Overview of the LHCb Calorimeter Electronics

... focus in the ECAL/HCAL

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Calorimeter System

■ Requirements:

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

Front-end partly common
same crates

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

same electronics
same crates

ECAL
Shashlik (Pb-scint.)
5953 cells

HCAL
Tiles (Iron-scint.)
1468 cells

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 Threshold (1.5MeV $\Leftrightarrow$ 0.5MIP)

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**

See following talk by Stéphane Monteil...

SPD

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

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: $10\%/\sqrt{E} \oplus 1\%$**
 - **HCAL resolution: $80\%/\sqrt{E} \oplus 10\%$**
- } 12 bit ADC
Noise max require ~ 1 ADC
- **Typically 500-1000 photo-electrons / GeV (50) in ECAL (HCAL)**
 - PM pulses shaped to 25ns before integration (delay line clipping)

Shaping and integration

- Pulse shaping in 25 ns
- Residue < 1% after 25 ns
- Integrator plateau : 4 ns
- Linearity < 0.5%
- Rise time ~ 5 ns

Level 0 trigger

■ Level-0 trigger : Hardware system

- Pipelined operations, fully synchronous, with fixed latency ($4\mu\text{s}$)
- 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

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 differantial point to point transmission 280Mbit
- Internal differantial 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

$\text{MeV}^{-1} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$

■ Components have been irradiated

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

	Simulation results 50°C		Test results	
Dynamic range	1,4V	1,5V	1,4V	1,6V
Non linearity	+/-0,5%	+/-1%	+/-0,4%	-1%
Residue after 25ns	<0,5%		<1%	
RMS noise after subtraction	160uV over 250 ohms		220uV over 250 ohms	
Integrator gm	31mA/V		18mA/V	
Fall time	5.5us		2us	
Rise time	4ns		6ns	
Integrator Rin	190 Ohms		270 Ohms	
Integrator Open Loop gain	65dB		65dB	
Crosstalk	<0,4%		<0,6%	
Power Consumption	60mW / channel		57mW / channel

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 ($\sigma \propto t$)

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

Intrinsic ADC noise

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

} AMS 0.8u BiCMOS technology
- **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**