Proton accelerators single event effects test procedure for COTS electronics: approach to reduce cost and time

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INTRODUCTION

- SPecialized ELectronic System (SPELS) is radiation test laboratory founded in 1989. More than 10000 IC's were tested in the last 15 years. About 50% of IC's radiation tests in Russia are done by SPELS. It is an innovative company and a lot of original radiation test methods and procedures were developed and implemented by SPELS: X-ray test method, focused laser test procedure, a lot of Russian radiation test standards.

- First paper about "PROMETEUS" medical proton accelerator used for IC's radiation test: A.O. Akhmetov, A.V. Yanenko, A.I. Bazhan "Proton accelerator with adjustable energy for ICs radiation test" (2013) Proceedings of the European Conference on Radiation and its Effects on Components and Systems, RADECS, № 6937364

INTRODUCTION

- COTS electronics **were**, **are** and **will be** used in space missions!
- There are a lot of modern ICs (ADC, DAC, FPGA, RAM, SRAM, SoC, Microprocessor) for space applications with sub-90nm process and even low energy protons are able to produce enough energy in sensitive volume to cause single event effects (upsets, transients, etc.).
- Single event upset (SEU) critical charge for modern ICs is equal to 0.1….1 fC.
- Upset threshold LET is close to 0.1 MeV×cm²/mg.
- Critical orbits for proton upsets:
  - International Space Station (South Atlantic Anomaly);
  - Circular orbits with altitudes 1500…4000 km;
  - Polar orbits with altitude 800 km;
  - GEO, solar flares.

5 g/cm²

Altitude [km] \ Inclination [°]	0	15	30	45	60	75	90
36 000	3,04E+03	2,59E+03	1,84E+03	1,40E+03	1,24E+03	1,17E+03	1,15E+03
34 000	4,03E+03	3,41E+03	2,35E+03	1,73E+03	1,50E+03	1,40E+03	1,38E+03
32 000	5,19E+03	4,43E+03	3,04E+03	2,17E+03	1,84E+03	1,71E+03	1,67E+03
30 000	6,58E+03	5,67E+03	3,91E+03	2,74E+03	2,28E+03	2,09E+03	2,04E+03
28 000	8,26E+03	7,16E+03	4,98E+03	3,43E+03	2,82E+03	2,56E+03	2,49E+03
26 000	1,01E+04	8,88E+03	6,26E+03	4,29E+03	3,46E+03	3,13E+03	3,04E+03
24 000	1,15E+04	1,03E+04	7,56E+03	5,16E+03	4,12E+03	3,70E+03	3,58E+03
22 000	1,30E+04	1,17E+04	8,86E+03	6,07E+03	4,78E+03	4,28E+03	4,14E+03
20 000	1,31E+04	1,23E+04	9,67E+03	6,72E+03	5,22E+03	4,66E+03	4,50E+03
18 000	1,17E+04	1,15E+04	9,61E+03	6,93E+03	5,31E+03	4,71E+03	4,55E+03
16 000	9,45E+03	9,72E+03	8,75E+03	6,64E+03	5,02E+03	4,44E+03	4,28E+03
14 000	6,54E+03	7,10E+03	7,18E+03	5,82E+03	4,36E+03	3,83E+03	3,68E+03
12 000	3,79E+03	4,39E+03	5,14E+03	4,59E+03	3,46E+03	3,01E+03	2,89E+03
10 000	4,59E+03	4,18E+03	4,08E+03	3,83E+03	3,06E+03	2,63E+03	2,52E+03
8 000	1,39E+04	1,12E+04	7,17E+03	5,49E+03	4,60E+03	4,01E+03	3,86E+03
6 000	7,67E+04	5,90E+04	3,22E+04	2,15E+04	1,75E+04	1,55E+04	1,50E+04
4 000	[illegible]	[illegible]	[illegible]	[illegible]	9,07E+04	8,05E+04	7,75E+04
2 000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,88E+04	8,56E+04
1000	1,03E+04	1,23E+04	1,44E+04	1,06E+04	7,75E+03	6,90E+03	6,69E+03
800	1,68E+03	3,50E+03	6,27E+03	5,09E+03	3,58E+03	3,10E+03	2,97E+03
400	0	1,00E-03	2,60E+02	4,53E+02	3,07E+02	3,65E+02	3,72E+02

10 g/cm²

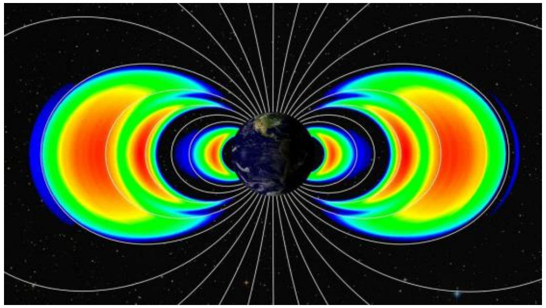
Altitude [km] \ Inclination [°]	0	15	30	45	60	75	90
36 000	1,62E+03	1,34E+03	8,96E+02	6,41E+02	5,31E+02	5,12E+02	5,00E+02
34 000	2,24E+03	1,86E+03	1,22E+03	8,48E+02	7,13E+02	6,55E+02	6,39E+02
32 000	2,99E+03	2,51E+03	1,65E+03	1,13E+03	9,29E+02	8,47E+02	8,23E+02
30 000	3,91E+03	3,32E+03	2,21E+03	1,49E+03	1,21E+03	1,10E+03	1,06E+03
28 000	5,05E+03	4,32E+03	2,92E+03	1,95E+03	1,57E+03	1,41E+03	1,36E+03
26 000	6,33E+03	5,50E+03	3,78E+03	2,52E+03	2,00E+03	1,79E+03	1,73E+03
24 000	7,60E+03	6,71E+03	4,75E+03	3,17E+03	2,49E+03	2,22E+03	2,14E+03
22 000	8,72E+03	7,81E+03	5,73E+03	3,84E+03	2,99E+03	2,65E+03	2,56E+03
20 000	8,91E+03	8,31E+03	6,39E+03	4,35E+03	3,34E+03	2,96E+03	2,85E+03
18 000	8,05E+03	7,89E+03	6,49E+03	4,55E+03	3,45E+03	3,04E+03	2,92E+03
16 000	6,55E+03	6,71E+03	5,99E+03	4,41E+03	3,29E+03	2,88E+03	2,77E+03
14 000	4,49E+03	4,89E+03	4,92E+03	3,88E+03	2,85E+03	2,48E+03	2,38E+03
12 000	2,52E+03	2,95E+03	3,49E+03	3,05E+03	2,23E+03	1,91E+03	1,83E+03
10 000	2,13E+03	2,11E+03	2,40E+03	2,33E+03	1,78E+03	1,50E+03	1,43E+03
8 000	5,41E+03	4,43E+03	3,10E+03	2,57E+03	2,12E+03	1,80E+03	1,73E+03
6 000	3,16E+04	2,43E+04	1,31E+04	8,91E+03	7,29E+03	6,43E+03	6,19E+03
4 000	[illegible]	[illegible]	9,15E+04	5,95E+04	4,77E+04	4,23E+04	4,07E+04
2 000	[illegible]	[illegible]	[illegible]	8,17E+04	6,42E+04	5,68E+04	5,48E+04
1000	7,79E+03	8,98E+03	9,88E+03	7,06E+03	5,22E+03	4,62E+03	4,47E+03
800	1,18E+03	2,60E+03	4,33E+03	3,37E+03	2,38E+03	2,02E+03	1,93E+03
400	0	7,04E-04	1,87E+02	2,87E+02	1,90E+02	1,95E+02	1,94E+02

20 g/cm²

Altitude [km] \ Inclination [°]	0	15	30	45	60	75	90
36 000	5,73E+02	4,70E+02	3,04E+02	2,13E+02	1,80E+02	1,66E+02	1,62E+02
34 000	8,25E+02	6,74E+02	4,29E+02	2,93E+02	2,44E+02	2,23E+02	2,17E+02
32 000	1,13E+03	9,39E+02	6,04E+02	4,04E+02	3,31E+02	3,00E+02	2,91E+02
30 000	1,52E+03	1,28E+03	8,36E+02	5,53E+02	4,47E+02	4,02E+02	3,89E+02
28 000	2,02E+03	1,71E+03	1,13E+03	1,13E+03	5,96E+02	5,34E+02	5,16E+02
26 000	2,59E+03	2,23E+03	1,51E+03	9,94E+02	7,85E+02	7,01E+02	6,76E+02
24 000	3,21E+03	2,81E+03	1,95E+03	1,29E+03	1,01E+03	8,96E+02	8,64E+02
22 000	3,77E+03	3,35E+03	2,41E+03	1,60E+03	1,24E+03	1,10E+03	1,06E+03
20 000	3,94E+03	3,65E+03	2,76E+03	1,85E+03	1,42E+03	1,26E+03	1,21E+03
18 000	3,65E+03	3,54E+03	2,87E+03	1,98E+03	1,50E+03	1,32E+03	1,27E+03
16 000	3,01E+03	3,06E+03	2,69E+03	1,95E+03	1,45E+03	1,27E+03	1,22E+03
14 000	2,05E+03	2,23E+03	2,22E+03	1,72E+03	1,26E+03	1,09E+03	1,04E+03
12 000	1,11E+03	1,31E+03	1,57E+03	1,35E+03	9,75E+02	8,32E+02	7,96E+02
10 000	6,80E+02	7,43E+02	9,76E+02	9,71E+02	7,22E+02	6,02E+02	5,73E+02
8 000	1,25E+03	1,06E+03	8,76E+02	8,25E+02	6,74E+02	5,59E+02	5,33E+02
6 000	9,38E+03	7,20E+03	3,83E+03	2,67E+03	2,20E+03	1,93E+03	1,86E+03
4 000	8,21E+04	6,25E+04	3,34E+04	2,19E+04	1,75E+04	1,56E+04	1,50E+04
2 000	[illegible]	8,95E+04	5,76E+04	3,64E+04	2,87E+04	2,54E+04	2,45E+04
1000	4,03E+03	4,52E+03	4,71E+03	3,27E+03	2,44E+03	2,16E+03	2,09E+03
800	5,84E+02	1,34E+03	2,07E+03	1,54E+03	1,10E+03	9,29E+02	8,89E+02
400	0	3,31E-04	8,86E+01	1,18E+02	7,93E+01	7,70E+01	7,54E+01

Altitude [km]

Inclination [°]

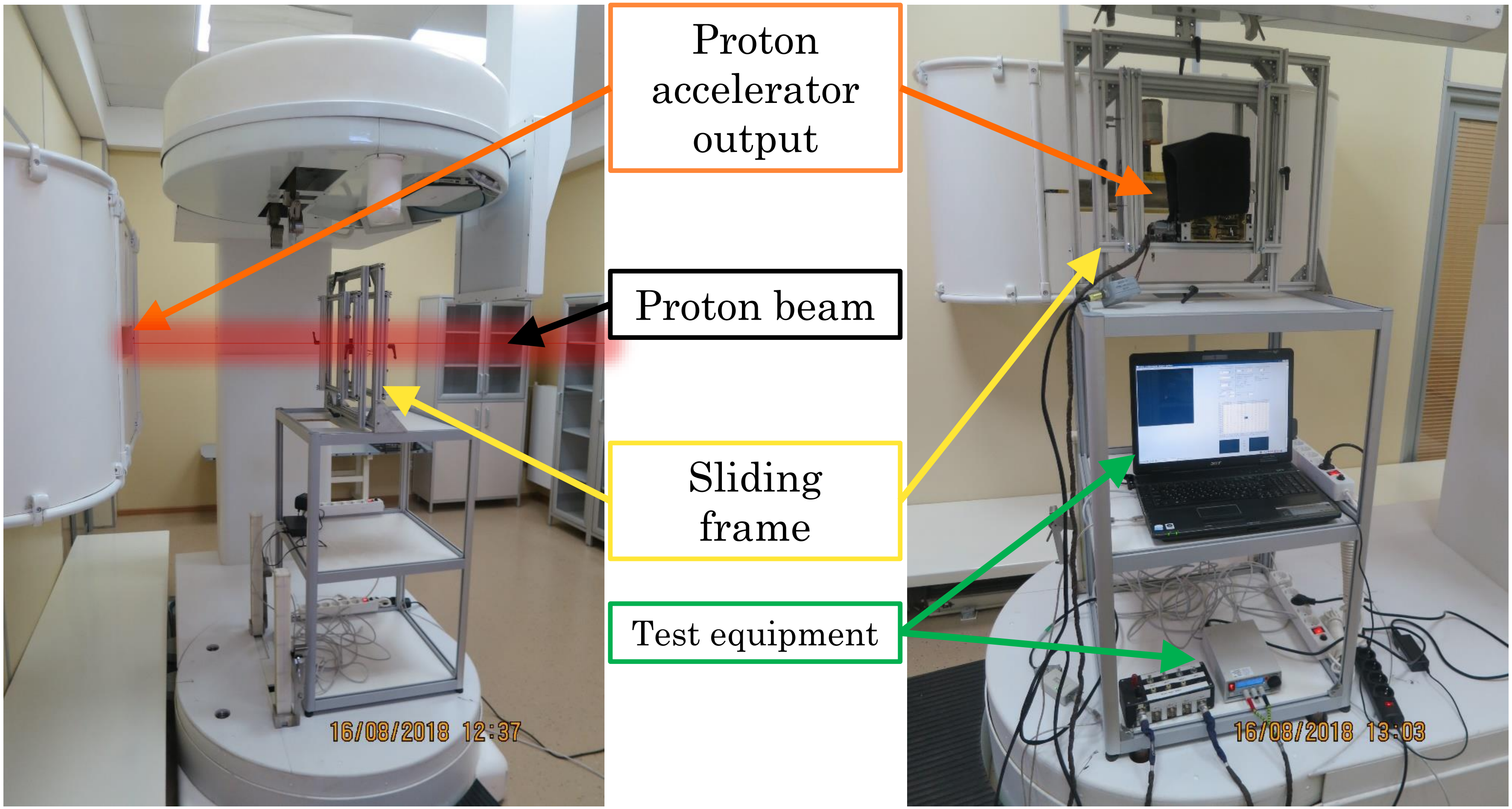


Van Allen belts

Proton Test Facility

- Proton accelerator "**PROMETEUS**" is a medical facility certified in 2018 for IC's radiation experiments;
- Proton energy from 30 MeV to 250 MeV with ±0.15% error;
- Proton flux in a bunch $10^7 \ldots 10^9$;
- Scanning system:
  - Y-axis ±50 mm, speed is up to 2000 mm/s;
  - X-axis ±350 mm, speed is up to 700 mm/s;
- Minimum scan step is 1 mm;
- Minimum proton beam diameter is 2…4 mm;
- Aluminum foils is used to decrease proton energy less than 30 MeV.

Test Facility – Proton Accelerator "Prometeus"

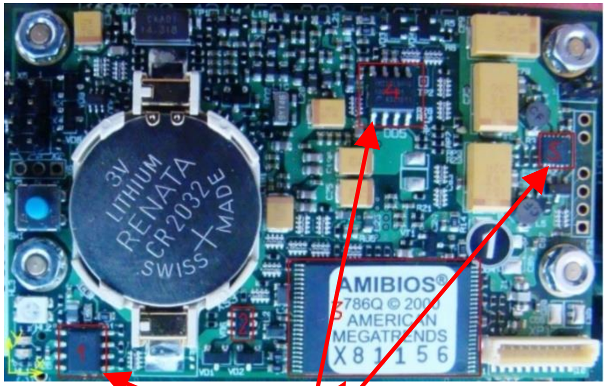


Test stand with installation and sliding system for device under test

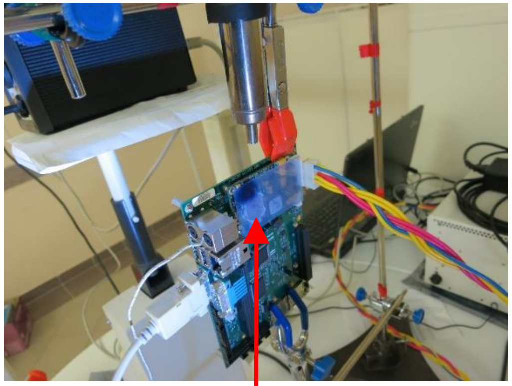
Test equipment example near device under test

Application for COTS electronics

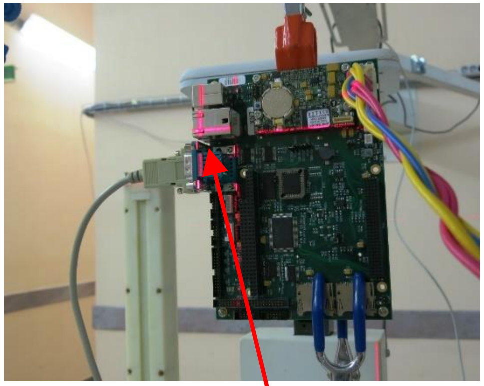
1. It's easier to choose IC's from different manufacturers.
2. It's possible to test COTS PC/104 modules. The probability of all critical IC's at the PCB decapsulation tends to zero and heavy ion test is impossible.



Critical IC's are irradiated with a help of proton facility scanning system



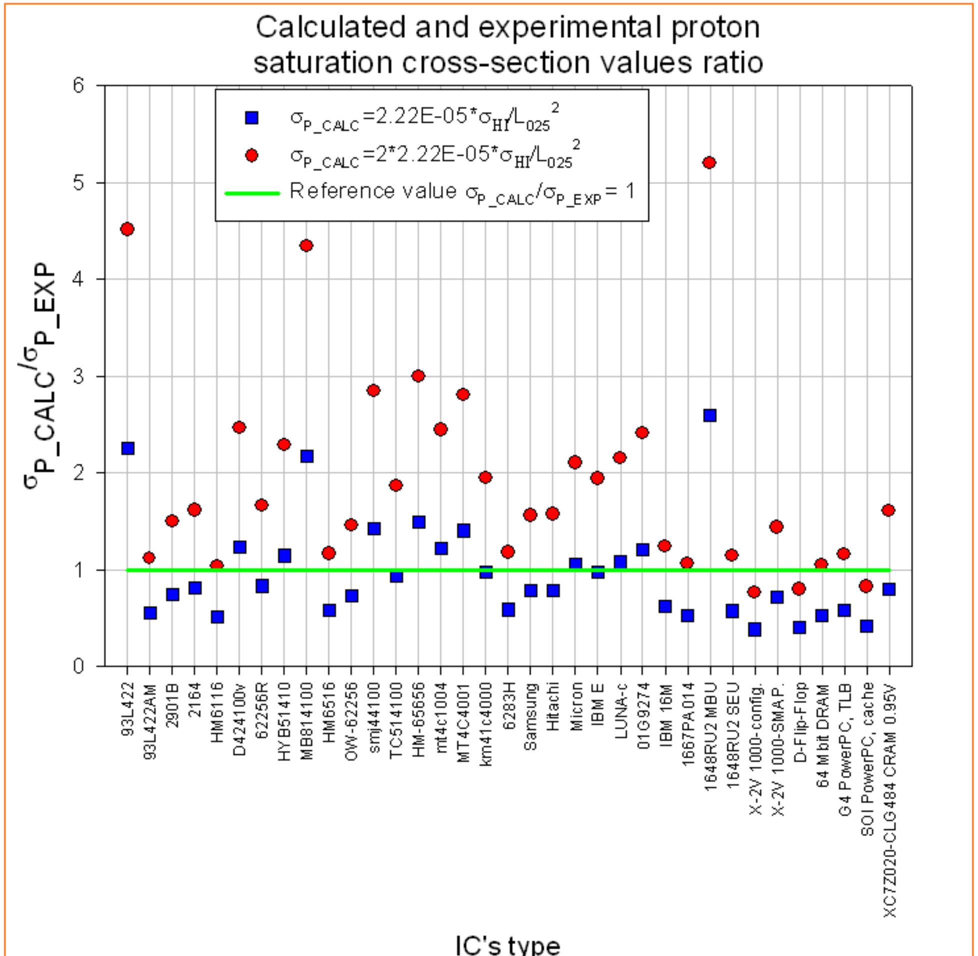
Additional dosimetry film GAFCHROMIC



Laser system to set up device under test

APPLICATION FOR COTS ELECTRONICS

3. It's possible to calculate heavy ion cross-section from proton cross-section data.

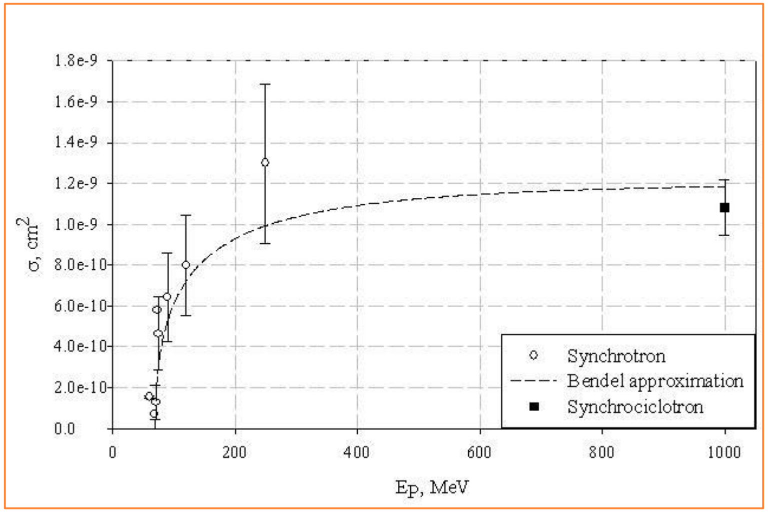


There are several semiempirical equations [1], [2] from Peterson, Barak and others to calculate proton SEU cross-section from heavy ion data and vice versa. More precise Monte-Carlo methods are also available.

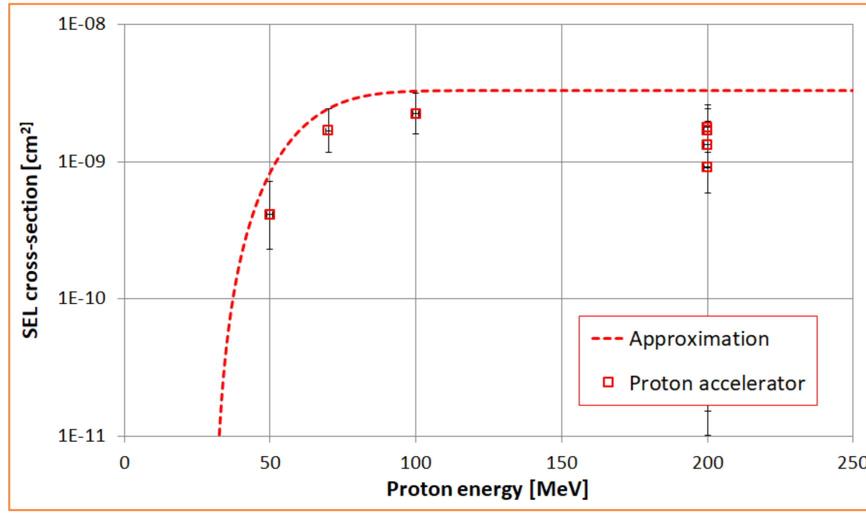
It's possible to do only one experiment (proton or heavy ion) to reduce time and cost. Proton test is less expensive and faster than heavy ion test.

*Experimental data from [1], [2] and SPELS database.

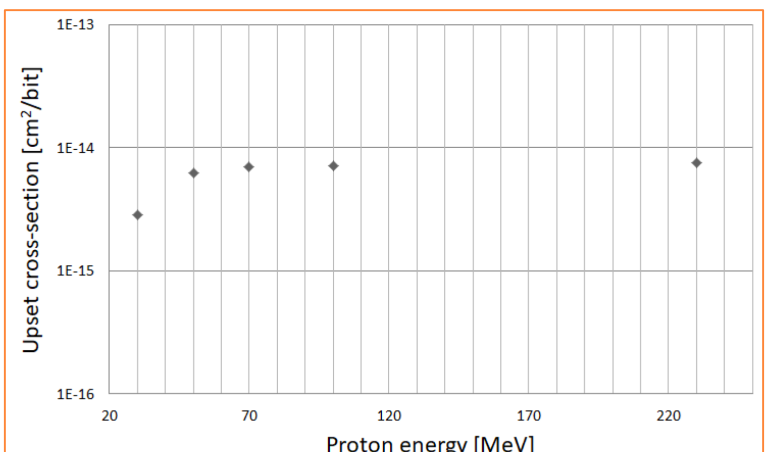
COTS IC’S EXPERIMENTAL RESULTS EXAMPLE



System on Module CPB906 flash memory controller SST55LD019 SEL cross-section obtained at PROMETEUS proton accelerator and 1 GeV proton accelerator. SEL threshold energy is about 70 MeV.



PC/104 single board computer flash memory controller PCM49EB0 SEL cross-section obtained at PROMETEUS proton accelerator. SEL threshold energy is about 30 MeV.



Spartan-6 FPGA SEU cross-section obtained at PROMETEUS proton accelerator.
FPGA configuration memory was tested.
SEU threshold energy is about 10 MeV.

CONCLUSION

- Proton accelerator test helps designer to choose more radiation tolerant IC from different vendors.
- COTS electronics usually has low proton energy SEE threshold and it's possible to calculate heavy ion cross-section and threshold LET from "good" proton experimental data (saturated cross-section and energy threshold). Modern mass production COTS nowadays has 7-nm design rules so SEE proton energy threshold would be lower and lower.
- Proton radiation test for COTS single board modules (PC/104 or similar) is a way to do fast and less expensive SEE test than heavy ion test.
- Total ionizing dose effects during proton irradiation are able to cause IC's failure.

Thank you for your attention!

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