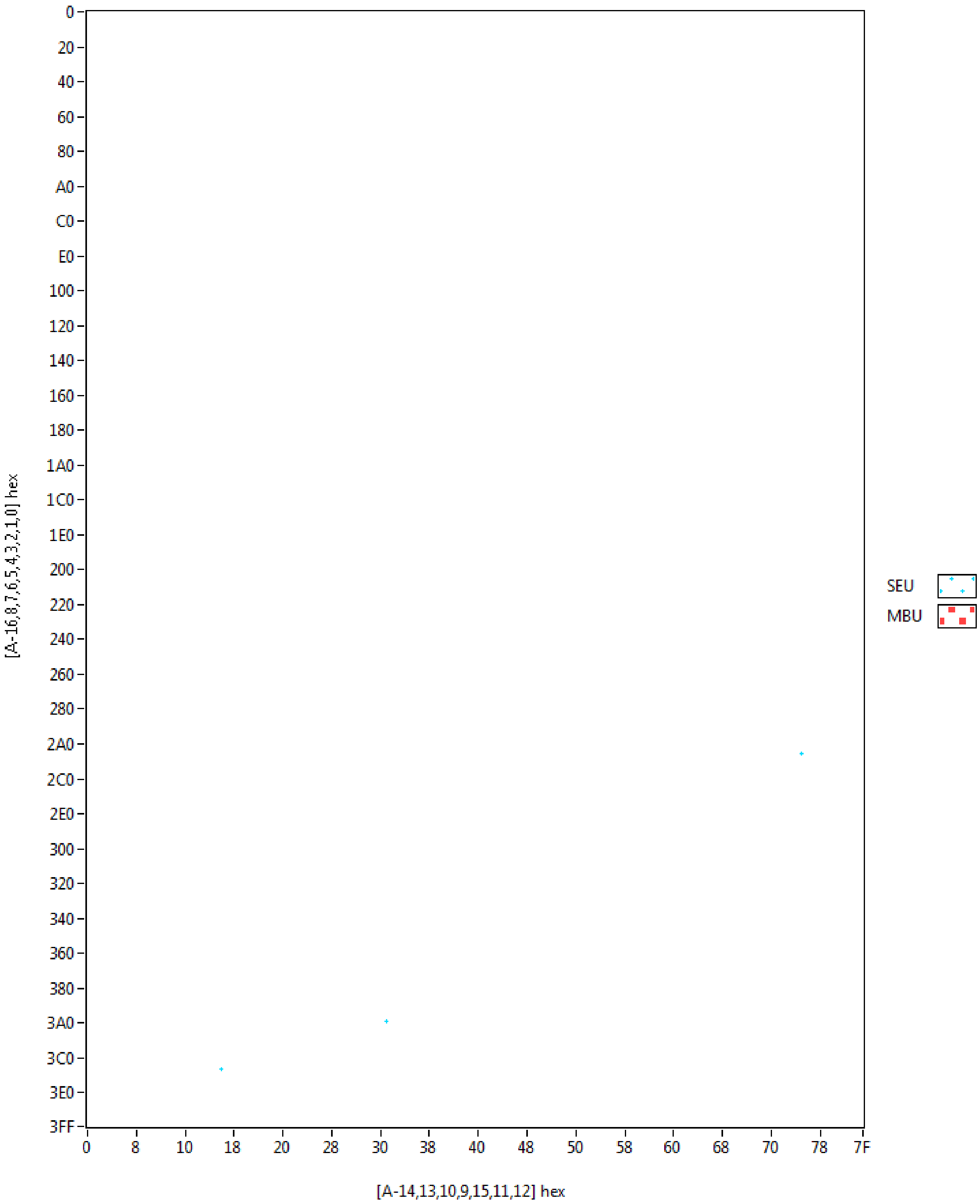
Run N°27 - part 74 - LET 3MeV Heavy ion beam.



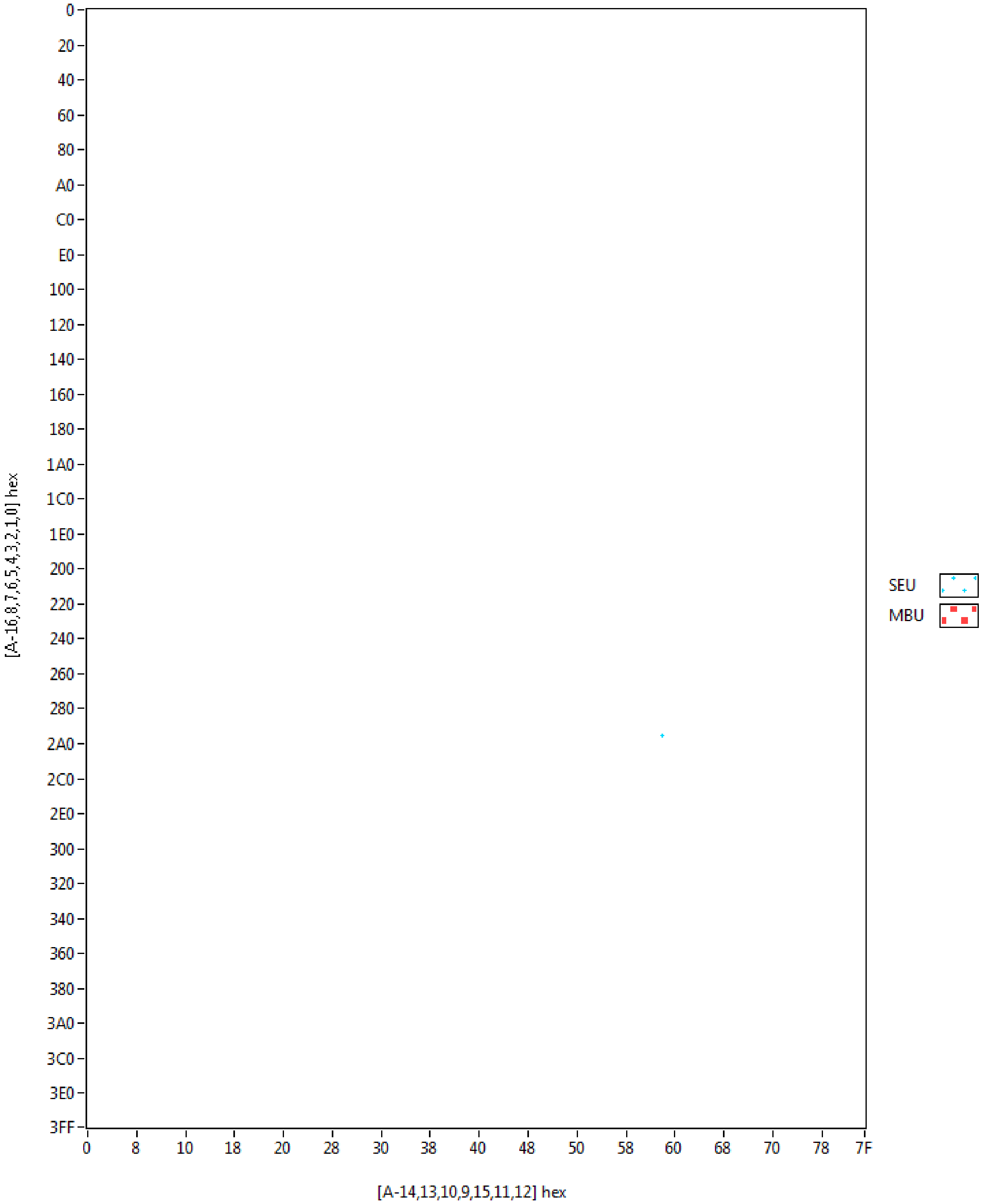
Run N°28 - part 74 - LET 4.24MeV Heavy ion beam.



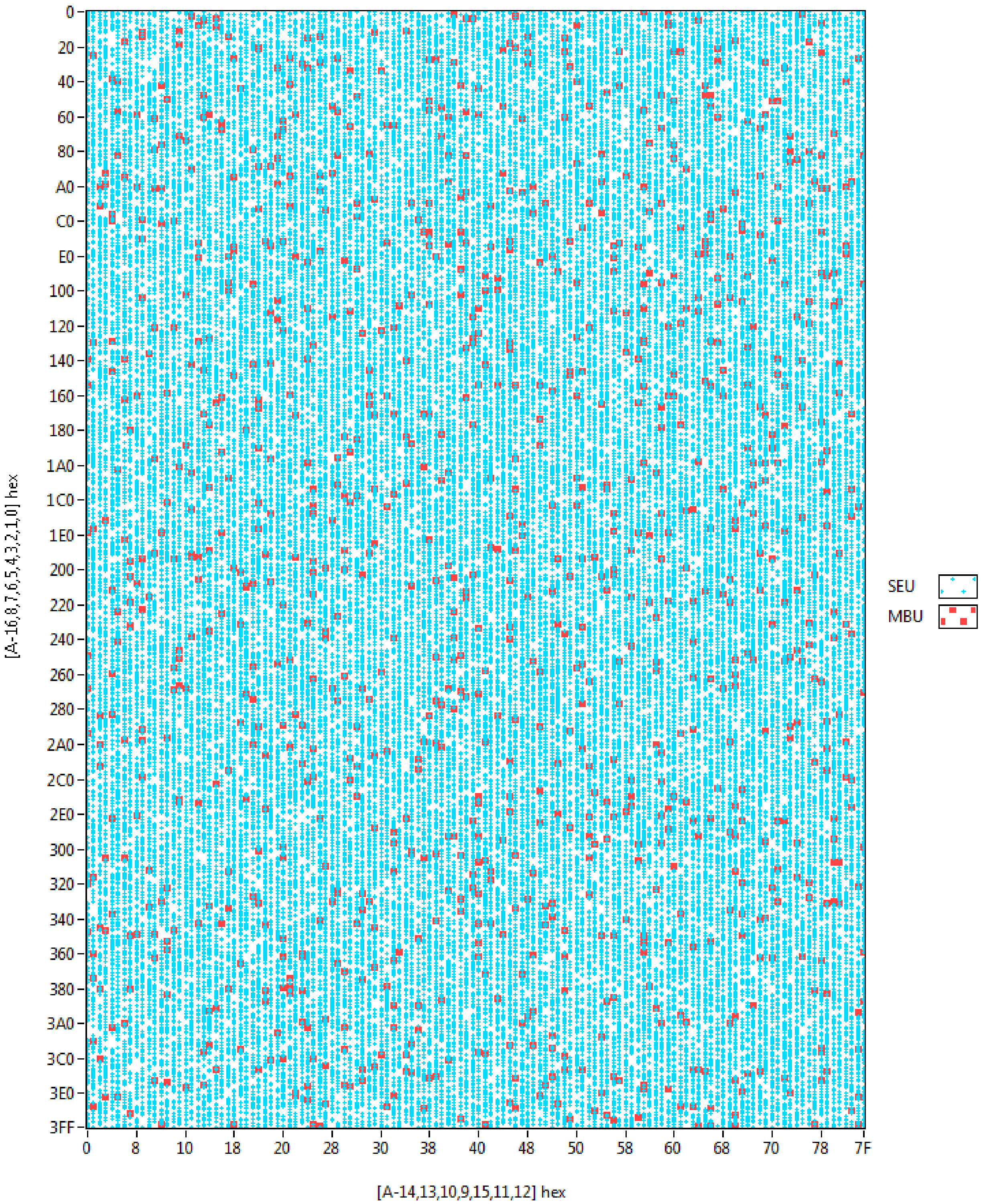
Run N°29 - part 70 - LET 4.24MeV Heavy ion beam.



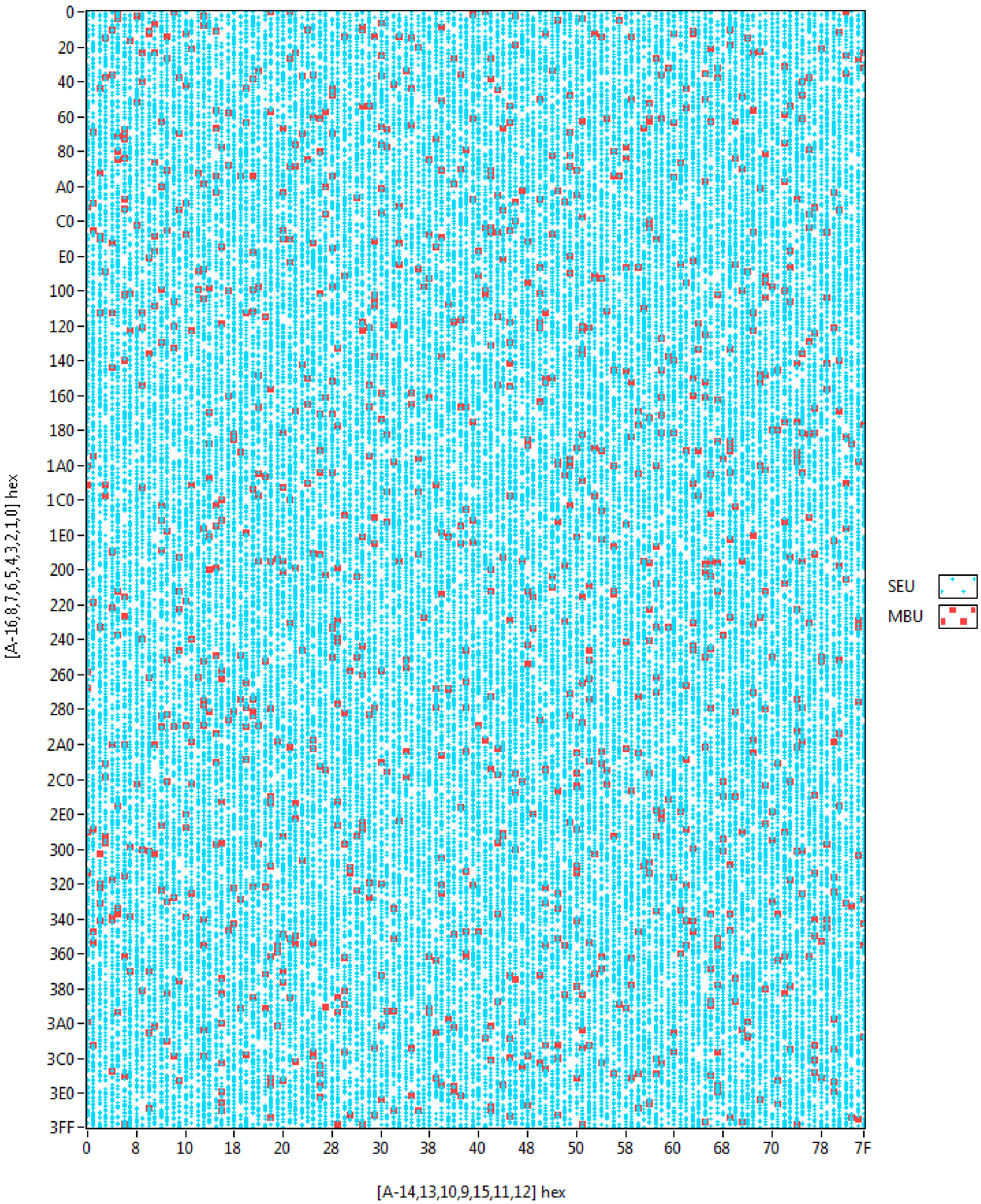
Run N°30 - part 70 - LET 1.1MeV Heavy ion beam.



Run N°31 - part 74 - LET 1.1MeV Heavy ion beam.



Run N°32 - part 74 - LET 65.2MeV Heavy ion beam.



Run N°33 - part 70 - LET 65.2MeV Heavy ion beam.