

Electronics and Triggering Challenges for the CMS High-Granularity Calorimeter

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Outline

- Brief Overview
 - Structure
 - Requirements
 - Constraints
- Tiling and Variants
- Readout Architecture
 - Data & Trigger Paths
- LD-HexBoard Design
- Power Tree
 - Power Modelling
- Mechanical Mockup
 - Phenomenology & design feasibility studies







Out with the old, in with the new...







- Calorimeter Endcap
 - Weight ~ 250 tonnes
 - Sampling calorimeter
 - CE-E(lectromagnetic) and CE-H(adronic)

Detector Structure and Key Parameters

Active Elements:

- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
- Scintillating tiles with SiPM readout in low-radiation regions of CE-H Key Parameters:
- HGCAL covers 1.5 < η < 3.0
- Up to 200 Mrads ; 8x10¹⁵ n/cm²
- Full system maintained at -30 °C
- ~400 m² of scintillators
- ~620 m² of silicon sensors
- ~28000 Si modules
- 6M Si channels, 0.5 cm² or 1.1 cm² cell size
- Data readout from all layers
- Trigger readout from alternate layers in CE-E and all layers in CE-H
- ~280 kW



TIPP2021





Cassettes: CE-E (Double Sided)

Outer Radius

Inner Radiu

TI



- Layers 1-28
- Silicon-only design
- 6-fold rotational symmetry
- High Density (HD) in inner regions
 - 0.5cm² diode pad
- Low Density (LD) in outer regions
 - $1.1 cm^2 \ diode \ pad$
 - Occupancy (=rate) and radiation field determined
- Hexagons optimise silicon wafer usage
 - Significant cost reduction cf rectangular (30%)
 - 200 mm wafers used
- Partials at inner/outer perimeters
 - Increases coverage
 - Increases # variants
 - Novel "multi-geometry" wafer





Coverage, Tiling and Partial Types







Vertical Stackup and Space Constraints



- 5.15mm between Cu & Pb .
- Stepped holes .
 - Connection through the PCB to sensor
 - Wire bonds used for CTE
 - Swiss cheese
 - Component placement and signal routing is difficult _
- Cassette access is radial .
 - Power,
 - Triggering, Timing, & Control,
 - Data (DAQ + Trigger)
 - **Bias voltage**
 - All must pass through outer periphery
- -30°C operation ٠
 - Requires dry environment \rightarrow pipe









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Main Si Front End Requirements



- Dynamic range:
 - 0.2fC → 10pC
- $T_{res} \sim 20ps \rightarrow 30ps rms$ (shower)
- HGCROC deals with these points
 - High Granularity Calorimeter Read-Out Chip
 - See Damien's talk tomorrow
- ~20 mW/channel
 - Analog + digital
- L1 Trigger Sums (fixed latency)
 - Alternate layers in CE-E
 - All layers in CE-H
- DAQ data zero suppression
 - 750 kHz trigger rate
 - Latency up to 12.5 µs



ReadoutTrain: Engines and Wagons



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EngineBoard Data and Trigger-Rate Requirements



- Very high-rate capacity required
- Data links
 - All LD fit in 1x 10Gb/s link

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- 25% of HD require 2
- Trigger
 - A few LD s require 3 links
 - Threshold
 - A few HD s require up to 5 links
- Mapping
 - Detailed matching of bandwidth requirements to fibres essential

V3-LD-HexBoard Design

3 sectors and reads 192 Si channels (64 ch/sector) Hosts 3×HGCROC 2× LDOs, Rafael Chip, HV connector, LD-WagonBoard & DCDC Interfaces

LD-HexModule Assembly



Services Routing Challenge







Cassette mockup activity – cassette internal routing

Crossings

HGCROCs

above

not

enough

space in

(see cross section drawing)

height

Unavoidable cable crossings

Not enough deported DC/DC in one modules row requires 'stealing' from other rows. This will develop additional cable crossings. Cables have to fit underneath LD wagons

2-6

Choke point, not enough space in height. Lack of space for cable supports

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To power some of the partials routing cables underneath wagons may be required (is it feasible in that particular place?)



Services routing space occupied with

01.5

cables (with HGCROC)

On-Cassette Power Trees

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On-Cassette Power Modelling

- Geometry and component based model
 - Power referred to at the cassette periphery
- Active components
 - HGCROC, ECONs, RAFAEL
 - VTRx+, lpGBT..
- Converter losses
- Cable losses
- · Allows detailed evaluation of
 - Where power is consumed
 - What the losses are
 - Consequences of cable choices
- Cable dimensioning
 - Supply droop and ground offsets
- Measured power consumptions will improve accuracy

| | | Engineticent-M PPO-Engineticent | 1.50 | n n | | + | | | | | | | | | | | Group-1 | | B | L-CODERECT | | | | | | - 1 |
|--|--|--|--|--------------------------|--|--|---|--|--|------------|--|---------------------|--|---|---|---|--|---|--|---|--------------------|---|----------|--|----------------------|-----|
| | | PPS-CCCC-Length CCCC-EngineExect | 125 | | | | _ | | | _ | | | | | | V_In 10.00 | LinPOL12V-TX V_put 2.50 | | 1_eut 40.00 | P_out 100.00 | _ | | _ | _ | | |
| | | | Hook- | loWine. | | | | | | | | - | | | | Panat ear | 400.00 | | | | | | Group-1 | | | |
| | | length (m) | Gauge LEAWG (2013 | Ringhal | Lout | 1 - | | | DC-DC-Medule | | | length (m) | Heek-UpWig-10V Geuge RimChard | Lout | | Vja | LinPOL12V-RX V_put | | Lout | P_out | 1-105.57(0)+200 | AT(T)-1VTRs- 1d | 2 V | Power_mW | | |
| | | 0.25 | Pjess | VARIAL OC | 732.03 | | 12 | 100 H | - | | | 1.25 | 30.51 36.14 | 160.00 | | 10.00 | 2.50 | | 40.00 | 100.00 | _ | × | 25 | 1524 | | |
| | | length (m) | Gauge | Rimphm) | 108 | Can | inector Infance | Elem. | Efficiency | | Connector Resistance | | 0.95 6.10 Healt-Up Wig-1.5V | | | 640000 | | | | | 1-10G ST (0) - 200 | at(T)+1VTRx+ 1v | Group-2 | Pewer_mW | | |
| | | 0.25 | 16AWG (26/3 14.44 | 2) 3.61 Vetree erV | 732.03 | | - | 1.430.05 | 54.23 75.00 | Leut | 0 | 22A/0 | Geuge Flip(2hp) VG (1234) 43.54 61.23 | 1_eut 2540.00 | _ | V in | LinPOL12V-TX | | Leut | F aut | _ | 75 | 112 | 1524 | mW | |
| | | | 1.83 | 2.64 | | | 112 | 5,720.32 | 4,220.24 | 2,000.16 | | | P_loss <u>Váce, mV</u> 393.52 157.29 | | | 10.00 Fanation | 2.50 | | 40.00 | 100.00 | | 8 | 23 | 100 | mW | |
| | | | | | | | | | | | | | | | | | LinPOL12V-RX | | | _ | | | | | | |
| | | Soulors | Contri Comm | | | | _ | | | | | ength (m) (1440 | Gauge RimChall | 108 | | V_in 10.00 Forcet.case | 2.50 300.00 | | 40.00 | P_out 100.00 | | | То | stal-Digital-1.2v P | Power | |
| | | Wire-Losses | 484.33 | mW mW | 1 | | | 1 | | | | 128 | 1107 | 2700.00 | 1 | Escodo- | 40.00 | 1 | | | 1 | | _ | 3048 | mW | |
| | | IInPOL12V-Losses | 1200.00 | mW mW | | 4 | 7 | | В | | L | | U | E | | ł | G | | н | | | 1 | _ | J | | _ |
| | | Total Losses | 378.4 | #W | | 5 | | | | | | | | | | | | | | | | | | | | |
| | _ | | _ | | | 7 | | | | | | | Region | | | НD | | | | | | D | | | | i – |
| | | | | | - | 9 | | | | | | | Region | | | | | | | | | | | | | = |
| | | | | | | 11 HGCROC | -Dig | | | | 227.27 | mW | | | | | | | - 2 | 10 10 | | | | | HO ID | |
| | | | | | | 13 HGCROCS | 3 Ana | | | | 835.67 | mW | | (7) Pull | (a) PMT | (k)/hve (d | rjSeni(-) (g1Oreptan(-) | (7)7-A | (a) Hall | (8)/Twe | 1.(Three | (d) Semi | (7) Pull | 00767 | (N) Pive | (= |
| | | | | | | 14 15 Rafael | | | | | 109.00 | mW | Variant | FI | al | bl | dl gl | FO | aO | bO | cO | dO | FM | aM | bM | |
| | | | | | <u> </u> | 16 17 ECON-T | | | | | 600.00 | mW | HGCROCs | HM 6 | 3 | 4 | 3 4 | 3 | 2 | 2 | 1 | 2 | 3 | 2 | 2 | |
| | _ | | - | | lin.mh | 18 ECON-D | | | | | 600.00 | mW | | | - | | | - | _ | _ | _ | _ | | _ | | |
| | Hashi | United and and and and and and and and and an | 1 444 | | 637.23 | 20 | | | | | | | | T | able 39 | : HGCF | ROC Counts | for e | ach F | lexMod | lule vari | ant | | | | |
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| Nominal | | HD | | LD | | | | | |
|------------|------|-------------|--------|------|------------|--------|--|--|--|
| Туре | Full | Partials | Engine | Full | Partials | Engine | | | |
| Power (W) | 14.0 | 7.6 to 11.5 | 7.3 | 6.4 | 2.1 to 6.4 | 3.8 | | | |
| Loss (W) | 7.6 | 3.7 to 6.0 | 3.9 | 2.6 | 1.3 to 2.6 | 2.1 | | | |
| Loss (%) | 55 | 50 to 52 | 53 | 41 | 41 to 60 | 54 | | | |
| 27.05.2021 | | | | TIP | P2021 | | | | |

| Total Power and losses at PP0 for 2 x 50 layer End-Caps | | | | | | | | | | | | |
|---|--------|--------|--------|--------|--------|--------|--|--|--|--|--|--|
| | М | in | No | om | Max | | | | | | | |
| | Power | Loss | Power | Loss | Power | Loss | | | | | | |
| Total (kW) | 223.44 | 110.86 | 239.86 | 112.05 | 257.34 | 113.04 | | | | | | |
| Total (kW) | 223.44 | 110.86 | 239.86 | 112.05 | 257.34 | 113. | | | | | | |

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15/17

CMS

CÉRN

Summary and Outlook

CMS

- Very demanding system requirements
 - High data rates
 - Tightly constrained physical volume
 - Huge number of channels
 - Optimal coverage introduces a plethora of variations
 - System has a phenomenology that needs to be explored
- Engine-Wagon architecture defined to respond to this complexity
 - Prototype system under evaluation

- Integrated electromechanical design process is required
 - Electronics engineers must work in synergy with the mechanical engineers
- Mechanical mockup developed in conjunction with very detailed modelling and design in use
- Huge design task remaining
 - Every partial needs similar attention to detail



Thank you for your attention!

Other HGCAL Contributions

- Clemens Lange: 26.05.2021
 - Beam Tests
 - https://indi.to/nGjyq
- Thorben Quast: 26.05.2021
 - Subdetector Overview
 - https://indi.to/qS3tX
- Mathias Reinecke: 26.05.2021
 - Scintillator Tileboard
 - https://indi.to/BY9Qs
- Damien Thienpont: 28.05.2021
 - HGCROC
 - https://indi.to/6xk3R



Control Architecture: LD Fast Command







Control Architecture: LD Slow Control





HD Slow Control







Concentrator Mezzanine Card





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