Radiation Tests for Single Event Effects for the ATLAS Tile Calorimeter Front End Electronics

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Proton irradiation tests for single event effects for the ATLAS Tile Calorimeter front end electronics are described, including the 3-in-1 card, the Mezzanine card, and the ADC integrator card.

1 Objective

This note describes proton irradiation tests for single event effects (SEE) of several components of the ATLAS Tile Calorimeter (TileCal) front end electronics [1]. The components tested include (i) the 3-in-1 card[a], (ii) the Mezzanine card, and (iii) the ADC Integrator card. For each of these components, Table 1 gives the expected fluence for 10 years of ATLAS operation at the LHC design luminosity, where 'SRL_SEE' is the SEE Simulated Radiation Level [3].

For each TileCal component, the total fluence is dependent upon its position in z along the TileCal electronics drawer, as can be seen in Figure 1. The 3-in-1 cards are equally spaced in z along the drawer, and the fluence drops exponentially with decreasing z. The outermost 3-in-1 card will receive a maximum fluence of 5.66×10^{10} h cm^{-2} / 10 y, while the average fluence over all 45 cards in a drawer is 5.2×10^{9} h cm^{-2} / 10 y.

For the proton irradiation tests, in order to calculate the total test exposure for each component, ATLAS guidelines [3] recommend multiplying the expected component fluence SRL_SEE by a safety factor of 5, to account for uncertainties in the simulation. The resulting fluences are given in the third column of Table 1 as F_{TOT}.

[a]The electronics include the Altera ELPD EPM7064STC44-10 which are manufactured from a single production batch.

Component	Fluence (h cm^{-2} / 10 y)	
	SRL_SEE	F_{TOT}
3-in-1 card	5.2×10^{9} (5.66×10^{10} max)	2.6×10^{10}
Mezzanine Card	7.00×10^{9}	3.5×10^{10}
ADC integrator	2.80×10^{9}	1.4×10^{10}

Table 1: Fluences for 10 years of ATLAS operation at nominal LHC luminosity for each TileCal electronic component.

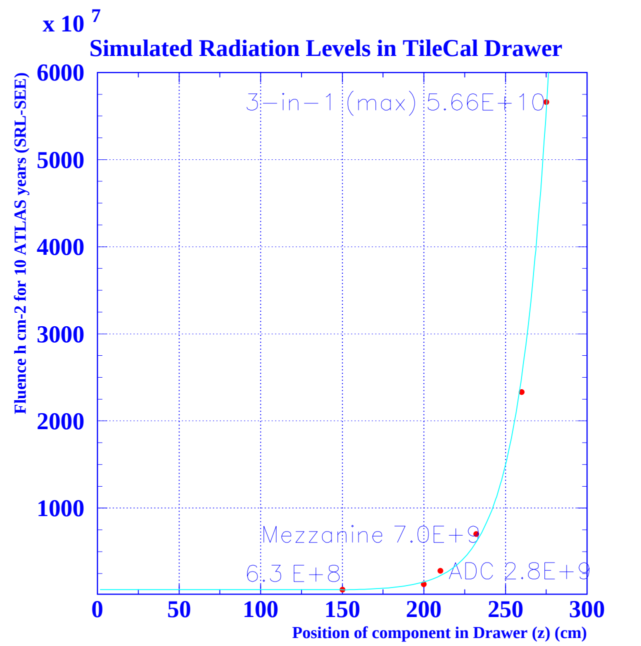

Figure 1: Fluences for 10 years of ATLAS operation at nominal LHC luminosity as a function of the z-position of electronic components in one TileCal barrel drawer.

2 Test Method

The SEE tests were performed at Louvain-la-Neuve, Belgium, using a 60 MeV proton cyclotron, with an adjustable flux from 1.0×10^{7} to 5.0×10^{8} h cm^{-2} s^{-1}. The beam diameter was approximately 8 cm. A laser pointer was calibrated to indicate the centre of the beam when positioning the electronics under test.

The test system comprised of the electronics components connected to a TileCal Mother Board, as shown in Figure 2. In the figure, the approximate beamspot size is indicated by a circle. Due to the overlap in beam position, when testing either the Mezzanine card or the ADC card, the other component was shielded from the beam by 8-10 cm of lead.

The remaining components of the test system included a Low Voltage Power Supply (Gossen stabil DC

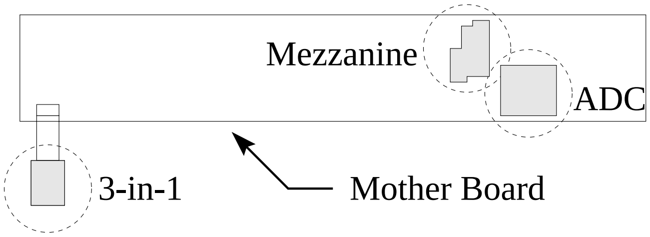

Figure 2: Mechanical arrangement of the electronics components on the Mother Board. The approximate beamspot size is indicated by the circle.

power supply), and a VME crate with an OS/9 controller (MVME 167), MVME712AM, TTCvi, TTCvx, and a Greenspring CANbus controller. A terminal connected via a serial port to the OS/9 controller was used for control and monitoring.

Each component (3-in-1, Mezzanine, ADC card) was exposed in sequence. The electronics were powered and executed test operations during the exposure. The electronics were driven by software on the OS/9 system, which continuously transmitted commands over an optical TTC fibre to the Mother Board. These commands cycled through the logic states of the 3-in-1 card, the Mezzanine card, and the ADC card. The logic states were then read back via CANbus and verified with the commands sent. A second set of logic states was then set, but with the complement of the bits from the first states, and then read back and verified. The process was repeated continuously at a rate of about 5 Hz. Any errors in reading back the logic states were recorded on local disk, with a time stamp and the serial number of the component.

During the test procedure, if a recoverable SEE occurred, the test continued up to the prescribed integrated dosage. If a non-recoverable SEE occurred, in which case errors were being continuously logged, the test was stopped, the beam stopped, the Low Voltage power supply cycled, and the test repeated. This allowed one to determine whether the SEE was a permanent or recoverable effect.

3 Results

The results of the tests are given in Table 2. SEE events in the digital functions of the 3-in-1 card and Mezzanine card were observed at fluences listed in the third column of the table. There were no permanent effects observed, and all digital functions could be restored by cycling the power[b]. The SEE events would affect only the digital

Component	Beam Flux	SEE at Fluence	Recovered
3-in-1	(h cm-2 s-1)	(h cm-2)	
SN 104213	6.0×10^7	1.2×10^{11}	YES
SN 104703	” ”	7.2×10^{10}	YES
” ”	” ”	1.3×10^{11}	YES
SN 103055	” ”	3.0×10^9	YES
” ”	” ”	1.5×10^{11}	YES
SN 104135	” ”	1.6×10^{11}	YES
Mezzanine			
SN 01	4.0×10^7	1.7×10^9	YES
” ”	” ”	1.4×10^9	YES
” ”	1.0×10^7	1.2×10^9	YES
” ”	” ”	2.2×10^9	YES
SN 02	1.0×10^7	4.5×10^9	YES
” ”	4.0×10^7	8.2×10^8	YES
” ”	1.0×10^7	5.1×10^9	By Itself
” ”	1.0×10^7	5.8×10^9	YES
ADC card			
PS2021	4.0×10^7	1.4×10^{10}	No errors

Table 2: Results of the SEE tests for each component. The third column gives the fluences at which a SEE event occurs. The last column indicates whether the component recovered after cycling the power.

communication function with the TileCal front end electronics. The analogue readout function of the calorimeter would remain unaffected. An effect on digital communication would limit only the calibration function of the cards, which would be exercised only during special runs without beam in the LHC.

For the 3-in-1 card, the average fluence[c] at which a SEE occurred was 1.1×10^{11} h cm^{-2}. Based on this fluence, Figure 3 illustrates the dependence of the 3-in-1 card SEE event rate for 10 ATLAS years as a function of the position of the card in z along a drawer[d]. For the outermost cards ($z > 200$ cm) the rate ranges from 0.1 to 2.5 events per drawer per 10 ATLAS years, while for the majority of the cards ($z < 200$ cm) the rate is below 0.03 events. Integrated over the system, the estimated SEE event rate would be 237 per year (safety factor of 5 included), or 14 per week with 30% of the calendar year at design luminosity[e]. These SEE events have no influence on the normal data taking since the analogue

[b]The typical pause time between cycling the power off and on was about 10-15 s. For one of the 3-in-1 cards (SN 103055), a longer waiting time would have been necessary. In this case, after one of the SEE events, the digital functions of the card were not restored immediately after 15 s, but later the card was retested and found to be fully functional.

[c]The uncertainty on the time measurement used to calculate the total fluence is approximately +/- 5 s, which corresponds to an error in the estimated total fluence of a few per cent.

[d]The event rate for all calculations includes the factor of safety of 5 for uncertainties in the simulation.

[e]10 ATLAS years correspond to 10^8s integrated beam time[3].

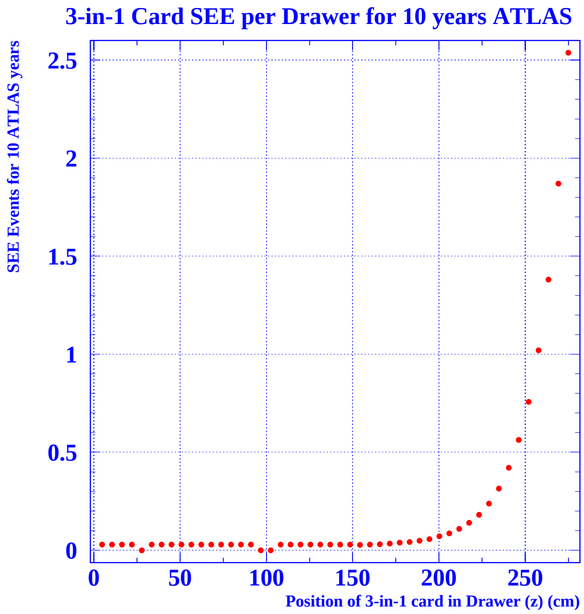

Figure 3: SEE event rate for the 3-in-1 cards in one TileCal barrel drawer for 10 years of ATLAS operation at nominal LHC luminosity. A safety factor of 5 has been included in the calculation to account for uncertainties in the simulation. The event rate is a function of the z-position in the electronics drawer. There are 48 points corresponding to the 48 PMT positions in a barrel drawer, including three spare uninstrumented cards per drawer indicated by the 3 points with zero event rate.

operation of the cards is unaffected. Prior to the weekly calibration the power could be cycled to restore any cards which have lost digital communication.

In the case of the Mezzanine card, the average fluence for a SEE event was found to be 2.8×10^9 h cm^{-2}, which corresponds to one event every 0.8 years at the nominal LHC luminosity. All of the events were recoverable by power cycling, except one which recovered by itself. Integrated over the system, the estimated SEE event rate for the Mezzanine cards would be about 320 per year (safety factor of 5 included) or 19 per week. Again these SEE events would have no effect on normal data taking, and prior to the weekly calibration the power could be cycled to restore any affected Mezzanine cards.

For the ADC integrator card, no SEE events were observed up to the maximum expected fluence for 10-years ATLAS operation of 1.4×10^{10} h cm^{-2}.

After each event, the current draw was checked on the low voltage supply, on a scale sensitive to changes of about 0.2 A. No increase in current draw was observed.

4 Conclusion

For all of the TileCal front end electronics components tested, all of the Single Event Effects observed were temporary, recoverable by power cycling. One SEE was observed in the Mezzanine card which recovered by itself. The events observed would affect only the digital communication with the cards, used during special calibration runs without beam. Based on 10 years of ATLAS operation at the nominal LHC luminosity, the digital SEE event rate for the system of 3-in-1 cards is approximately 237 per year or 14 per week, while for the Mezzanine cards about 320 per year or 19 per week (safety factor of 5 included for both 3-in-1 and Mezzanine cards). No SEE events were observed for the ADC integrator card for the total fluence of 10-year ATLAS operation.

1. Details on the TileCal electronics can be found at: http://atlasinfo.cern.ch/Atlas/SUB_DETECTORS/TILE/elec/electronics.html.
2. A summary of radiation testing of the TileCal electronics can be found at: http://atlasinfo.cern.ch/Atlas/SUB_DETECTORS/TILE/production/electronics/radiation/rhawg.html
3. M. Dentan, P. Farthouat, “ATLAS Policy on Radiation Tolerant Electronics”, available under: http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/radhard.htm.