SEE tests for commercial off-the-shelf DSPs to be used in a space experiment

M.Menichelli[1,2], B.Alpat[1,2] , R.Battiston[1] , M.Bizzarri[1], S.Blasko[1], J.Burger[5], D.Caraffini[1], E.Cortina Gil[4], T.Dai[5], C.Haller[5], A.Kounine[5], O.Maris[3], A.Papi[1], V.Plyaskine[5], D.Schartd[6], R.S.Simon[6] and M.Steuer[5].

(1)INFN Sez. di Perugia and Dipartimento di Fisica dell'Universita' di Perugia, Via Pascoli 1, 06100 Perugia, Italy.

(2)IEEE Member.

(3)Institute of Microtechnology Polithecnica University of Bucharest, R-76900 Bucharest.

(4)University of Geneva CH-1211 GENEVA 4, Switzerland.

(5)Massachusetts Institute of Technology, Cambridge, MA 02139 USA.

(6) Gesellschaft fur Schwerionenforschung (GSI) D-64291 Darmstadt, Germany

***Abstract*--DSPs from Analog Device (ADSP2187 and ADSP2189) have been tested for Single Event Effects in order to be used in a Space Station Particle Physics experiment. We tested those devices at GSI (Darmstadt, Germany) with high energy (100 to 800 MeV/nucleon) Xenon Gold and Uranium ions. We also tested laser induced latchup on ADSP2187L. The results on cross section are compared with those obtained during the beam test.**

I. INTRODUCTION

THE use of carefully tested commercial off-the-shelf components (COTS) in Low Earth Orbit (LEO) payloads is becoming a possible choice in order to reduce costs and use state-of-the-art components which usually are not available in space qualified version shortly after their commercial release. Radiation tests for COTS include a Total Dose test and a Single Event Effects (SEE) test. For total dose, components are irradiated with a ^{60}Co gamma ray source following the specification for a space qualification test (we used for example the ESA/SSC 22900)[1]. For SEE test we irradiated components with heavy ions at GSI (Gesellschaft fur Schwerionenforschung) in Darmstadt, Germany. Those tests were performed in order to select components to be used in the data acquisition system of the AMS (Alpha Magnetic Spectrometer) experiment.

The AMS experiment will measure the charge composition of cosmic rays in an energy range from 0.5 GeV to about 300 GeV using a precision high-acceptance magnetic spectrometer. In particular the AMS experiment is designed to search anti-matter nuclei with a sensitivity of one particle out of 10^9 – 10^{10} . Additional goals are the search of dark-matter, the measurement of the spectra of antiprotons, positron, light nuclei as well as isotopic composition of cosmic rays.

The AMS instrument is composed of a silicon tracker, a superconducting magnet, a scintillator time of flight system, an anticoincidence counter around the inner wall of the magnet, a tungsten-scintillating fibres calorimeter, a transition radiation detector and a ring-image Cherenkov detector. The complete AMS instrument will be installed on the International Space Station in year 2004 and therefore it will fly on a Low Earth Orbit (LEO) at about 350 km altitude for at least 3 years. A preliminary version of this instrument was flown in June 1998 on a 10 days Space Shuttle mission (STS-91). For this shuttle flight ADSP2181 from Analog Devices were extensively used in the DAQ architecture of the AMS instrument without major problems.

For the Space Station version of the apparatus we plan to use the newer and more performant members of the same family: the ADSP2187L or the ADSP2189M after a proper evaluation of their radiation tolerance.

The ADSP218x family from Analog Devices includes 16-bit processors optimized for digital processing algorithms with on-chip program and data memory.

In particular the ADSP2187L has: 3.3V I/O and core power supply voltage, 52 MIPS processing power, 32 kword data memory and 32 kword program memory. The ADSP2189M has 3.3V I/O and 2.5V core power supply voltage , 75 MIPS processing power, 48 kword data memory and 32 kword program memory. The size of a word is 16 bit in the data memory and 24 bit in the program memory.

Total dose tests have been performed on the ADSP2187L and on the ADSP2189M (for results see reference [2]) and we observed mainly no degradation in performances up to 30 krad.

A SEE test of a similar device (ADSP2181) has already been performed and the results are published in reference [3].

We also measured the infrared laser induced cross-section on ADSP2187L, the results are reported on section V in this paper.

II. Test setup at GSI

ADSP2187L and ADSP2189M DSPs have been tested at the GSI (Gesellschaft fur Schwerionenforschung, Darmstadt Germany) laboratory starting from October 31st 2000 with Xenon, Gold, and Uranium beams together with several other digital components. A paper devoted to the entire test is under preparation [4]. Energy range for ions ranged from 100 to 800 MeV/nucleon. A list of LET values for each given ion is given in table I.

In order to increase the effective LET range and have a larger set of values we tilted the device under test (DUT) by 0^0 , 30^0 and 60^0 by means of an appropriate support structure provided by the laboratory.

Beam energy	100 MeV/nucl	200 MeV/nucl	400 MeV/nucl	800 MeV/nucl
Xe^{159}	-	11.3	7.6	5.8
Au^{197}	-	23.8	16.1	12.4
U^{238}	53.	32.0	21.8	16.8

Table I
LET (MeV/(mg/cm^2)) values of ions used during the test.

To have a precise alignment of the DUT we also had a laser system that produced a visible spot in the DUT that could be viewed from the counting room by means of a camera; from the counting room it was also possible to give remote commands to the support structure to move the device without entering the beam area.

The intensity of the beam we used for this test was about 10000 ions/spill; we had a 6 sec spill duration and a 4 sec interspill time. We use the beam in raster scan mode. We scanned a surface of 2 x 2 cm^2 divided into 100 pixel, each pixel was crossed by 100 ions before passing to the neighboring pixel; hence one complete scan per spill was done.

In order to have precise flux control we used one MWPC provided by GSI upstream of the DUT and a scintillator downstream. By reading the beam profile from the MWPC precise flux measurement along one test run could be made if the position of the chip inside the package is known.

The readout electronic scheme is shown in fig. 1. It consists of an analog part (in a NIM crate) that received signals from the fluence counters (both scintillator and MWPC) and machine status signals; a digital conversion part (CAMAC crate), and a DAQ part including a control logic box, and a PC collecting data from the crates.

The aim of this readout system was to give a count of the number of latchup and upsets and the calculation of the fluence. In order to detect a latchup and protect the component from burnout, an instrument, called SELDP (Single Event Latchup Detector and Protector), was used. This system, that will be fully described in the next section, consists, of a power supply with programmable current threshold; each time it senses an overcurrent it stops the power and issues a NIM signal to the NIM crate and waits for a command in order to restore power. For upset determination we used a program that after boot fills the memory with checkerboard patterns that are tested continuously, in case of mismatch (SEU event in memory) sends a signal to the glue logic FPGA that notify this SEU event to the control logic box that count the event during next interspill period. This FPGA also contains a watchdog circuit to detect program crashes due to program memory data corruption or errors induced in the program sequencer circuit, those errors are also counted as upsets.

After every spill a power off signal was issued and the DSP was powered down, the CAMAC counters giving the number of latchup and upsets were read out, after 1 second a power on command was issued via the CAMAC crate, the DSP booted and the scaler was reset, after 2.5 second the control logic block receives the boot ok signal from the DSP . If a upset occurs during the spill it is detected from the control logic box and the fluence count for upset is stopped at that moment; if a latchup occurs it is detected from the SELDP, the DSP is powered down till the end of the spill and both the fluence monitors for latchup and upset are vetoed. The DSP is booted only between spills in order not to load a corrupted program into DSP memory.

III. The SELDP

The SELDP (fig.2) is a general purpose latchup detector and protector developed to make SEL tests using accelerator , laser or radioactive source. The Device Under Test (DUT) should be powered from the SELDP that has a programmable current threshold.

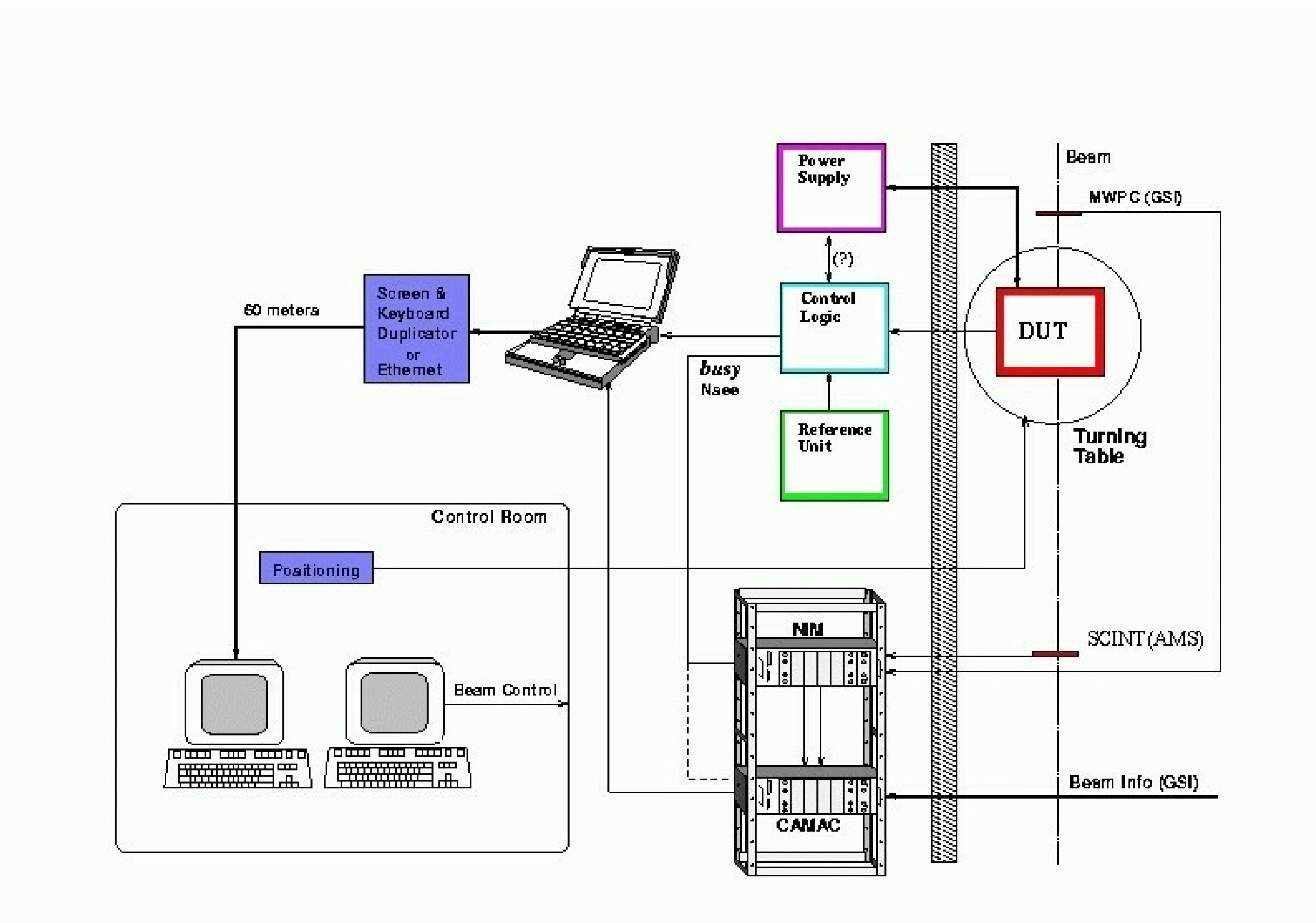

Fig.1 GSI test beam setup

If there is an overcurrent the SELDP interrupts the power to the DUT and increments a counter. After a delay time that can be programmed using internal or external circuits, the instrument restores the power on the DUT.

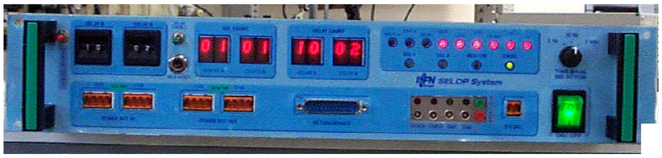

Fig. 2 SELDP front panel

The SELDP has two output channels:

- ChA provides dual output voltages ranging from +/-2 V to +/-12V with a maximum output current of 150 mA. This output is suited for analog low power components with dual rail, if an overcurrent occurs on one rail also the other rail is powered down.
- ChB provides two single output voltages ranging from +3.3 V to +15V with a maximum output current of 1.5 A. These outputs are for digital circuit and other high power electronics.

The reaction time to an overcurrent is about 2 µs. As mentioned above, there are two ways to control power restoring: one is via an internal set of timers and the other is via a NIM interface. The internal timer and the latchup counter are implemented in a FPGA from ALTERA. The possible power restore time, ranges from 1 ms to 99 s and the maximum latchup counts is 99.

The external NIM logic interface has two edge sensitive inputs and two outputs. The two outputs are the status of chA and chB (positive true); one of the two inputs is a common (chA + chB) stop the other is a common start. When a latchup occurs one of the two status bits becomes 0; after a delay, that should be generated with external logic, a signal should be sent to the common start in order to restart the power. The common stop can be used to force power cycles.

Since it can be useful to study the buildup of a latchup effect we are developing a second version of this instrument that includes the possibility of monitoring the current via a National Instrument DAQ card that can sample the current at 5 μs intervals.

IV. Data Analysis

We irradiated the DSPs in a beam test that lasted from the 31st of October to the 9th of November 2000 where many other digital components were also tested. We collected 26 data runs for ADSP2187L and 59 for ADSP2189M, most runs having from 100000 to 500000 crossing ions. During data taking with ADSP2189M we encountered DAQ problems especially during the test with gold ions, but nevertheless we collected 22 valid data points for ADSP2187L and 13 data points for ADSP2189M. We calculated effective LET using SRIM 2000 program taking into account the energy loss on the packaging material. The cross section was calculated according to the formula:

$$\sigma_{l,u} = \frac{N_{l,u}}{F \cos\theta}$$

where $\sigma_{l,u}$ is the latchup/upset cross section, $N_{l,u}$ is the number of latchups/upsets, F is the flux obtained by summing all fluxes accumulated before each SEE event, and θ is the angle of incidence.

Results for ADSP2187L are shown in figs 3 and 4.

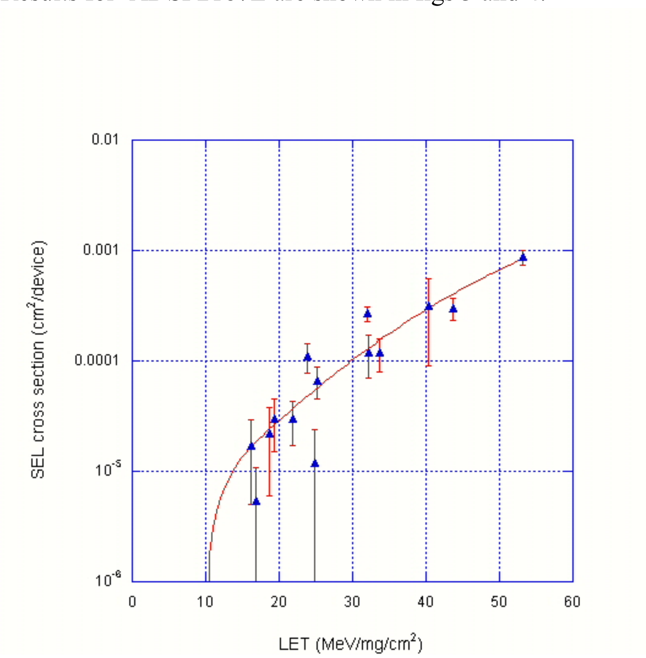

Fig. 3 SEL cross section versus LET in ADSP2187L.

In latchup measurement there is a clear indication of threshold under 15 MeV/(mg/cm^2). Above the threshold the cross section does not have the typical "flat" behavior but it continues to rise.

In upset measurement the threshold is around 5 MeV/(mg/cm^2), as in the latchup case also in SEU there is not a clear plateau but the behavior is flatter than for latchup and we can assume a cross section at plateau around 10^{-2} cm^2 .

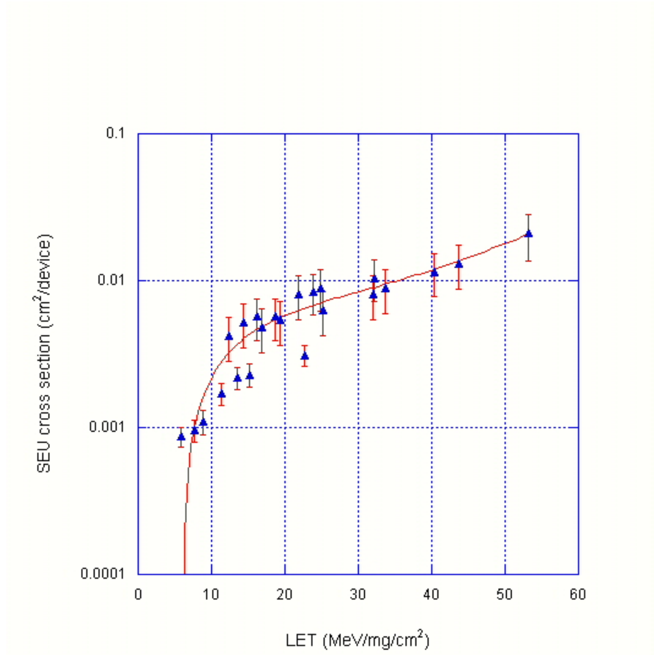

Fig. 4 SEU cross section versus LET in ADSP2187L

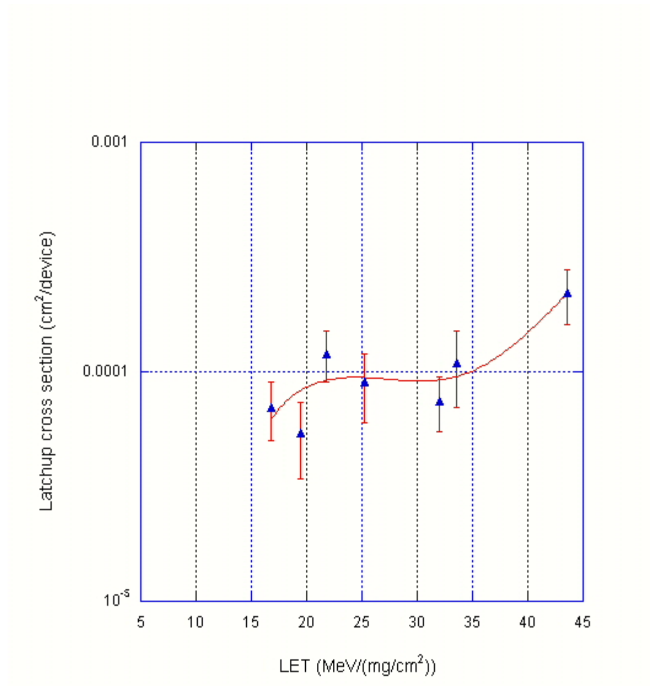

Fig. 5 SEL cross section versus LET in ADSP2189M

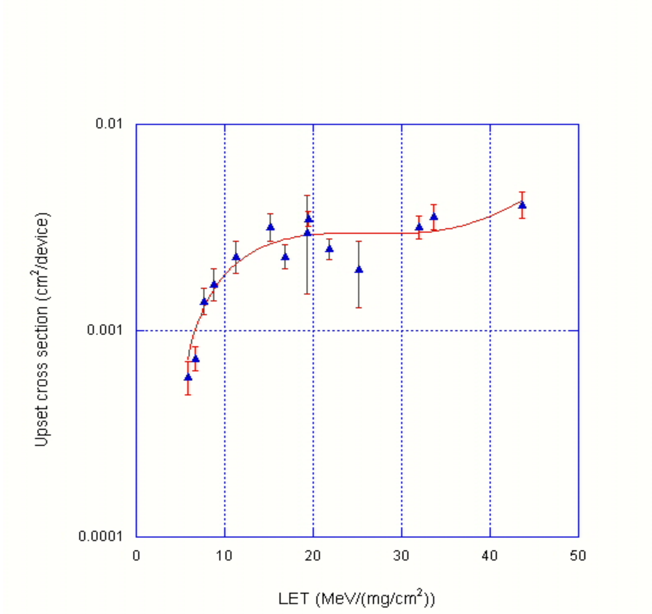

Fig. 6 SEU cross section versus LET in ADSP2189M

Results for ADSP2189M are shown in fig. 5 and 6. Below 15 MeV/(mg/cm^2) we did not observe any latchup for this component so we can assume that the cross section below that LET value is below 10^{-5} cm^2; at higher LET values the cross section flattens around 10^{-4} cm^2. For upsets we notice a clear threshold around 5 MeV/(mg/cm^2) and the cross section at plateau is around 3 x 10^{-3} cm^2 .

V. LASER SETUP AND RESULTS OF LASER TESTS

Laser test evaluation on integrated circuits provides a cost and time effective means to have an estimation on device sensitivity to SEE. However the comparison with test beam data needs particular care and should be considered within some approximation. Using a setup that we are going to describe we performed SEL test on the ADSP2187L and we give a comparison with the results we obtained with the beam test.

Additionally, since the component is delidded and laser spot moves on the component by means of a stepper motor it is easy to evaluate the sensitivity not only on the entire chip but also on the different blocks (i.e. memory, I/O, ALU etc.) of the device considered; however for the comparison with test beam data we made a global scan and the results can be compared with the results on the test beam. For a complete description of the system see [5]

The test setup consists of (fig. 7):

- An infrared laser diode having 913 nm wavelength, 15 ns pulse width, 20W peak power.
- A polarizer to attenuate the intensity of the pulse up to a maximum of 10^{-5} .
- A beam splitter having ratio 0.5 to send 50% of the beam to a photodiode connected to an electronic measuring system in order to monitor the energy of the pulse sent to the DUT (Device Under Test).
- An objective having 12 mm width and 100x magnification to focus the beam on the DUT
- A motor stage to move the DUT for scanning measurements.
- A SELDP, described in the previous section to protect the components from destructive burnout and to count latchups.
- A National Instruments (PCI6025E) DAQ card connected to a computer to trigger the laser diode, read the photodiode electronics and send commands to the SELPD.

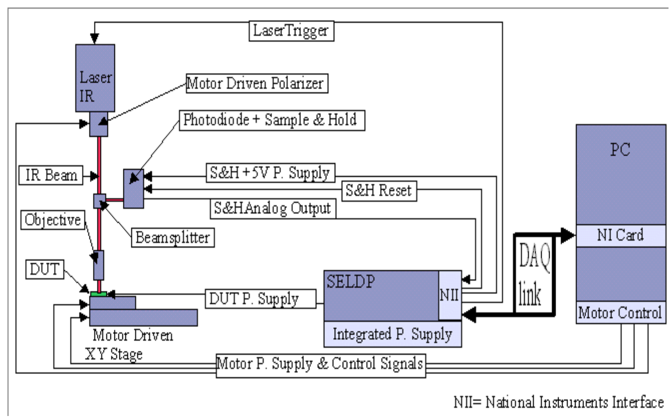

Fig. 7. Laser setup block scheme

For cross-section calculation we used the formula:

$$\sigma = \frac{NbSEL}{IntFlux}\frac{A}{\cos\theta}$$

Where *IntFlux* is the total number of pulses delivered during the scan, *NbSEL* is the total number of SEL, *A* is the total area scanned on the DUT and θ is the angle of incidence (in our case θ = 0).

The LET calculation is more complex, it is based on the formula:

$$LET = \frac{E}{\rho_{Si} \bullet d_{Si}}$$

Where LET is the linear energy transfer, E is the total energy of the photons during the pulse, ρ_{Si} is the density of silicon and d_{Si} is the penetration depth on the silicon.

However this equation needs some corrections, especially for pulse duration and for reflection effects. Details of this calculations can be found in reference [5].

The results are displayed in fig.8. We notice a reasonable agreement with GSI data and the latchup threshold value is roughly around 18 MeV/(mg/cm^2).

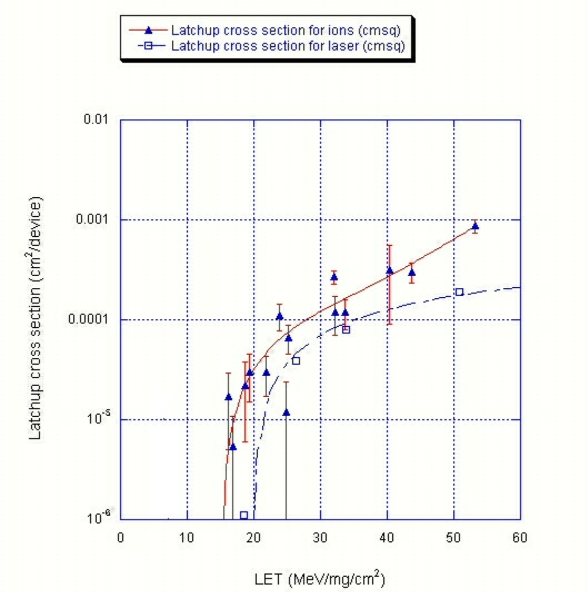

Fig. 8. Comparison between laser and test beam data on the latchup cross section versus LET in ADSP2187L.

VI. Conclusions

We tested ADSP2187L and ADSP2189M for latchup at GSI using high energy Xenon, Gold and Uranium ions.

The results were quite satisfactory, we measured a threshold for latchup of 15 MeV/(mg/cm^2) in both components. Latchup cross section shows a flat behavior for ADSP2189M and its value is around of 10^{-4} cm^2 , while for ADSP2187L the cross section is not flat above the threshold but it remains below 10^{-3} cm^2 for LET values lower than 53 MeV/mg/cm^2 . The upset threshold is around 5 MeV/(mg/cm^2) for both devices as for latchup, the ADSP2189M shows a flatter plateau around 3 x 10^{-3} cm^2, while ADSP2187L cross section increases smoothly with LET up to 2 x 10^{-2} cm^2 at 53 MeV/(mg/cm^2).

We can state that with an appropriate current protection that will be expressly designed, the ADSP2187L and ADSP2189M can be used in space for LEO payloads since no destructive latchup happened and the total SEL cross-section is sufficiently low. In order to detect upsets we can implement CRC algorithms in the DSP and additionally we can generate a checksum in a antifuse FPGA, having a lower SEU cross-section, that will be used in conjunction with the DSP. This checksum will be used to make a consistency test in the data in higher level computers. Recovery of the DSP after crashes or SEL will be done in a watchdog logic circuit implemented in the same FPGA.

We also tested consistency of laser data and test beam data in the measurement of SEL cross section in the ADSP2187L, the agreement is reasonable.

.

VII. References

[1] ESA/SSC Basic Specification 22900, Total dose steady state irradiation test method. Edited by ESA

[2] M.Menichelli et al.," Total Dose Test of Commercial off-the-shelf Components to be used in Power Supply for Space Experiments" *IEEE Trans. On Nucl. Science*. Vol. 47, N.6 pp.1879-1884 (2000).

[3] R. Koga et al., "The Risk of Utilizing SEE sensitive COTS Digital Signal Processor (DSP) Devices in Space." *IEEE Trans. On Nucl. Science*. Vol. 43, N.7 pp. 2982-2989 (1996).

[4] "Study of Single Event Effects on Electronic Components" Paper in preparation to be submitted to *Nuclear Instruments and Methods in Physics Research*..

[5] B.Alpat et al., "A pulsed nanosecond IR laser diode system to automatically test the Single Event Effects in the laboratory," Submitted to *Nuclear Instruments and Methods in Physics Research*.