Comparison of beam test results for irradiated SCT modules

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Abstract

Four new irradiated modules were tested during the August 2002 beam period in H8, two K5 end-cap and two barrel. Given the importance of these modules, some results are made available to a small audience through this note. All results should be considered very PRELIMINARY and are intended for internal use only.

1 Setup and calibration

A total of nine irradiated modules were present in the August beam test, six barrel and three end-cap. The irradiated modules have been marked with an asterisk (*). A hybrid module [1] and five non irradiated modules were used for comparison.

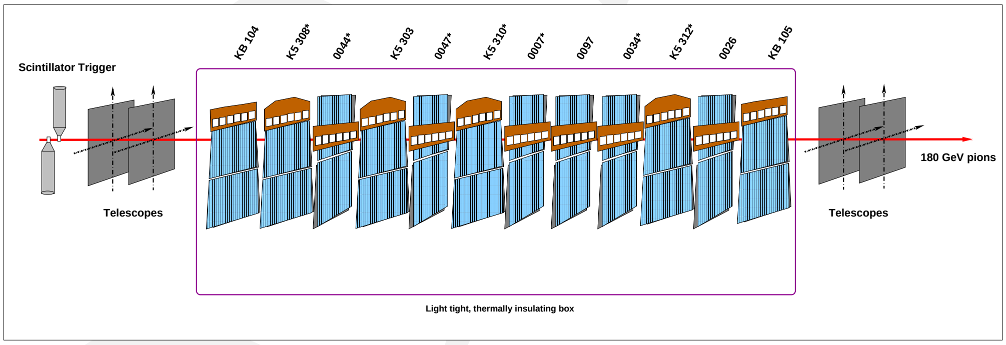

Fig. 1. Setup for the firsts runs of the August 2002 Test Beam.

For all of them a high statistics threshold scan at a bias voltage of 150 Volts for non-irradiated and 500 Volts for the irradiated was taken. Figure 1 shows the first setup used, twelve modules (four K5 end-cap modules, two KBs and

[1] K5 315 is a module with an irradiated K5 hybrid and non irradiated sensors. This module will be marked with a dagger (†)

six Barrel modules). Due to the high number of modules tested up to three different setups were necessary.

Table 1 shows the modules analyzed [2] with the number of masked channels, online + (offline) used in the analysis. In the same table the chip-set type and the previous beam tests where the module was present is written.

Module	Chip set	Present @	Ccal	Masked Channels
0044*	new epi	Oct 01	1.11	4 + (0)
0047*	new epi	Oct 01	1.09	7 + (4)
007*	old epi	July 02	1.09	Chip + 18 + (5)
034*	old epi	July 02	1.08	6 + (1)
096*	series		1.04	16 + (0)
USQ3*	new epi		1.15	24 + (0)
097	series		1.04	0 + (0)
K5 308*	new epi	May/July 02	1.10	5 + (1)
K5 310*	new epi		1.10	Chip + 59 + (0)
K5 312*	old epi		1.11	16 + (2)
K5 315†	new epi		1.15	8 + (0)
K5 303	new epi	July 02	1.17	9 + (0)

Table 1
Ccal correction factors for the modules analyzed. Masked channels have been divided in online + offline analysis.

The modules were calibrated in-situ. Noise and Gain from calibration need to be corrected. Figure 2 is the simplified representation of electronics of the chip. Two different circuits are used, one for calibration and another for the detectors readout. For calibrating, a voltage step is generated by DAC The pulse goes through the calibration capacitor (Ccal) to the front-end electronics. The charge is proportional to the height of the voltage step and the capacitance. When a pulse comes from the detector it goes directly to the front-end. For a proper characterization, deviations from the nominal value of the calibration capacitor have to be corrected. The results of this calibration, noise, in Equivalent Noise Charge (ENC), and gain for the irradiated end-caps and the new

[2] In the test beam were present barrel module 0026, anchor, and 2 KB's (104 and 105) but they are not analyzed in this note.

barrel modules is written in tables 2 and 3. Equation 1 is the correction applied for noise and gain. The values of the individual Ccal correction factors are listed in table 1.

$$ENC_C = ENC \times Ccal \qquad Gain_C = Gain/Ccal \tag{1}$$

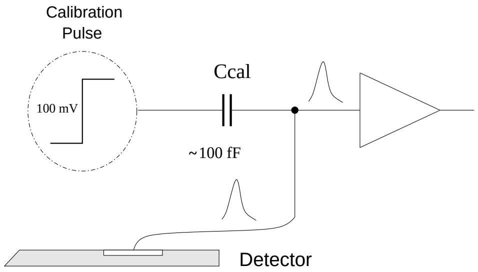

Fig. 2. Schematic representation of the chip read-out.

Chip	K5 308*		K5 310*		K5 312*		K5 315	
	ENC_C	$Gain_C$	ENC_C	$Gain_C$	ENC_C	$Gain_C$	ENC_C	$Gain_C$
M0	1992	38.0	2097	39.7	1818	40.1	1915	41.0
S1	2142	34.9	1796	42.4	1796	43.6	1862	42.3
S2	2144	32.0	1746	39.5	1841	41.4	1845	41.4
S3	1923	31.6	1748	40.9	1830	40.2	1942	40.0
S4	2090	34.9	1845	38.2	1936	41.3	2029	41.6
E5	2193	35.4	0	0.0	1843	36.1	1949	40.6
M8	2211	34.4	1736	41.2	1925	36.6	1948	41.3
S9	2081	34.6	1990	39.2	1886	41.7	1865	39.7
S10	2378	26.8	2011	35.4	1859	40.2	1865	39.7
S11	2463	27.7	1698	39.4	1875	40.5	1778	41.7
S12	2291	34.0	0	0.0	1856	40.5	1841	42.4
E13	2185	39.1	1922	40.2	1711	44.6	1800	43.0

Table 2
Corrected values of ENC_C (e^- ENC @ 2 fC) and $Gain_C$ (mV/fC) for the end-cap modules.

2 Analysis

Once the alignment of the modules is obtained one of the firsts results is the tracking efficiency for a certain discriminator threshold. With runs at different threshold the tracking efficiency dependence on threshold (fC), s-curve, can be studied. The s-curve is the integration of the charge distribution (Landau). The figures 3 and 4 are the s-curves for the irradiated end-caps, K5 310* and K5 312*, and the barrels 096* and USQ3*. With the binary readout the pulse height can not be extracted directly. The 50 % point corresponds to the median charge of the charge distribution[1], an example can be seen in figure 3 (left). The threshold values have been corrected by the calibration factor.

The region around the envisaged operating threshold is blown up in figures 5 and 6. In the same figure the noise occupancy corresponding to the same threshold is plotted. Noise occupancy is obtained during the time in between spills, with no beam on the modules. The efficiency and noise occupancy specifications are indicated as straight lines. The results are compared to those of other modules in this and previous test beams [2][3] in the tables at the end of the section (table 5 and 4).

An estimate of the peaking time is obtained from a fit of the ABCD to the pulse

Chip	097		096*		USQ3*	
	ENC_C	$Gain_C$	ENC_C	$Gain_C$	ENC_C	$Gain_C$
M0	1506	55.9	2146	36.4	2171	38.0
S1	1563	50.8	2137	36.9	2527	30.4
S2	1587	50.1	2136	35.5	2473	33.1
S3	1647	55.2	2296	31.2	2177	36.3
S4	1643	50.2	2290	33.8	2259	32.1
E5	1350	59.7	2346	31.9	2433	33.2
M8	1452	55.3	2278	32.0	2538	34.4
S9	1497	55.2	2464	33.7	2612	34.1
S10	1538	51.0	2415	33.6	2478	33.4
S11	1610	49.0	2304	32.7	2663	33.1
S12	1458	57.2	2243	35.5	2527	34.6
E13	1485	55.7	2313	34.8	2519	34.4

Table 3
Corrected values of ENC_C (e^- ENC @ 2 fC) and $Gain_C$ (mV/fC) for the barrels modules.

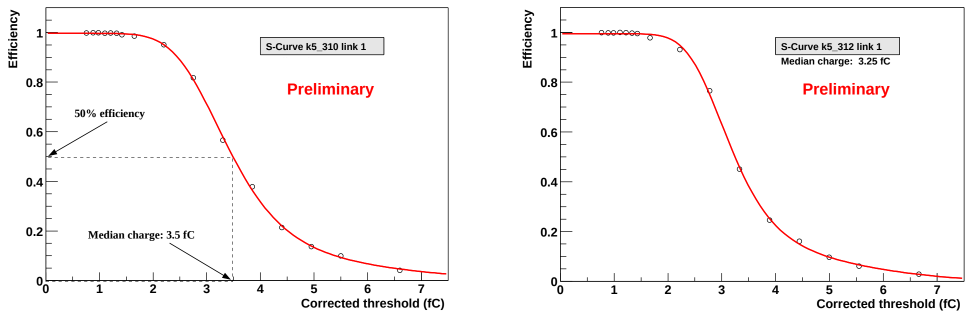

Fig. 3. S-curves of module K5 310* link 0 (left) and K5 312* link 1 (right). Response to perpendicularly incident tracks. Bias voltage of 500 Volts.

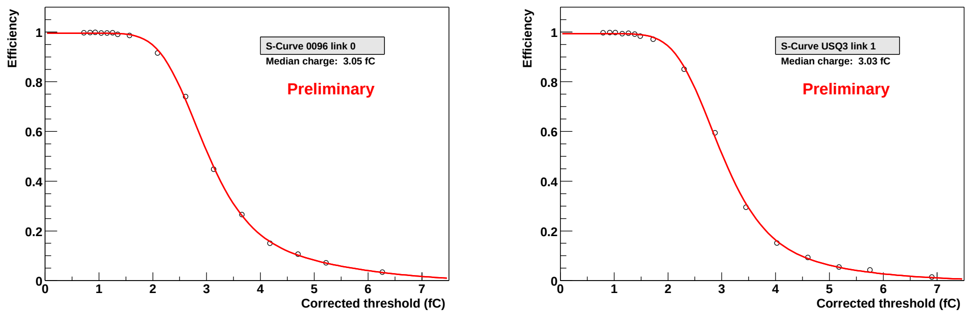

Fig. 4. S-curves of module 0097* link 0 (left) and USQ3* link 1(right). Response to perpendicularly incident tracks. Bias voltage of 500 Volts

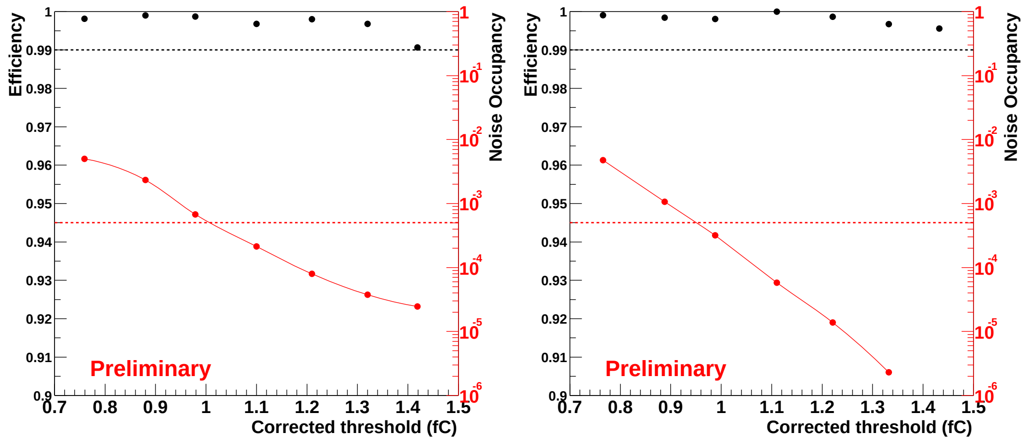

Fig. 5. Efficiency and noise occupancy of module K5 310* link 1 (left) and K5 312* link 1 (right). Response to perpendicularly incident tracks. Bias voltage of 500 Volts.

shape reconstructed from the binary data and the trigger phase measurement. The fit assumes a $CR - RC^3$ transfer function[4] for the ABCD front-end. Figure 7 shows two different pulse shapes, a non-irradiated module on the left and an irradiated, right. The ABCD function, the continuous line, fits perfectly

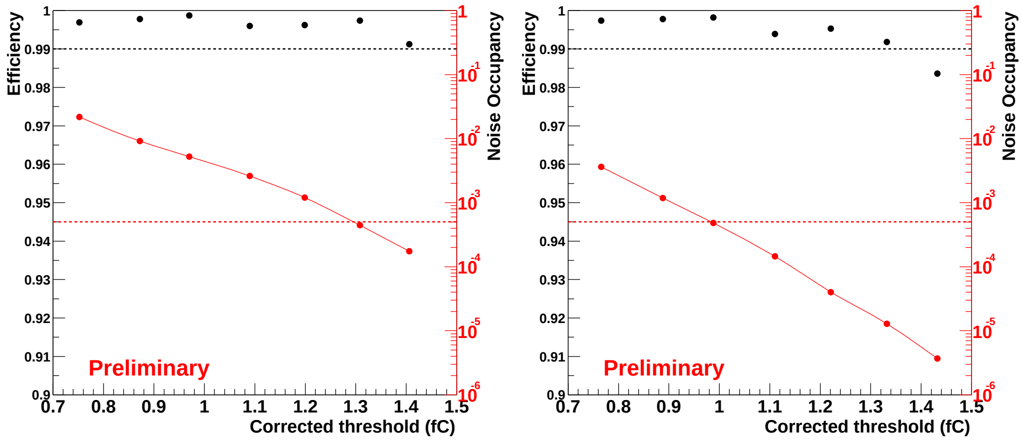

Fig. 6. Efficiency and noise occupancy of module 0096* link 0 (left) and USQ3* link 1 (right). Response to perpendicularly incident tracks. Bias voltage of 500 Volts.

for the non-irradiated modules. The pulse of the irradiated modules is well fitted for the rising edge. But, the pulse is wider than the shape described by the function.

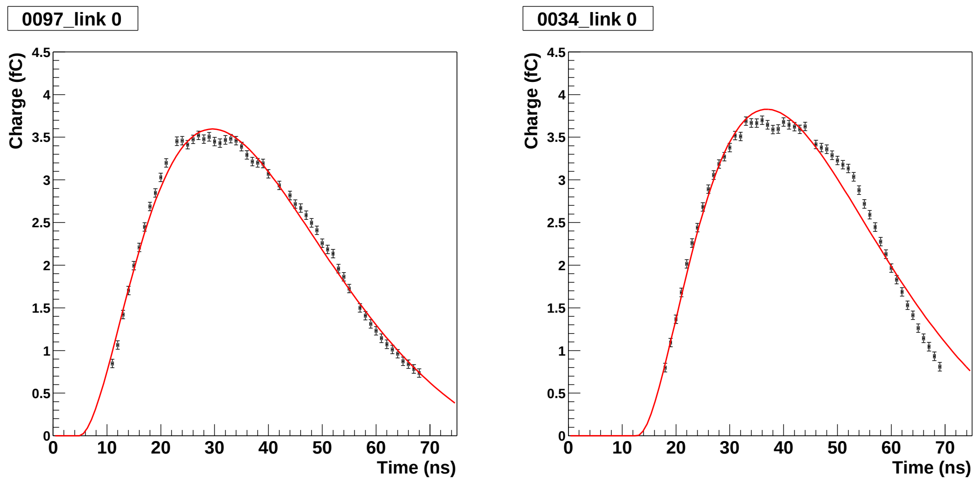

Fig. 7. Pulse shape of a non-irradiated module left and irradiated one right. The continuous line corresponds to the fit with the ABCD function.

A summary of all the results is written in tables 4 and 5. The tables contains efficiency, occupancy, charge, peaking time measurements, bias voltage and the chips pointed by the beam on a set of modules. Table 4 lists the PRELIMINARY [3] results from the reference threshold scan in the August 2002 beam test. Table 5 is a collection of the values from previous test beams. The August results are compatible within errors with the previous ones.

[3] K5 303 calibration file needed.

Module	Eff @ 1fC	NO @ 1fC	Q_{med} (fC)	S/N	Pktime (ns)	Current (μA)	Bias (V)	Chips
0047*	99.8	7×10^{-4}	3.2	9.7	23.2	1697	500	(S2)
	99.7	1.6×10^{-3}	3.0	9.8	27.6			(S11)
0044*	99.7	1.0×10^{-3}	3.3	10.0	22.2	1485	500	(S2)
	99.8	1.5×10^{-3}	3.1	9.9	22.1			(S11)
007*	99.7	1.9×10^{-3}	3.8	12.1	25.3	1348	500	(S2)
	99.9	2.3×10^{-3}	3.3	11.5	25.6			(S11)
034*	99.8	2.2×10^{-3}	3.5	10.7	24.1	1284	500	(S2)
	99.7	1.8×10^{-3}	3.4	10.8	23.8			(S11)
K5 308*	98.9	2.3×10^{-3}	2.4	7.8	26.8	1968	500	(S3)
	99.8	4.0×10^{-3}	3.0	7.9	24.9			(S10)
K5 303	99.8	1.4×10^{-4}	3.9	-	22.6	0	150	(S3)
	99.9	1.2×10^{-4}	3.6	-	22.2			(S9)
K5 310*	99.8	6×10^{-4}	3.1	11.0	24.3	950	500	(S3)
	99.8	7×10^{-4}	3.5	10.9	25.2			(S10)
K5 312*	99.8	4×10^{-4}	3.2	10.9	24.3	944	500	(S2)
	99.8	3×10^{-4}	3.3	11.0	24.7			(S11)
K5 315†	99.8	7×10^{-4}	3.6	12.2	24.2	0	150	(S2)
	99.8	6×10^{-4}	3.4	12.0	25.4			(S10,S11)
USQ3*	99.7	9×10^{-4}	3.1	7.8	22.9	2860	500	(S1,S2)
	99.8	5×10^{-4}	3.0	7.0	23.2			(S11)
096*	99.8	5×10^{-3}	3.0	8.8	24.5	3040	500	(S2)
	99.8	8×10^{-3}	3.2	8.7	24.3			(S11)
097	99.6	7×10^{-5}	3.3	14.2	25.3	0	150	(S2)
	99.7	9×10^{-5}	3.3	14.0	24.6			(S11)

Table 4
PRELIMINARY Summary of August 2002 results at perpendicular incidence, no magnetic field. The K5 315 is the hybrid module, irradiated hybrid and non irradiated sensors. The last column shows the chips pointed by the beam.

Module	Eff (1fC)	NO (1fC)	Q_{med} (fC)	Pktime (ns)	Bias	Chips
0047*	99.7	3×10^{-3}	3.1	23.4	350 V	??
				24.8		??
0044*	99.4	3×10^{-3}	3.1	23.2	350 V	??
				23.3		??
007*	99.6	1.7×10^{-3}	3.7	26.6	500 V	(S2,S3)
	99.7	2.4×10^{-3}	3.3	28.1		(S10,S11)
034*	99.7	1.5×10^{-3}	3.5	24.6	500 V	(S2,S3)
	99.7	1.2×10^{-3}	3.5	24.2		(S10,S11)
K5 308*	99.4	2.7×10^{-3}	2.7	25.3	500 V	(S2,S3)
	99.6	5.8×10^{-3}	3.1	25.7		(S10,S11)
K5 303	99.7	5×10^{-5}	3.8	23.2	150 V	(S2,S3)
	99.7	4×10^{-5}	3.5	22.7		(S9,S10)

Table 5
Summary of previous results at perpendicular incidence, no magnetic field. Efficiency and noise occupancy at 1 fC, median charge, peaking time, bias and chips in which the beam was pointing has been written.

3 Bias Scan

In the irradiated modules the collected charge is strongly dependent on the bias applied to the detectors. For the non-irradiated detectors a plateau is reached, collecting the full deposited charge a few tens of volts after depletion voltage. For irradiated detectors, the collected charge continues to increase, although slowly, even tens of volts after depletion.

In the beam test threshold scans at different bias were taken. For biasing the detectors a pad on the hybrid is used. In between the hybrid bias pad and the detector a resistance of 11 KΩ has been measured. In order to know the real voltage on the detector it is necessary to subtract the voltage drop in the resistance. Currents from 1 mA to 3 mA at 500 V lead to a voltage on the detector of 490 to 470 Volts.

The ratio of both numbers, median charge and noise, the S/N, is less sensitive to errors in calibration. Figures 8, 9 and 10 are some examples from the modules of the test beam.

The plots have been put into groups of similar types. Figure 8 shows two end-cap modules from two irradiation periods. Not only S/N value at 500 V is

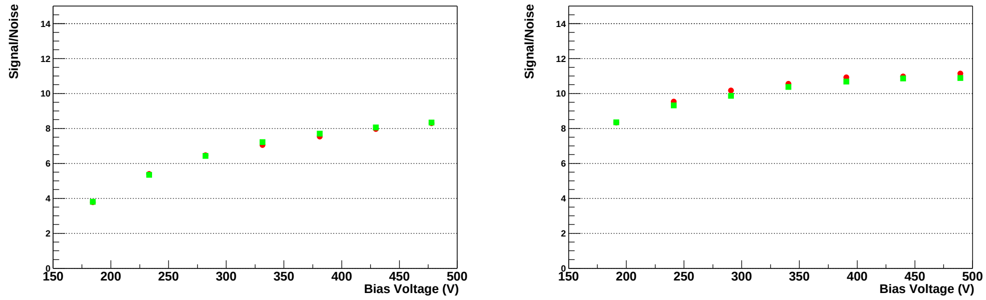

Fig. 8. Variation of the signal to noise ratio with detector voltage for two endcap modules, K5 308* (left) and K5 310* (right). Different markers distinguish different links (chips).

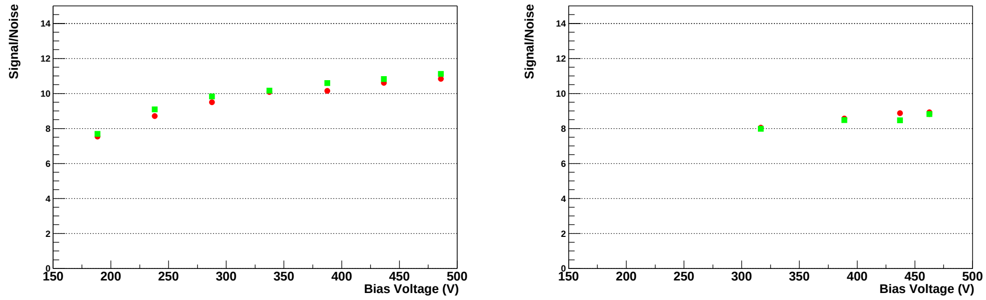

Fig. 9. Variation of the signal to noise ratio with detector voltage for two barrel modules, 0034* (left) and 0096* (right). Different markers distinguish different links (chips).

different (table 4), also the bias dependence. In figure 9 the 0034* and 0096* variation with bias is plotted.[4] The last two plots, figure 10, are S/N from a non-irradiated barrel and the end-cap hybrid, K5 315†.

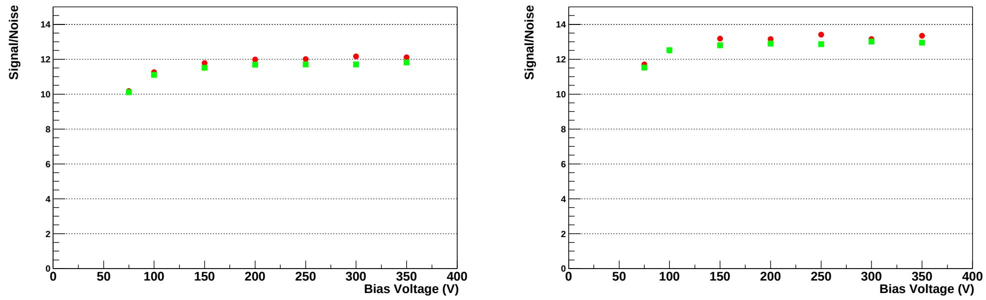

Fig. 10. Variation of the signal to noise ratio with detector voltage for two modules, hybrid K5 315† (left) and non irradiated 0097 (right). Different markers distinguish different links (chips).

[4] The annealing of the 0096* module finished close to the end of the beam test, and only four bias points were taken.

4 Chip-to-Chip variation

In previous beam tests it was noticed that the behavior of chips of the same module is not the same. It was found that the median charge and S/N changes form one chip to another. The spread is larger after irradiation.

In order to quantify the deviation, scans at the same voltage, but with the beam pointing to different chips were taken. Figure 11 shows the values for charge and S/N across the module for the K5 308*.

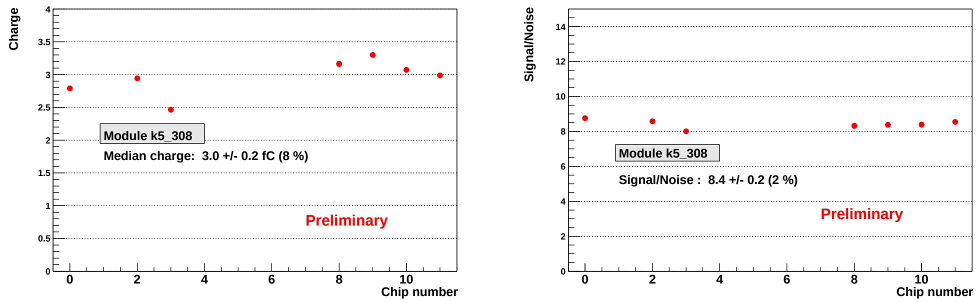

Fig. 11. Values of the charge in fC (left) and S/N (right) for the chips of the module K5 308* measured in the test beam.

Table 6 shows the mean value of median charge and S/N . The error in both cases is the standard deviation. The spread in observed charges in the irradiated modules is quite large. The error due to variations in the calibration of the chips is estimated to be around 0.2 fC (standard deviation). For the end-cap modules the variation in the S/N from different chips is smaller than the variation of either charge or noise. This reflects the cancellation of the absolute scale of the calibration [5] .

Different front end settings were probed in the end-cap modules to see the influence in the S/N value. An optimization of the gain and noise was done. One of the settings with a high pre-amplifier bias current (A) minimizes the noise, leading to a relatively low gain. The second set with low pre-amplifier current (B) has a slightly higher gain, at a moderate cost in noise. For each of the front-end settings the modules were calibrated. A table has been made with results for the different settings. The median charge of six chips is written in table 7. No change in the median charge is observed due to difference in the front-end settings. The S/N ratio doesn't improve increasing the gain.

[5] The barrel modules results are being investigated

Module	Charge (fC)	S/N
0044*	3.32 ± 0.12 (3%)	10.8 ± 0.9 (8%)
0047*	3.2 ± 0.2 (6%)	10.2 ± 0.7 (6%)
007*	3.68 ± 0.17 (4%)	12.8 ± 0.7 (5%)
034*	3.51 ± 0.09 (2%)	11.6 ± 0.6 (5%)
097	3.19 ± 0.15 (4%)	12.9 ± 0.6 (4%)
K5 308*	3.0 ± 0.2 (8%)	8.4 ± 0.2 (2%)
K5 310*	3.3 ± 0.3 (8%)	11.2 ± 0.2 (2%)
K5 312*	3.21 ± 0.08 (2%)	11.0 ± 0.2 (1%)
K5 315†	3.6 ± 0.2 (5%)	11.8 ± 0.3 (2%)

Table 6
Mean values for charge in fC and signal to noise ratio of the irradiated modules and the new barrel at 500 V. We have written the standard deviation and the equivalent percentage of the error

Module	Chip	Settings	
		A	B
K5 308*	S2	2.95	2.94
	S11	3.29	3.30
K5 310*	S2	3.08	3.05
	S3	3.13	3.16
	S10	3.62	3.59
K5 312*	S11	3.27	3.29

Table 7
Median charge values at a bias voltage of 500 Volts for the different front-end settings. *A* high pre-amplifier current and *B* low pre-amplifier current.

References

[1] J.E.Garcia et al. Charge collection with binary readout. ATLAS Internal Note in preparation.

[2] A.Barr et al., Beamtests of ATLAS SCT Modules in August and October 2001, submitted as ATLAS internal note, ATL-COM-INDET-2002-017

[3] A.Barr et al., Results from an LHC structured beam test on SCT module prototypes, ATLAS Internal Note in preparation.

[4] S.Gadomski, P.Reznicek, Measurement of amplifier pulse shapes in SCT modules using a laser setup. ATL-INDET-2001-010