Overview of the LHCb Calorimeter Electronics

… focus in the ECAL/HCAL

Frédéric Machefert
(LAL, Orsay)

On behalf of the LHCb calorimeter group

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Calorimeter System

Requirements:
- Energy / Position measurements
- Identification of hadrons, electrons, ?, p
- 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 Crates
Power Supply

Calibration Power supply
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

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

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

Production Readiness Review passed

See following talk by Stéphane Monteil…
Electronics Overview ECAL - HCAL

- 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%/\sqrt{E}+1%
- HCAL resolution: 80%/\sqrt{E}+10%

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

12 bit ADC
Noise max require ~ 1 ADC
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 ~ 5 ns

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

This diagram illustrates the trigger and readout architecture for calorimetry, focusing on the PreShower, ECAL, and HCAL sections. It shows the flow of data from the calorimeter to the various processors and controllers, including LVDS links, 8 inputs x 8 bits, 2x8 Front-End boards, and 9U custom crates.

Key components include:
- PreShower/SPD
- ECAL
- HCAL
- Validation Card
- L1, HLT, DAQ
- TTC, ECS

The diagram highlights the integration of various technologies and components to ensure efficient data processing and transmission.
ECAL – HCAL: Front-end digital electronics

**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): 2krad 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

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

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</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>
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<tr>
<td>Non linearity</td>
<td>+/-0.5% +/-1%</td>
<td>+/-0.4% -1%</td>
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<td>Residue after 25ns</td>
<td>&lt;0.5%</td>
<td>&lt;1%</td>
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<td>RMS noise after subtraction</td>
<td>160uV over 250 ohms</td>
<td>220uV over 250 ohms</td>
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<td>Integrator gm</td>
<td>31mA/V</td>
<td>18mA/V</td>
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<td>Fall time</td>
<td>5.5us</td>
<td>2us</td>
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<td>Rise time</td>
<td>4ns</td>
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<td>Integrator Rin</td>
<td>190 Ohms</td>
<td>270 Ohms</td>
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<td>Integrator Open Loop gain</td>
<td>65dB</td>
<td>65dB</td>
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<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**