Overview of the LHCb Calorimeter Electronics

… focus in the ECAL/HCAL

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On behalf of the LHCb calorimeter group

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Calorimeter System

- **Requirements:**
  - Energy / Position measurements
  - Identification of hadrons, electrons, $\gamma$, $\pi^0$
  - L0 Trigger input (SPD/PRS/ECAL/HCAL):
    - High sensitivity & Fast response (40MHz)
  - No electronics pile-up (25 ns shaping)

**Scintillating Pad Det (SPD)**
- Preshower (PRS)
  - Scint. Pad + Fibres+ MAPMT
  - 5953 cells each

**ECAL**
- Shashlik (Pb-scint.)
  - 5953 cells

**HCAL**
- Tiles (Iron-scint.)
  - 1468 cells

Front-end partly common same crates

Calibration Power supply

Front-end Crates Power Supply

SPD-PRS Very front-end

same electronics same crates
Electronics Overview: SPD - PRS

- **Light transporter by clear fibers to 64 anode PMT**
  - Very front-end away from beam: no radiation problem

- **Dynamic range: 0 – 100 MIPs and accuracy required ~ 10%**
  - PRS: electron/pion separation → 10 bits
  - SPD: photon/mip separation → 1 bit

- **20 – 30 photo-electrons per MIP → large fluctuations**
- **25 ns integrator mounted on the PMT – Reset with switches**
  - Cheap and maximum use of the photo-electrons
  - Potentially more sensitive to noise, drift of pedestal and switch time versus beam crossing
SPD and PRS ASIC

- 25 ns integration contains ~80% of the charge
- Two parallel integrators running at 20MHz and multiplexed at the output
- Differential chips
- Need to remove ~20% of the previous sample

**PRS**

- LSB is fixed to 1/10 of MIP
  - Proper precision
  - Dynamic coverage
- The integrator drives a 10bit ADC

**SPD**

- Threshold is low and need to remove 20% of previous sample
- Threshold comparison
- Digital Output (one bit)
  - LVDS serializers

See following talk by Stéphane Monteil…

Production Readiness Review passed
PMT are located (partly) in high radiation area (0.4Mrad/year)
- Signal transported to shaper/integrator by coax cable

- Dynamic range is 0 - 10GeV/c (Et)
- ECAL resolution: 10%/√E⊕1%
- HCAL resolution: 80%/√E⊕10%

- Typically 500-1000 photo-electrons / GeV (50) in ECAL (HCAL)
  - PM pulses shaped to 25ns before integration (delay line clipping)
ECAL – HCAL ASIC

**Shaping and integration**
- Pulse shaping in 25 ns
- Residue < 1% after 25 ns
- Integrator plateau: 4 ns
- Linearity < 0.5%
- Rise time \( \sim 5 \) ns

![Diagram showing pulse shaping and integration](image.png)

- **INTEGRATOR INPUT SIGNAL**
- **ADC INPUT SIGNAL**

Already produced and tested
Level 0 trigger

- **Level-0 trigger : Hardware system**
  - Pipelined operations, fully synchronous, with fixed latency (4µs)
  - Reduce rate from 40MHz to 1MHz
  - Detector used : Vertex detector, Muon and Calorimeter (SPD, PRS, ECAL and HCAL)

- **Select High Pt particles**
  - Because of the B meson high mass, at least one decay particle has a high Pt (several GeV/c)

- **Calorimeter trigger works for**
  - electron, photon and neutral pions : ECAL deposits
  - Hadrons : HCAL deposits
  - SPD-PRS : particle identification

- **Logic based on Et on 2x2 cell area**
  - Value converted to 8 bits and sum cell Et
  - Access neighbours
    - Either from the same board
    - Or connect several boards/crate : dedicated backplane for connections
  - Keep only the highest local Et deposit

- **Calorimeter used to reject busy events at the trigger level : SPD multiplicity**
Trigger and readout architecture

PreShower / SPD  ECAL  HCAL

Detector + PM
6x4 cells/FE card

10 m cables
9U crates
14 ECAL crates
4 HCAL crates
8 FE cards per half
LVDS links
One Validation card
per half ECAL crate

Platform on top of calorimeter

2 x 8 Front-End boards
8U custom crate

Crate and Readout Controller
Trigger Validation

Validation Card

8 inputs x 8 bits

LUT

Highest Electron
highest Photon
highest local \eta
highest global \eta

8 inputs

LUT

address match

highest

4 inputs

4 outputs

WALL

Merge back to 50

Selection Crate

LVDS links

L0 Decision Unit

L1, HLT, DAQ

TTC, ECS

Level 0 Decision Unit

To DAQ

Barack

Frédéric MACHEFERT
Digital data treatment (x8/x4):
- Channel synchronisation
- Pedestal correction
- Trigger 8-bit generation:
  - Calibration
  - 5 GeV/c saturation
Data:
- L0 latency (256 deep)
- Derandomizer (16 deep)

Trigger data treatment:
- Send to neighbours
- Receives from neighbours
- Make 2x2 sums
- Sends maximum

Event Builder – Control:
- Header (evt id, evt type, …)
- 32 channels
- Trailer (parity, …)
Dedicated backplane

- ECS Power Supply Clock
- Trigger Readout
- Boards/crate interconnections

- External differential point to point transmission 280Mbit
- Internal differential point to point transmission 280Mbit
- point to point transmission 40MHz
- multi drop transmission 40MHz
- Isochronous point to point clock 40MHz
Radiation problems

- **Potential problems:**
  - Accumulated doses (200 rad/year at the level of the racks): 2 krad in 10 years
  - Single Event Effects (SEE):
    - Single Event Upset (SEU) – bit-flip in re-programmable FPGA/RAM
    - Single Event Latchup (SEL) – possibly destructive “short-circuit”

- In LHCb, main worry comes from neutron flux

![Spectrum](image)

- Components have been irradiated
  - Centre de Proton-Thérapie (Orsay)
    - Proton ($10^8 \text{cm}^{-2} \cdot \text{s}^{-1}$, 200 MeV)
  - GANIL (Caen): Heavy Ions
    - Krypton, 73 MeV/A & 58 MeV/A, ($10^5 \text{cm}^2 \cdot \text{s}^{-1}$)

Very efficient: the fragment is directly sent through the component!
Irradiation tests

- Typical dose effects starts to be observed only after 50 krad → OK!

- SEU quite easily observed
  - Protections implemented:
    - Registers are protected
      - Triple Voting (majority vote among three copies of the register)
    - Parity bit coded in the data
    - FPGA configuration protected intrinsically
      - Anti-fuse FPGA (ACTEL)

- SEL have been observed with typical flux corresponding several LHCb years
  - Very pessimistic assumptions included in the rate estimations
  - Never been destructive
    - power cycle
    - use MAX power switch component (tested at GANIL)
ECAL – HCAL electronics performances

Performances have been tested with a prototype of the board
- at CERN (test beam)
- on a dedicated test bench

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<th>Simulation results (50 °C)</th>
<th>Test results</th>
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<td>Dynamic range</td>
<td>1.4V 1.5V</td>
<td>1.4V 1.6V</td>
</tr>
<tr>
<td>Non linearity</td>
<td>+/-0.5% +/-1%</td>
<td>+/-0.4% -1%</td>
</tr>
<tr>
<td>Residue after 25ns</td>
<td>&lt;0.5%</td>
<td>&lt;1%</td>
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<tr>
<td>RMS noise after subtraction</td>
<td>160uV over 250 ohms</td>
<td>220uV over 250 ohms</td>
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<tr>
<td>Integrator gm</td>
<td>31mA/V</td>
<td>18mA/V</td>
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<tr>
<td>Fall time</td>
<td>5.5us</td>
<td>2us</td>
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<tr>
<td>Rise time</td>
<td>4ns</td>
<td>6ns</td>
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<tr>
<td>Integrator Rin</td>
<td>190 Ohms</td>
<td>270 Ohms</td>
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<tr>
<td>Integrator Open Loop gain</td>
<td>65dB</td>
<td>65dB</td>
</tr>
<tr>
<td>Crosstalk</td>
<td>&lt;0.4%</td>
<td>&lt;0.6%</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>60mW / channel</td>
<td>57mW / channel</td>
</tr>
</tbody>
</table>
ECAL – HCAL electronics performances

Test beam results

- By comparing FE and Lecroy (long int.)
  - Linearity measurements
- Taking into account particle time arrival in the coincidence window
  - Plateau width/shape effects (<1%)
Electronics performances: noise

Noise measured from 10 consecutive (40MHz) samples (no input signal)

**Incoherent noise** ($\sigma^2 \propto t$)

$$\sigma^2(t) = 0.60 + 0.02 \times t \text{ ADC}^2$$

**Coherent noise** ($\sigma \propto t$)

$$\sigma(t) = 0.08 + 0.5 \times 10^{-2} \times t \text{ ADC}$$

Extrapolation to a typical 3x3 cluster:

Coherent noise: 3.5 ADC
Incoherent noise: 2.4 ADC
Conclusion

- SPD, PRS and ECAL/HCAL are specific detectors

- Provide L0 input for trigger decision

- Three ASIC have been designed for the readout of the four Detectors
  - SPD → Barcelona
  - PRS → Clermont-Ferrand
  - ECAL/HCAL → Orsay

- Common system wherever possible
  - Digital electronics design (front-end board) partly common
  - Same crate with a dedicated backplane for trigger treatment

- Components have been tested for irradiation
  - Dose is OK – SEE protection taken into account in the design

- Electronics fulfill requirements

- Front-end board series production in autumn 2004