Performance of the liquid argon final calibration board

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ATLAS

Performance of Calib128 LArG final calibration board

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ATLAS Lar em calorimeter readout overview

Calibration :
116 boards @ 128 ch

Front End Board (FEB) :
1524 boards @ 128 ch

Electrodes

Front End Crate:

Cold to warm
Feedthrough

Readout and
Calib. signals

Cryostat

CALIBRATION: Requirements and Principle

- **Goal:** Inject a precise current pulse as close as possible as the detector pulse
 - Injection with precision resistors
 - Rise time < 1ns, Decay time ~ 450 ns .
- **Dynamic range : 16 bits**
 - Output pulse : 100 μ V to 5V in 500
 - Integral non linearity < 0.1% .
- **Uniformity between channels < 0.25%**
 - To keep calorimeter constant term below 0.7%)
- **Timing between physics and calibration pulse ± 1 ns**
- **Operation in around 100 Gauss field**
- **Radiation hardness:**
 - 50 Gy, $1.6 \cdot 10^{12}$ Neutrons/cm² in 10 years
 - Qualification at 500 Gy, $1.6 \cdot 10^{13}$ Neutrons/cm² to include safety factors
- **Run at a few kHz**

$$I_{cal} = I_{dc} \frac{R_0/2}{R_{ini}} e^{-2R_0 t/L}$$

HISTORY

12 boards produced in 1998 with COTS for module 0

- 5 years successful operation in beam tests.
- Excellent uniformity : 0.11% rms on 1300 channels
- But **radiation soft** : COTS failed at 20 Gy

Active elements designed in DMILL in 1999-2001

- DAC, Pulser, Control logic, delay chip
- Radiation qualified at 5 kGy
- **Improved performance** (DAC stability, parasitic signal at DAC=0, DAC stability and offset)
- Simplified logic, 10 Alteras replaced by 6 identical ASICs (DMILL Calogic)
- **All ASICs produced** in 2003, currently under test

3 radiation hard boards produced in 2002-2003

- Final design review in 2002
- Production readiness review passed in march 2004
- Production of 140 boards in 2004-2005

CALIBRATION BOARD : ANALOG PART

- A 16 bit DAC voltage is distributed to the 128 channels.
- One low offset op.amp. per channel generates the calibration current I_{CAL} through a 50 [0.1%] external precision resistor.
- The pulse is made by interrupting I_{CAL} with a high frequency switch

Final calibration board layout

DC linearity

■ DC output current : I_{CAL}

■ Linearity on the 3 shaper ranges

- High gain HG = G100 :
DAC = 0 – 655 (0-10 mV)
- Medium gain MG = G10 :
DAC = 0 – 6535 (0-100 mV)
- Low gain : LG = G1 :
DAC = 0 – 65535 (0-1 V)

■ Linearity < 100 ppm (0.01%)

- HG : $< \pm 1 \mu\text{V}$ (0.07 LSB) rms 58ppm
- MG $< \pm 10 \mu\text{V}$ (0.7 LSB) rms 85 ppm
- LG $< \pm 50 \mu\text{V}$ (3 LSB) rms 28 ppm
- Dominated by DAC linearity

IDC/DAC	P0	P1	RMS
High Gain	2.5 μA	3.0080 $\mu\text{A/DAC}$	58 ppm
Mid Gain	7.1 μA	3.0056 $\mu\text{A/DAC}$	85 ppm
Low Gain	6.7 μA	3.0056 $\mu\text{A/DAC}$	28 ppm

DC uniformity

DAC=0 : offset dominated

- AVG = $4.5\mu\text{A}$ = 1.5 LSB
- RMS = $2.2\mu\text{A}$ = 0.7 LSB

DAC=655 (full scale HG)

- Without offset correction
 - AVG = $1975\mu\text{A}$
 - RMS = $2.7\mu\text{A}$ = 0.9 LSB
- With offset correction
 - AVG = $1971\mu\text{A}$
 - RMS = $1.21\mu\text{A}$ = 0.06 %

DAC = 6553 (full scale MG)

- AVG = 19.71mA
- RMS = $13.6\mu\text{A}$ = 0.06%
- Dominated by dispersion on 50 0.1% resistor

DC uniformity 128ch

IDC (μA)

IDC (mA)

IDC (mA)

DAC=2999

Pulse shape before shaping

- **Full DAC range**
 - $100\text{ }\mu\text{V} \rightarrow 1\text{V}$
 - Up to 5V pulses in 500
- **Rise time < 2 ns**
 - Small increase at large DAC
- **Decay time ~ 450 ns**
 - Matched to Argon drift time
 - Accuracy : $\pm 2\%$
- **HF Ringings :**
 - At small DAC values, due to parasitic package inductance in HF switch
 - « Parasitic injected charge »
 - 20 mV pk-pk
 - Very small area

Pulse output without shaping

Pulse shape after shaping

Parasitic injected charge (PIC)

- Peak of Q_{inj} : equivalent to $DAC=30\text{ }\mu\text{V}$ (2LSB)
- At signal peak :
 $PIC < DAC = 15\text{ }\mu\text{V} = 1\text{ LSB}$
($\sim 30\text{ MeV}$ in Barrel Middle $<$ noise)
- Improvement by >10 compared to module 0

CMD feedthrough

- Parasitic pulse on disabled channels
- Equivalent to $DAC=3\text{ }\mu\text{V} = 0.2\text{ LSB}$: $\sim$ negligible

pulse uniformity and linearity

■ Linearity : $< 0.1\%$

- Red : at signal peak
- Black : peak of signal
- Dominated by readout non-linearity

■ Uniformity at DAC=5000

- Rms : 0.13% (DC was 0.07%)
- Additional contribution from output resistors, output lines, inductors and scanner board

pulse linearity vs DAC

Timing performance

- **Jitter of output pulse < 75 ps**
 - Diminated by TTCRx chip
- **Delay chip (PHOS4)**
 - Used to adjust timing between calibration pulses and particles with 25 steps of ~ 1 ns
 - Linearity : residuals within 50ps
 - Slope : varies with channel inside chip (by up to $\pm 10\%$)

Output pulse jitter vs channel#

Delay linearity

Delay step vs channel#

Calibration sensitivity to cables

■ Sensitivity to cable characteristic impedance Z_c

- Second order effect (if terminated both ends) : $dV/V = 1 - (dZ_c/2Z_c)^2$
- $\pm 2.5\Omega$ tolerance on cable gives $\pm 0.1\%$

■ Sensitivity to skin effect

- First order effect :
 - - 1.2 %/m @ 300 K,
 - - 0.5 %/m @ 77 K
- Correction necessary for cable length
- Calibration cable length : 3-6 m :
expect ~ 0.2% contribution at cold
(~0.4% at warm)

Calibration at cable output

Calibration pulse at cable output

pulse uniformity at cable output

Difference between calibration and physics

■ Calibration pulse shape

- Exponential shape vs triangle
- Systematic effect in $t_{\text{SHAPER}}/t_{\text{CAL}}$
- Accuracy in calib decay time t_{CAL} : $\pm 2\%$

■ Detector inductance

- Physics signal at shower max in the middle of the accordion : non negligible output line : **inductive effect**
- Sizeable effect : - **0.2%/nH** on physics/calibration ratio
- Inductance measurement necessary

LAr : detector modelization

Line model

- "stripline" Absorber-LAr-HV-Kapton-Signal. Propagation $t_d = 4.12 \text{ ns/m}$
- Solving Poisson to calculate capacitances C_d , C_x and impedance : $Z_c = t_d/Ct$

Good lumped model

- Detector ($Z_c = 1.5\text{-}20 \text{ } \Omega$) = capacitance (1 - 1.5nF)
- Connection ($Z_c = 15\text{-}200 \text{ } \Omega$) = inductance (20-30 nH)
- (Difficult) measurement of $f_0 = 1/2\pi\sqrt{LC}$

Conclusion

- **Calibration board for ATLAS Lar calorimeter final**
 - 16 bits dynamic range : 100 μ V – 5 V pulses
 - Linearity better than 100 ppm
 - Board uniformity < 0.2%
 - Overall uniformity < 0.3%
 - Jitter < 100 ps
 - Radiation hard
- **Production of 140 boards in 2004**
 - DMILL ASICs all produced
 - Final prototype validated
 - Installation beginning of 2005
- **Calibration of calorimeter needs additional inputs**
 - Fine effects due to detector parasitic inductance need to be corrected for
 - A major activity in 2002-2003
 - See talks by L. Serin and O. Gaumer