Performance of the liquid argon final calibration board
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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

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 µV to 5V in 50O
  - Integral non linearity < 0.1%
- **Uniformity between channels** < 0.25%
  - To keep calorimeter constant term below 0.7%
- **Timing between physics and calibration pulse** ±1ns
- **Operation in around 100 Gauss field**
- **Radiation hardness:**
  - 50 Gy, 1.6 $10^{12}$ Neutrons/cm$^2$ in 10 years
  - Qualification at 500 Gy, 1.6 $10^{13}$ Neutrons/cm$^2$ to include safety factors
- **Run at a few kHz**
**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

![Uniformity of Calib0](image)
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 5Ω [0.1%] external precision resistor.
- The pulse is made by interrupting $I_{CAL}$ with a high frequency switch.

16 bits R-2R DAC
- $V_{max} = 1V$
- LSB = 15 µV

V follower
- $V_{DAC}$

$5Ω$
- 0.1%

VP5 reference point

50Ω
- 0.1%

128 Low Offset Opamps
- Offset < 10 µV
- V -> I conversion
- $I_{max} = 200 mA$
- LSB = 3 µA

Vout: 50µV to 5V
Final calibration board layout

- 128 Opamps & switch
- Outputs CH0-63
- DAC
- Outputs CH64-127
- Callogic
- VP5 «star point»
- DCU
- TTCRx
- Delay (bottom)
- SPAC3
DC linearity

- **DC output current**: $I_{\text{CAL}}$

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

<table>
<thead>
<tr>
<th>IDC/DAC</th>
<th>P0</th>
<th>P1</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Gain</td>
<td>2.5 µA</td>
<td>3.0080 µA/DAC</td>
<td>58 ppm</td>
</tr>
<tr>
<td>Mid Gain</td>
<td>7.1 µA</td>
<td>3.0056 µA/DAC</td>
<td>85 ppm</td>
</tr>
<tr>
<td>Low Gain</td>
<td>6.7 µA</td>
<td>3.0056 µA/DAC</td>
<td>28 ppm</td>
</tr>
</tbody>
</table>
**DC uniformity**

- **DAC=0**: offset dominated
  - AVG = 4.5 µA = 1.5 LSB
  - RMS = 2.2 µA = 0.7 LSB

- **DAC=655** *(full scale HG)*
  - Without offset correction
    - AVG = 1975 µA
    - RMS = 2.7 µA = 0.9 LSB
  - With offset correction
    - AVG = 1971 µA
    - RMS = 1.21 µA = 0.06 %

- **DAC = 6553** *(full scale MG)*
  - AVG = 19.71 mA
  - RMS = 13.6 µA = 0.06%
  - Dominated by dispersion on 5Ω 0.1% resistor
Pulse shape before shaping

- **Full DAC range**
  - 100 $\mu$V $\rightarrow$ 1V
  - Up to 5V pulses in 50O

- **Rise time $<$ 2 ns**
  - Small increase at large DAC

- **Decay time $\sim$ 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

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Pulse output without shaping
Pulse shape after shaping

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

- **CMD feedthrough**
  - Parasitic pulse on disabled channels
  - Equivalent to $\text{DAC}=3 \ \mu\text{V} = 0.2 \ \text{LSB} : \sim\text{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
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 ± 10%)
Calibration sensitivity to cables

- **Sensitivity to cable characteristic impedance \( Z_c \)**
  - Second order effect (if terminated both ends): \( \frac{dV}{V} = 1 - \left( \frac{dZ_c}{2Z_c} \right)^2 \)
  - ± 2.5Ω tolerance on cable gives ± 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

50Ω coax
l=1-5m

50Ω coax
l=1m

35Ω stripline
l=0.3m

35Ω stripline
l=0.3m

Feedthrough

Calibration pulse at cable output

T=300K

Feedthrough reflection

pulse uniformity at cable output

T=300K

rms 0.44%
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 $t_{\text{CAL}}$: ± 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

[Diagram showing physics and calibration signals]
**ATLAS 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: $Z_c = t_d/C_t$
- **Good lumped model**
  - Detector ($Z_c = 1.5-20\Omega$) = capacitance (1 - 1.5nF)
  - Connection ($Z_c = 15-200\Omega$) = inductance (20-30 nH)
  - (Difficult) measurement of $f_0 = 1/2\pi vLC$

![Diagram of detector modelization](attachment:image.png)

**Detector simulated impedance**

![Graph of measured and simulated impedance](attachment:graph.png)

**Measured impedance**

- **Frequency**
  - **Amplitude in db**

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31 march 2004
C. de La Taille
ATLAS LAr calibration board
CALOR 2004
Perugia
Conclusion

- **Calibration board for ATLAS Lar calorimeter final**
  - 16 bits dynamic range: 100 $\mu$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