Module 0 FEB Measurements of the DMILL Engineering Run SCA Chips

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Abstract

A set of 16 DMILL Switched Capacitor Array (SCA) chips taken from the engineering run have been installed on an ATLAS LAr Module 0 Front End Board (FEB). We describe results of measurements of the SCA chip performance on the Module 0 FEB.

1 Introduction

The Module 0 FEB [1] is a full-sized prototype of the FEB, developed for evaluation of the FEB concept and to enable the readout of the calorimeter modules in the on-going testbeam effort. The Module 0 FEB implements the final FEB functionality and channel density. The analog signal processing chain employs full-functionality prototypes of the preamplifiers, shapers, and SCAs, and very closely resembles that foreseen for the final ATLAS FEB. However, the Module 0 FEB utilizes prototypes of some components which are not expected to satisfy the ATLAS radiation tolerance specifications. In particular, the Module 0 SCA chips were produced with a (now obsolete) 1.2 μm CMOS process from HP.

For use on the final ATLAS FEB, the SCA design has been migrated to the DMILL process. The DMILL "HAMAC" SCA and the Module 0 (HP) SCA are pin-to-pin compatible; by simply changing the values of some external resistors used to set bias currents for on-chip amplifiers, it is possible to operate a Module 0 FEB with HAMAC SCA chips.

In order to evaluate the *in situ* performance of the HAMAC SCA chips, we have retrofitted a Module 0 FEB with 16 DMILL SCA chips, corresponding to 1/2 FEB, or 64 channels.

2 Measurement setup

We installed 8 HAMAC Standard chips and 8 HAMAC Mirror chips, for a total of 16 HAMAC SCA chips (corresponding to 64 channels) onto one-half of a Module 0 FEB. The Standard and Mirror chips are installed on the top and bottom layers of the same half of the FEB, so that the test provides verification that the Standard and Mirror versions of the SCA properly obey the sharing of the same analog output lines to the ADC.

Measurements were made using the FEB test setup at Nevis Labs. The Module 0 FEB was equipped with 10 mA, 25 Ohm preamps, and installed in a slot of the Front End Crate equipped with prototypes of the final input connector shields. At the back of the crate baseplane, each FEB input was loaded with a 400 pF capacitor to mimic the connections to a detector. Injection resistors were also present in order to allow injection of calibration pulses from the Module 0 Calibration (CALIB) Board. The CALIB board allows injection of calibration signals which approximate the expected calorimeter pulseshape. The pulse delay, pattern of channels which are pulsed, and pulse amplitude are all programmable. The range of possible amplitudes covers the entire dynamic range of LHC physics signals.

3 Noise Measurements

Measurements without calibration pulses enabled were used to analyse the noise performance. We have analysed the data from three perspectives: the total noise per channel, the noise contribution coherent to all channels, and the so-called "Fixed Sequence Noise" related to the spread in measurements over the 144 capacitor cells of a single SCA channel.

3.1 Total noise

Figure 1 shows the noise as a function of channel number for the 64 HAMAC-equipped channels.

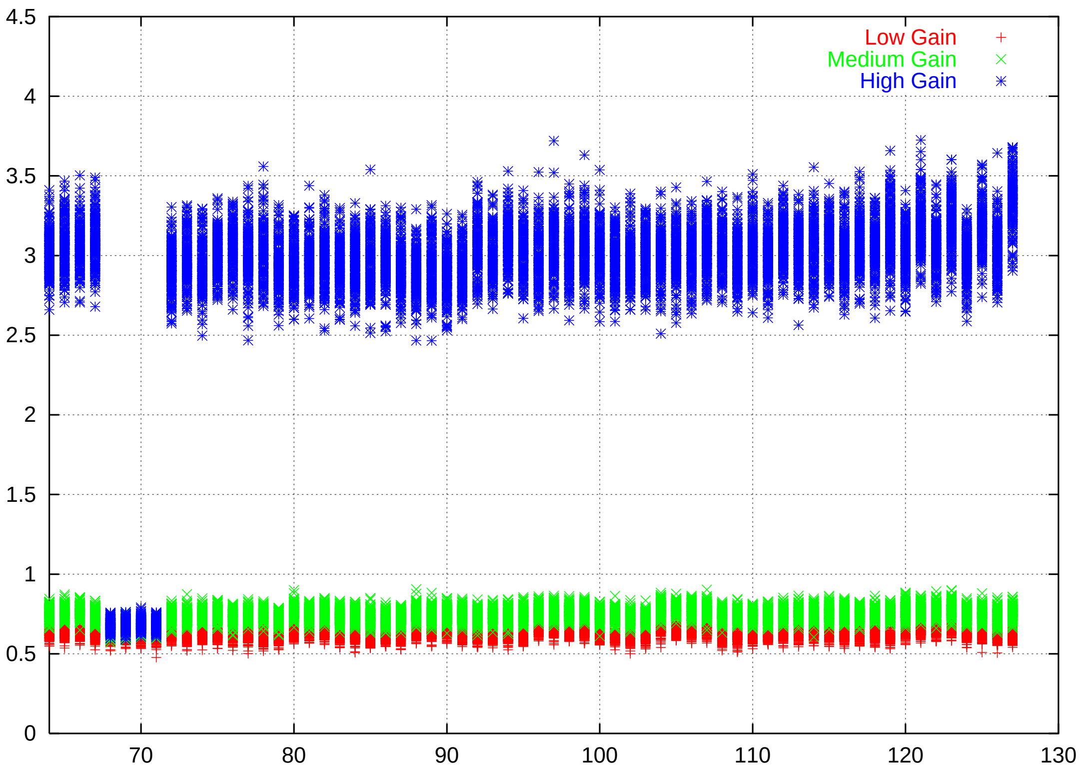

Figure 1: Measured noise, in ADC counts, versus channel number. For each channel and gain, a total of 144 measurements are plotted since the noise is shown separately for each SCA capacitor cell.

Gain Scale	Noise (ADC Counts)	
	Individual Channels	Sum of 64 Channels
HIGH	3.1	40.7
MED	0.75	8.15
LOW	0.62	6.62

Table 1: Summary of noise measurements for the three gain scales. The middle column lists the mean of the measured noise values for the 64 individual channels, while the last column lists the noise measured in the digital sum of 64 channels. One ADC count corresponds to approximately 1 mV as measured at the SCA output.

Table 1 summarizes the results of the noise measurements in the three different gain scales of the readout. Consistent with previous Module 0 FEB measurements using HP SCA chips, the noise on the HIGH gain scale is dominated by the preamplifier noise. (This can be seen clearly in Figure 1 by the set of 4 channels with "low" HIGH gain noise, where the corresponding preamplifier has been removed for sake of illustration.) The results for MED and LOW gain are dominated by the quantization error of the ADC but receive also non-negligible contributions from the shaper and SCA chips. The MED noise is slightly higher than for LOW gain due to the larger noise contribution from the shaper. The noise measurements summarized in Table 1 are very similar to measurements made with Module 0 SCA chips.

The SCA noise contribution is difficult to determine from measurements on the FEB since, by design, the SCA contributes a relatively small part of the overall noise. Measurements made in the past on a partially assembled Module 0 FEB [1] yielded a noise of 0.4 ADC counts from the ADC and discrete op-amps, increasing to 0.5 ADC counts when adding the HP SCA, and finally to 0.6 ADC counts for LOW gain when adding the shaper and preamp. This analysis implies an SCA noise contribution of about 0.3 mV, with however an almost 100% uncertainty.

A more precise characterization of the SCA noise requires a separate test jig with higher gain, such as was used for the noise measurements of the HAMAC chips (see the other PRR presentations). From the FEB measurements, we can conclude that the HAMAC SCA noise is sufficiently small so as to not significantly degrade the FEB measurements.

3.2 Coherent noise

An important parameter for the LAr readout is the level of coherent noise, which we compute by comparing the noise of the sum of the 64 HAMAC-equipped channels with the individual noise measurements of the 64 channels (the data is listed in Table 1). With the assumption that contributions to the coherent noise are constant across all 64 channels, we determine a coherent noise per channel of 0.5, 0.09, and 0.07 ADC counts for the HIGH, MED, and LOW gain scales, respectively. The rather large value in HIGH gain is due to the use of early prototype connector shielding and isolation on this Module 0 FEB, allowing some ground noise to be injected into, and subsequently amplified by, the preamplifier and shaper chain. However, the small values for MED and LOW gain make clear that the coherent noise performance of the SCA chips is perfectly satisfactory.

3.3 Fixed sequence noise

An additional quantity of interest for the noise performace of the SCA is the level of "Fixed Sequence Noise" (FSN), namely the RMS of the baseline as measured for the 144 individual capacitors of a given channel. FSN can arise due to effects such as capacitor address-related noise injection on the SCA or differences in the offsets of individual cells. The measured FSN versus channel number is displayed in Figure 2 for all three gain scales.

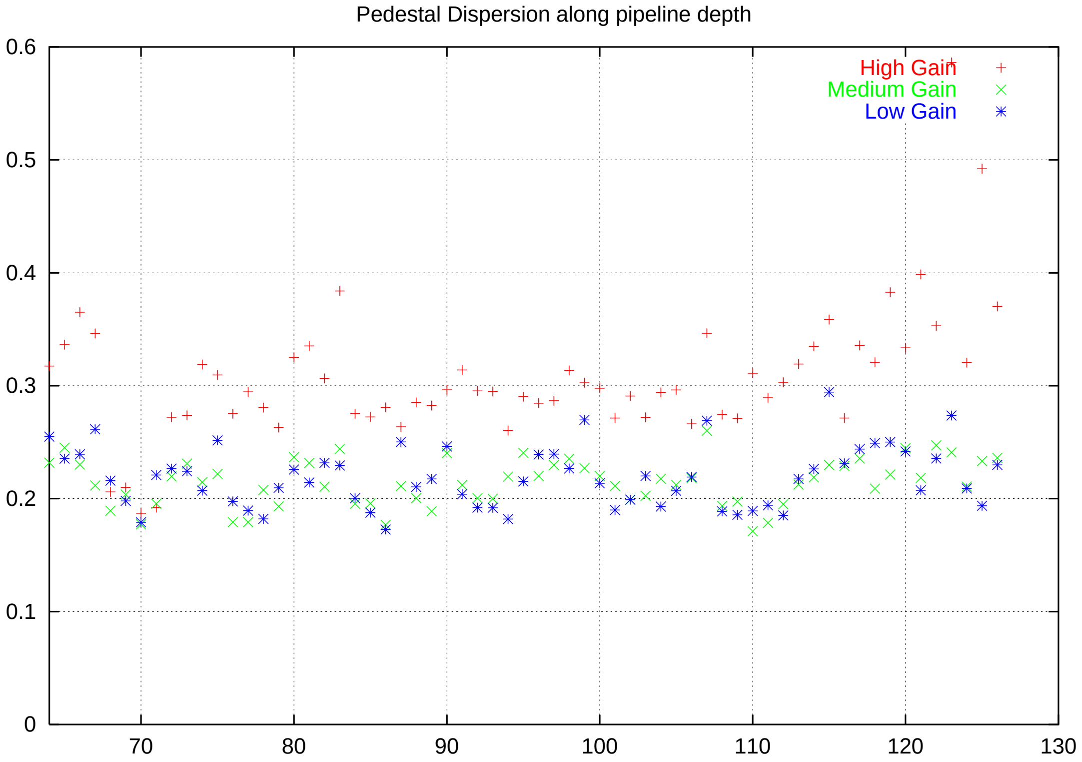

Figure 2: "Fixed sequence noise", in ADC counts, versus channel number.

As can be seen from Figure 2, the FSN noise for MED and LOW gains is approximately 0.22 ADC counts (0.22 mV), with the HIGH gain value being a somewhat higher 0.35 ADC counts (0.35 mV), due presumably to a slight sensitivity of the preamp/shaper section of the FEB to noise from the on-board SCA address buses.

3.4 Summary of noise measurements

Measurements of the noise, coherent noise and fixed sequence noise of the HAMAC-equipped channels all show results which are satisfactory, and which are very similar to previous measurements with HP SCA chips.

4 Pulse Measurements

We have used the Module 0 CALIB board as a programmable source of calibration pulses similar in shape to the calorimeter physics signals. Figure 3 shows the pulse shapes measured in one HAMAC-equipped channel of the FEB.

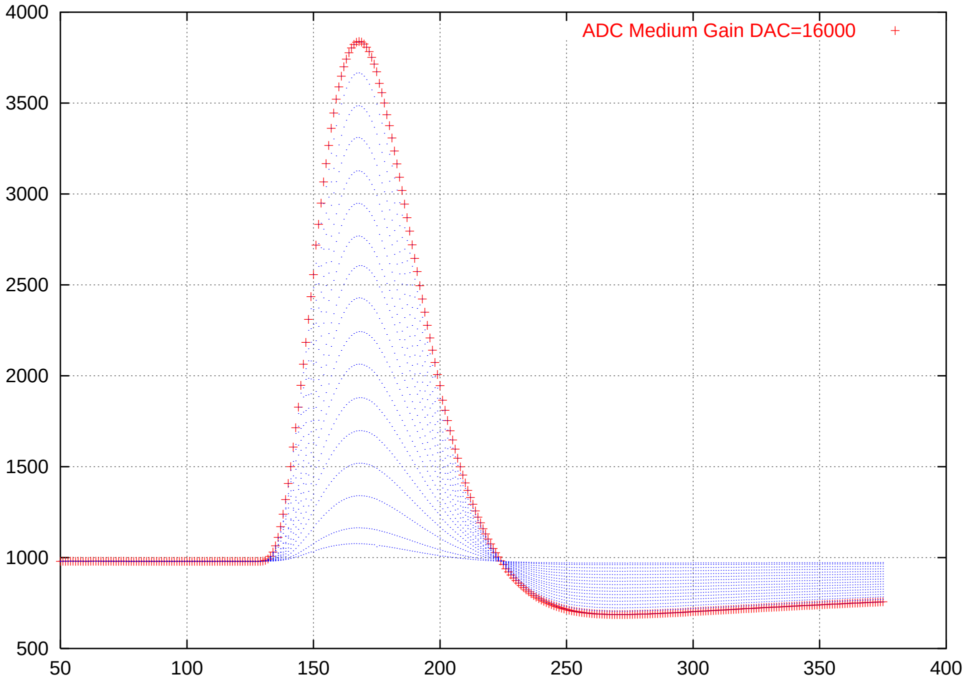

Figure 3: Calibration pulses measured with one of the HAMAC-equipped channels of the Module 0 FEB. The pulse height is measured in ADC counts, while the horizontal axis displays the time in ns.

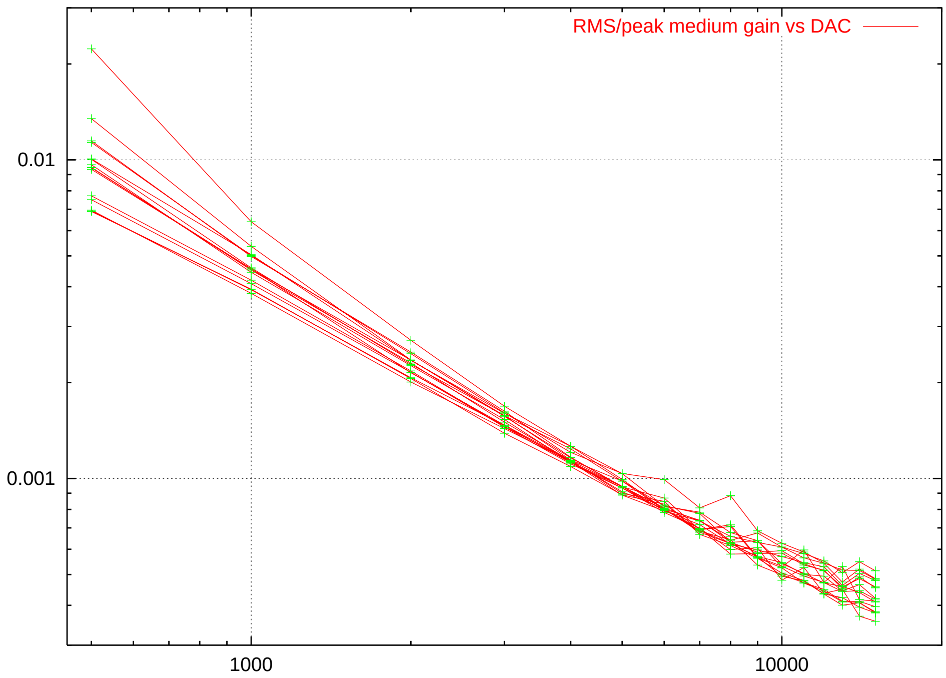

Figure 4: Pulseheight resolution for several HAMAC-equipped channels as a function of the calibration pulseheight.

The curves in Figure 3 were formed by pulsing with a range of amplitudes, and by superimposing runs of the same amplitude but with different values programmed for the pulse delay.

4.1 Pulse amplitude reconstruction

While the final readout will use an optimal digital filter to calculate the pulse amplitude from typically 5 samples of the waveform, it suffices for our purposes here to measure the amplitude using a single sample placed at the peak of the pulse. While this simplified reconstruction does not have optimal noise performance, it is sensitive to any distortion of the pulse or non-linearity introduced by the FEB, including the HAMAC chips.

Figure 4 shows the RMS of the peak sample divided by the peak amplitude for a number of MED gain channels, as a function of the DAC setting (ie. pulseheight programmed on the CALIB board). The displayed results are typical of the results of all HAMAC-equipped channels.

For small pulseheights, the RMS of the peak sample is identical to the noise measured on the baseline. As the amplitude increases, the relative resolution (RMS/peak) should drop as 1/peak assuming a constant RMS, producing a straight line on Figure 4. In fact, the data follows this behavior closely, deviating only slightly for large pulses, as would be expected due to a number of effects such as timing jitter, imperfect placement of the peak sample exactly at the peak, etc. However, large pulses are measured with a resolution well below 0.1%, which is significantly better than the requirement of 0.25%. Similar behavior was observed with the HP SCA chips.

4.2 Pulse linearity

The peak sample can also be used to measure the linearity of the FEB. Figure 5 shows the residuals, normalized to the maximum pulse amplitude, from a straight line fit of the peak versus the CALIB DAC value.

As can be seen from Figure 5, beginning at reasonably large DAC values the non-linearity is below 1% of fullscale. The somewhat larger deviations for small DAC values result from the fact that using only the peak sample does not allow for proper subtraction of the clock feedthrough introduced by the calibration pulser.

5 Conclusions

Measurements of noise and response to calibration pulses were made with 64 channels of a Module 0 FEB retrofitted with 16 HAMAC SCA chips. The tests verified proper operation of the HAMAC chips in an environment very similar to their use on the final ATLAS FEB. The analog measurements showed excellent agreement with previous measurements using Module 0 HP SCA chips, verifying the suitability of the HAMAC chips for use in the ATLAS LAr readout.

References

"Design of the ATLAS LAr Front End Board", ATLAS Note number ATL-AL-EN-0009; Available at `http://www.nevis.columbia.edu/~atlas/electronics/Module0FEB/Module0FEB.html`.

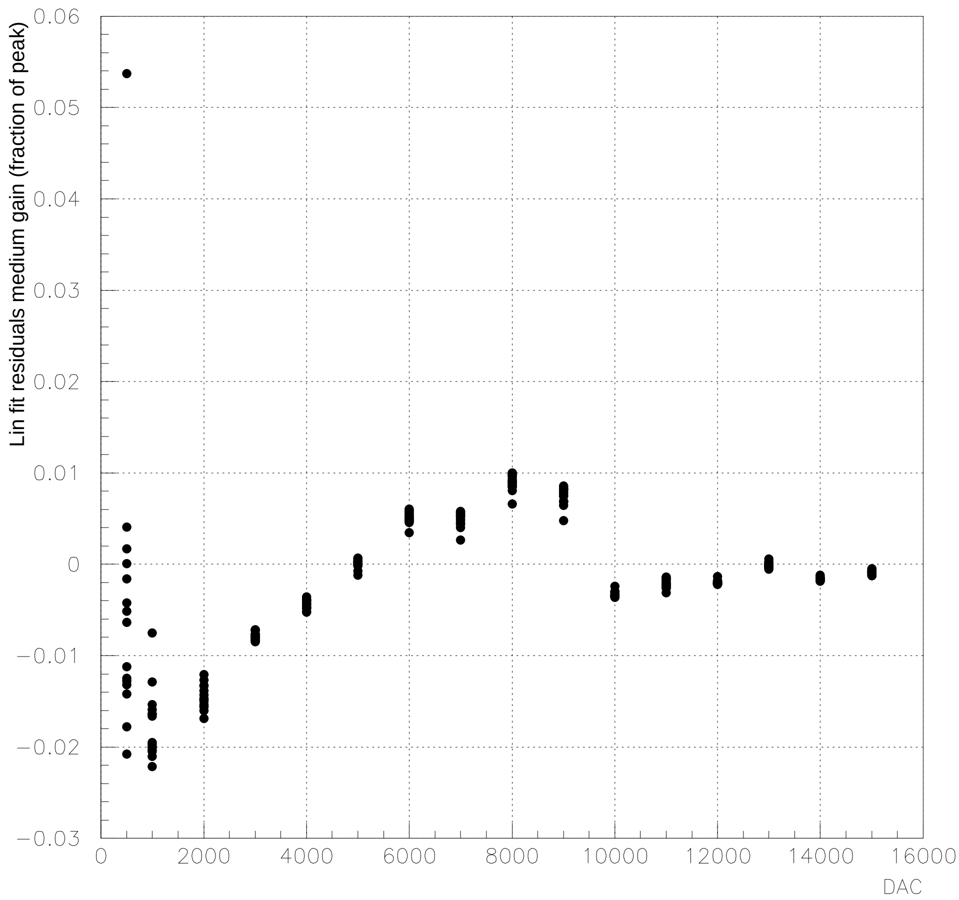

Figure 5: Normalized deviations from linearity of the FEB peak sample versus CALIB DAC setting.