CMS Internal Note

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Note: This document was updated July 2004 to include updated versions of Figures 2, 3, and 5 with revised ϕ-mapping necessary to reduce trigger primitive cable lengths and overall latency.

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Revised CMS Calorimeter Trigger Primitive Generator to Level 1 Regional Trigger Interface

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Abstract

The specification of the interface between the CMS Calorimeter Trigger Primitive Generator and the Level 1 Regional Calorimeter Trigger (RCT) electronics crates is updated. The cabling, data format, and timing are described. Changes from CMS Internal Note 2001/016 include the mapping and destination of the Forward Calorimeter towers, crate arrangement in the USC55 racks, and bunch crossing zero (BC0) specification instead of the "Gap Flag".

1 Interface Specification

The general design and function of the Level-1 Regional Calorimeter Trigger (RCT) has been described in several references [1,2,3]. Likewise, the design and function of the Calorimeter Trigger Primitive Generator (TPG) has been described elsewhere [3,4,5,6,7]. This document aims to specify the cabling, data, and electrical interface between the RCT and the TPG and update the previous version of this document, CMS Internal Note 2001/016 [8].

The hadronic calorimeter (HCAL) and electromagnetic calorimeter (ECAL) TPGs will use the same interface. The data transfer between the calorimeter TPGs and the Level-1 RCT crates will take place at 1.2 GBaud using the Vitesse VSC7216-1 serial link transceiver chip on both transmission and reception ends. Parallel inputs and outputs are low voltage 120 MHz TTL. The connection between the TPG and RCT will use copper cable 20 meters in length. Studies are underway to determine if this length can be reduced, but present knowledge of the cable layout in USC55 is insufficient to allow a reduction. The proposed type of cable is a quad Spectra-Strip Skewclear (specifications are attached at the end of this document) and the connector type currently used by the RCT is a 15-pin high-density D-sub connector (VGA connector). The 15-pin connector is wired as follows:

Channel	+ side pin	− side pin
A	2	1
B	12	11
C	15	14
D	5	4

All of the remaining pins are connected to ground. The metal shell (cable braid) should be connected to ground at the transmitting end. We retain the option of connecting the cable braid to ground at the receiving end as well. TMODE(2:0) must be 000. There is 150 Ohm differential termination at the receiver.

Figure 2 shows the layout of the calorimeter towers for HCAL and ECAL, including the HF. The endcap and barrel calorimeters send their input signals to the receiver cards, in the back of each RCT crate. The HF input is received at the top of the Jet/Summary Card (JSC) at the front of each RCT Crate.

Barrel and Endcap Calorimeters

In Figure 3 is the layout of the barrel and endcap calorimeter towers with respect to η and ϕ (ϕ=0 is on the x-axis of the spectrometer, pointing towards the center of the LHC ring). The arrangement of the towers in the RCT crates and receiver cards is required by the RCT inter-crate data sharing and data sharing on the crate backplanes. The electron algorithms, for example, require information from as many as 5 other crates.

Channels A and B are for one value of η (one tower in width). Channel A transmits ϕ_1 and ϕ_2 (each also corresponding to a tower width), with ϕ_1 transmitted first and $\phi_1 < \phi_2$ Channel B transmits ϕ_3 and ϕ_4, ϕ_3 transmitted first and $\phi_1 < \phi_2 < \phi_3 < \phi_4$. Channels C and D are also for one tower-width in η. Channels C and D transmit ϕ in the same order as Channels A and B. If channels A and B are η_1 and channels D and C are η_2, then $|\eta_1| < |\eta_2|$. (See Figure 3.)

The Vitesse VSC7216-1 chip has four full duplex channels. The 8bit/10bit per channel encoding/decoding is provided as an integral part of the Vitesse chip.

At the TPG the VSC7216-1 will be located on a mezzanine link board attached to a Synchronization and Link Board (SLB), which is attached to the ECAL Trigger Concentrator Card (TCC) [9]. The HCAL will use the same mezzanine link board attached to the HCAL Trigger readout card (HTR) [3]. On the RCT side, it will be located on a mezzanine board on a RCT crate Receiver card and Jet/Summary Card. The links will be tested in the laboratory to operate with a bit error rate less than 10^{-15}.

Twenty-four bits of serial link data per channel are transmitted every 25 ns crossing period using the Vitesse chip. This done in three eight bit frames for an input data rate of 120 MHz in low-voltage TTL. The format of the data, for barrel/endcap channels is (two calorimeter towers per channel) [6]:

<7:0>   Eight bit compressed transverse energy, tower 0 (lower ϕ), bit <0> is LSB ($d_7...d_0$)

<8>   Tower characterization bit, tower 0 (d_8)

<16:9>   Eight bit compressed transverse energy, tower 1 (higher ϕ), bit <9> is LSB ($d_{16}...d_9$)

<17>   Tower characterization bit, tower 1 (d_{17})

<22:18>   Five bit inverted Hamming code for bits < 17:0 > ($c_4...c_0$).

<23>   Bunch Crossing Zero (BC0) (d_{18})

The <n> notation indicates the nth bit in the 24 bits of serial link data. The c_n and d_n notation refer to the Hamming code below. (Note: In the Trigger TDR [3] and CMS IN 2001/16 [9] the BC0 is instead the gap flag and is written as d_{23} instead of d_{18}. The d_{18} is consistent with earlier discussions, and reference [6]. Its bit position is still <23>.) The least significant byte (LSB) is transmitted first in time over the serial link. Descriptions of the quantities appear below.

HF Calorimeter

The bit arrangement of the HF is similar. Eight HF towers are read out on one V7216-1 located on a mezzanine card on the JSC at the front of a RCT crate. Four different values of η from 3<|η|<5 ($\Delta\eta$=0.5) and two values of ϕ ($\Delta\phi$=20°) are sent to the RCT per Vitesse link (18 links in total). Each channel is similar to that for the barrel and endcap calorimeters except that now the ϕ is the same for both 8-bit E_T values, and the η changes:

<7:0>   Eight bit compressed transverse energy, tower 0 (lower |η|), bit <0> is LSB ($d_7...d_0$)

<8>   Tower characterization bit, tower 0 (d_8)

<16:9>   Eight bit compressed transverse energy, tower 1 (higher |η|), bit <9> is LSB ($d_{16}...d_9$)

<17>   Tower characterization bit, tower 1 (d_{17})

<22:18>   Five bit inverted Hamming code for bits < 17:0 > ($c_4...c_0$).

<23>   Bunch Crossing Zero (BC0) (d_{18})

This is in part due to the way the Phase ASIC handles the data from the 120 MHz parallel TTL outputs of the Vitesse serial link. Figure 5 shows the Vitesse 7216-1 channel assignment of the HF towers. (For reference the tower segmentation is shown in terms of HF readout channels in Figure 4.) Descriptions of the quantities appear below.

1.1 Quantity Descriptions

The transverse energy is transmitted in an 8 bit non-linear compressed scale [3,5]. The value should be monotonically increasing. This encoding is implemented using a Lookup Table (LUT) at the HCAL, ECAL, or HF TPG. It will be decoded to a linear E_T using a LUT on the RCT Receiver Card or Jet/Summary Card. LUTs can be changed depending on experimental conditions and physics priorities.

In the barrel and endcap, the two towers, 0 and 1, are adjacent in ϕ in the same η slice. Tower 0 is at lower detector ϕ in the CMS coordinate system. In the forward calorimeter (HF) the two towers, 0 and 1, are adjacent in η in the same ϕ slice. Tower 0 is at lower detector |η| in the CMS coordinate system.

The tower characterization bit for the ECAL is a fine-grain veto used for electron identification [3]. The tower characterization bit for HCAL is a minimum ionizing flag used for muon identification. It has recently been improved using thresholds and a LUT so that showers leaking into the cell from adjacent cells do not incorrectly set the muon bit [10]. The tower characterization bit for the HF will come directly from the HF and be forwarded along with the HF towers directly to the GCT, not undergoing any processing on the Jet/Summary card. It will be used to describe the energy profile in the HF, i.e. whether the energy is in one or two of the six segments or diffused through all six.

The five bit inverted Hamming code $c_{0...4}$ (bit position <18> to <22>) is computed from the data bits $d_{0...17}$ (bit position <0> to <17>) and the BC0 d_{18} (bit position <23>), and given by the following [6]:

$c_0 = \text{NOT}(d_0 \oplus d_1 \oplus d_3 \oplus d_4 \oplus d_6 \oplus d_8 \oplus d_{10} \oplus d_{11} \oplus d_{13} \oplus d_{15} \oplus d_{17})$

$c_1 = \text{NOT}(d_0 \oplus d_2 \oplus d_3 \oplus d_5 \oplus d_6 \oplus d_9 \oplus d_{10} \oplus d_{12} \oplus d_{13} \oplus d_{16} \oplus d_{17})$

$c_2 = \text{NOT}(d_1 \oplus d_2 \oplus d_3 \oplus d_7 \oplus d_8 \oplus d_9 \oplus d_{10} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{17})$

$$c_3 = \text{NOT}(d_4 \oplus d_5 \oplus d_6 \oplus d_7 \oplus d_8 \oplus d_9 \oplus d_{10} \oplus d_{18})$$

$$c_4 = \text{NOT}(d_{11} \oplus d_{12} \oplus d_{13} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{17} \oplus d_{18})$$

and on the reception end the decoding computes:

$$s_0 = \text{NOT}(c_0) \oplus d_0 \oplus d_1 \oplus d_3 \oplus d_4 \oplus d_6 \oplus d_8 \oplus d_{10} \oplus d_{11} \oplus d_{13} \oplus d_{15} \oplus d_{17}$$

$$s_1 = \text{NOT}(c_1) \oplus d_0 \oplus d_2 \oplus d_3 \oplus d_5 \oplus d_6 \oplus d_9 \oplus d_{10} \oplus d_{12} \oplus d_{13} \oplus d_{16} \oplus d_{17}$$

$$s_2 = \text{NOT}(c_2) \oplus d_1 \oplus d_2 \oplus d_3 \oplus d_7 \oplus d_8 \oplus d_9 \oplus d_{10} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{17}$$

$$s_3 = \text{NOT}(c_3) \oplus d_4 \oplus d_5 \oplus d_6 \oplus d_7 \oplus d_8 \oplus d_9 \oplus d_{10} \oplus d_{18}$$

$$s_4 = \text{NOT}(c_4) \oplus d_{11} \oplus d_{12} \oplus d_{13} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{17} \oplus d_{18}$$

$$\text{error} = s_0 + s_1 + s_2 + s_3 + s_4$$

Where the $\oplus$ symbol is the exclusive or (XOR) operator and the + is the logical "or" operator. Note also that the net XOR is inverted so that in the case of all zero data bits, all the error detection code bits will be one.

The bunch crossing zero bit, d_{18}, will be equal to one when the data simultaneously accompanying it corresponds to the data from the LHC bunch crossing zero. For all other bunch crossings BC0 is zero. This flag will be used on the receiving side in the regional trigger to verify the synchronization of the HCAL, ECAL, and HF data. Each mis-synchronization is recorded. Continuously mis-synchronized data can be zeroed in the LUT or flagged as defective.

2 Timing and Synchronization

The trigger primitive data on the serial links across the entire calorimeter, ECAL, HCAL, and HF shall arrive together for each bunch crossing to within ±6 ns. The spread in time at the transmitter end should be kept as close to 0 ns as possible across the entire calorimeter to ensure the spread in time at the receiver end does not exceed 12 ns. The data transmission will take place on equal length cables. The synchronization is taken care of by the switch of the link from idle to data mode of the Vitesse chip on the RCT's Receiver Mezzanine Card. The Vitesse chip provides this information in its status bits. Within each interval, the relative phases of the data may not be aligned due to variations in transmission time over "equal length" cables and phase differences between the transmitting and receiving clocks. The correction for this phase difference will be done on the regional trigger side, in the Receiver Card's and JSC's Phase ASICs.

3 Serial Link Channels and Cabling

The specification of calorimeter cell assignments to trigger towers and the location of their data on specific cables to the RCT has been determined. A cross section of the CMS detector with the η divisions for the barrel and endcap calorimeters is shown in Figure 1 [5]. A two-dimensional map displaying the arrangement in η and ϕ of the barrel and endcap crates and receiver cards with trigger towers is shown in Figure 2. Shaded borders represent the boundaries of the crates, receiver cards, and trigger towers. Crate numbers are shown in large bold numbers. Shown in Figure 3 is regional crate 0 with the numbering of the receiver cards in the background, and numbering of the mezzanine card (0...7) and serial link channel (A,B,C, and D) for each trigger tower (ECAL and HCAL separately). Two towers representing two ϕ divisions will be transmitted on one serial link channel, as described in Section 2. In the diagram the smallest rectangle with a dashed line in the center represents a pair of towers: 0 and 1. The lower ϕ part is tower 0 as described above, and the higher ϕ part tower 1. Regional trigger crates on the opposite side of Figure 2, crates 9-17, are a mirror image of crate 0.

A diagram of the very forward calorimeter is shown in Figure 4 with two trigger towers highlighted. The channel assignment for the Vitesse links on the Jet/Summary cards for the very forward calorimeter (HF) crate is shown in Figure 5. The crate numbers are shown to the left of each 2ϕ by 4η area of the HF.

4 RCT Crate and Rack Arrangement in USC55

The front view of the crate and rack layout of the RCT is shown in Figure 6. Since data sharing takes place on 10 foot (305 cm) cables the arrangement of the crates is not sequential. Only two crates are placed in each rack. Heat exchangers, fan units, and two crate power supplies per rack occupy the remainder of the space. Since all adjacent crates need to communicate with each other, cables should not have to cross over more than two crates.

These requirements lead to the arrangement of the RCT crates as shown in Figure 6. The front of the racks with the JSC will face the HCAL crates and the rear with the receiver cards will face the ECAL racks [2,10].

References

[1] J. Lackey, et al. *CMS Level 1 Calorimeter Trigger Design,* CMS TN 94/284.

[2] J. Lackey, et al. *CMS Level 1 Calorimeter Regional Trigger Design,* CMS NOTE 98/074.

[3] CMS, *The TRIDAS Project Technical Design Report, Volume 1: The Trigger Systems*, CERN/LHCC 2000 38, CMS TDR 6.1 and references therein.

[4] J. Varela, et al. *Trigger Primitives Boards,* CMS IN 96/008.

[5] J. Varela, et al. *A Compression Scheme for ECAL Trigger Primitives,* CMS IN 96/007.

[6] J. Varela and J. C. Silva, *Technical specifications of the ECAL trigger Synchronization and Link Board prototype,* CMS IN 2000/005.

[7] J. Varela and J.C. Silva, *Revised specifications of the calorimeters synchronization and link board*, In preparation.

[8] E. Machado et al. *CMS Calorimeter Trigger Primitive Generator to Level 1 Regional Trigger Interface,* CMS IN 2001/016.

[9] P. Busson *Overview of the New CMS Electromagnetic Calorimeter Electronics,* Proceedings of the Eighth LHC Electronics Workshop, Colmar, France, September 2002. CERN-2002-03

[10] http://www.physics.umd.edu/hep/HTR/preprod/PreProdMainFPGA.pdf

[11] USC55 Rack Layouts: http://cmsdoc.cern.ch/~wsmith/USC55_racks.html

Table 1: Distribution of the 24 bits of Trigger Primitive data by frame. The <n> notation refers to the bit position in the data, the d_n and c_n notation refers to the Hamming code.

Frame 1		
<0>	d_0	E_T Tower 0 Bit 0 (LSB)
<1>	d_1	E_T Tower 0 Bit 1
<2>	d_2	E_T Tower 0 Bit 2
<3>	d_3	E_T Tower 0 Bit 3
<4>	d_4	E_T Tower 0 Bit 4
<5>	d_5	E_T Tower 0 Bit 5
<6>	d_6	E_T Tower 0 Bit 6
<7>	d_7	E_T Tower 0 Bit 7 (MSB)
Frame 2		
<8>	d_8	Tower 0 Characterization Bit
<9>	d_9	E_T Tower 1 Bit 0 (LSB)
<10>	d_{10}	E_T Tower 1 Bit 1
<11>	d_{11}	E_T Tower 1 Bit 2
<12>	d_{12}	E_T Tower 1 Bit 3
<13>	d_{13}	E_T Tower 1 Bit 4
<14>	d_{14}	E_T Tower 1 Bit 5
<15>	d_{15}	E_T Tower 1 Bit 6
Frame 3		
<16>	d_{16}	E_T Tower 1 Bit 7 (MSB)
<17>	d_{17}	Tower 1 Characterization Bit
<18>	c_0	Hamming Code 0
<19>	c_1	Hamming Code 1
<20>	c_2	Hamming Code 2
<21>	c_3	Hamming Code 3
<22>	c_4	Hamming Code 4
<23>	d_{18}	BC0
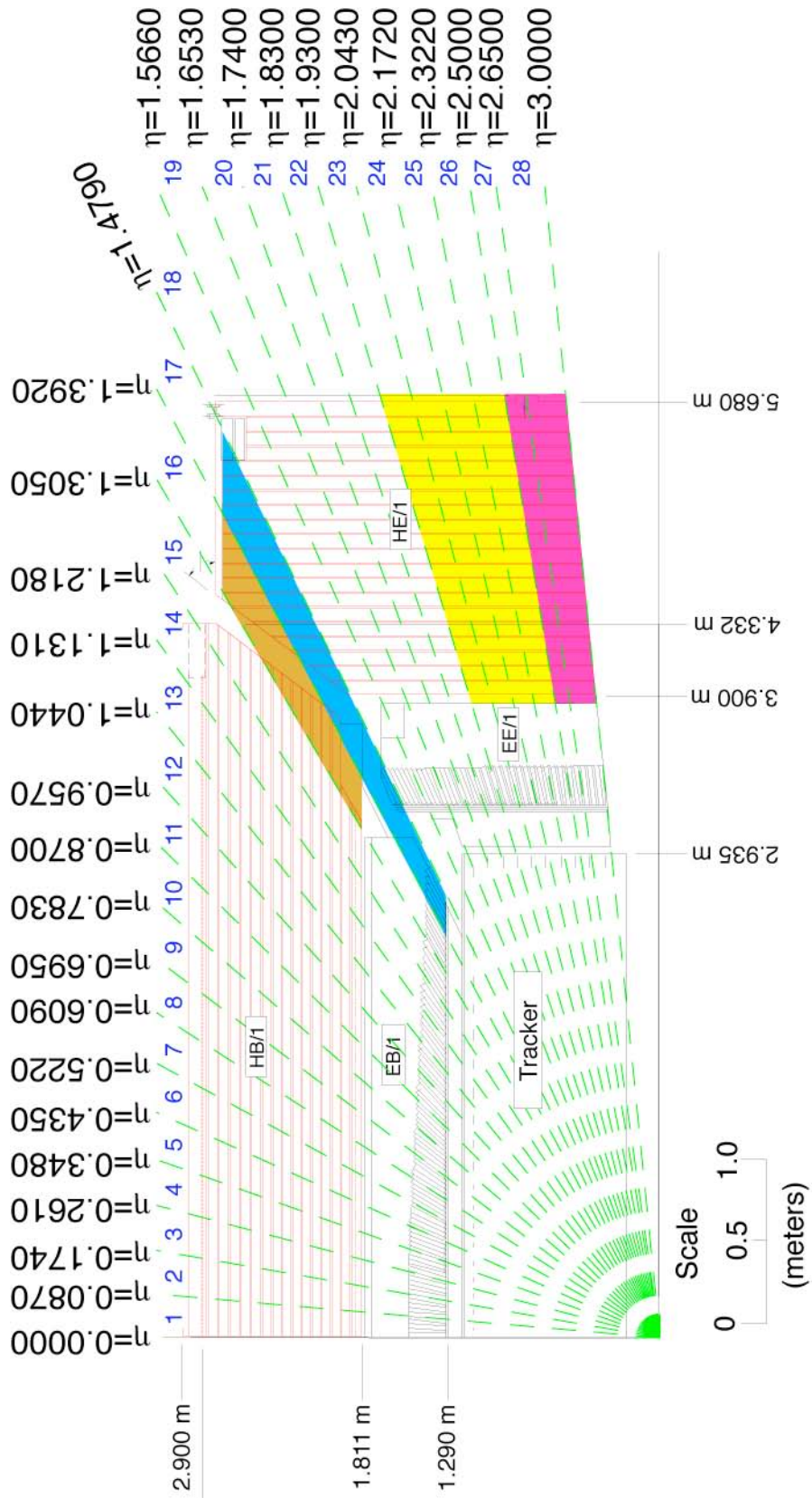
Figure 1: Cross section of CMS showing individual trigger towers vs. η.
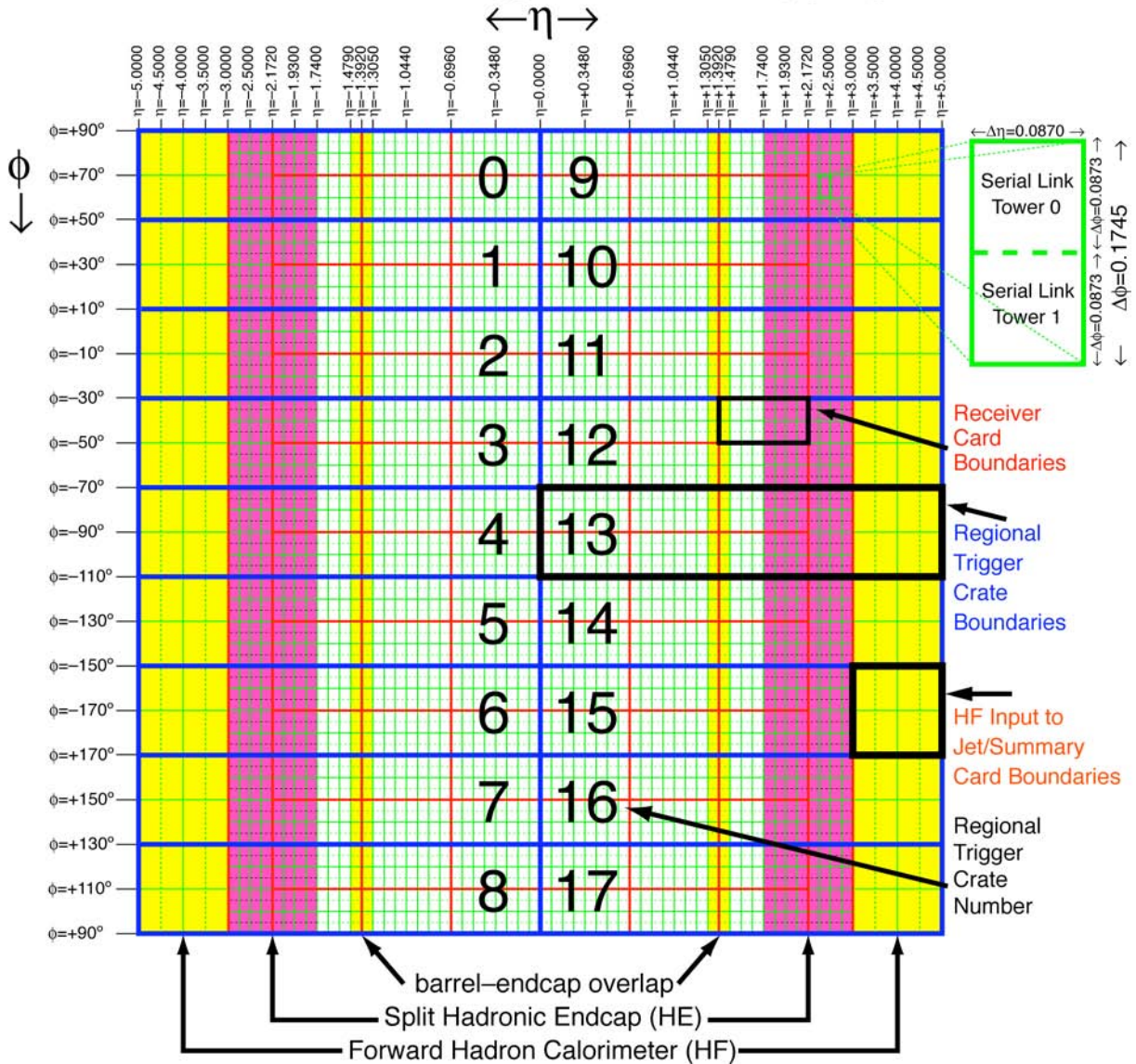
Figure 2: Detailed diagram showing the layout of the crates and receiver cards by tower η and φ.
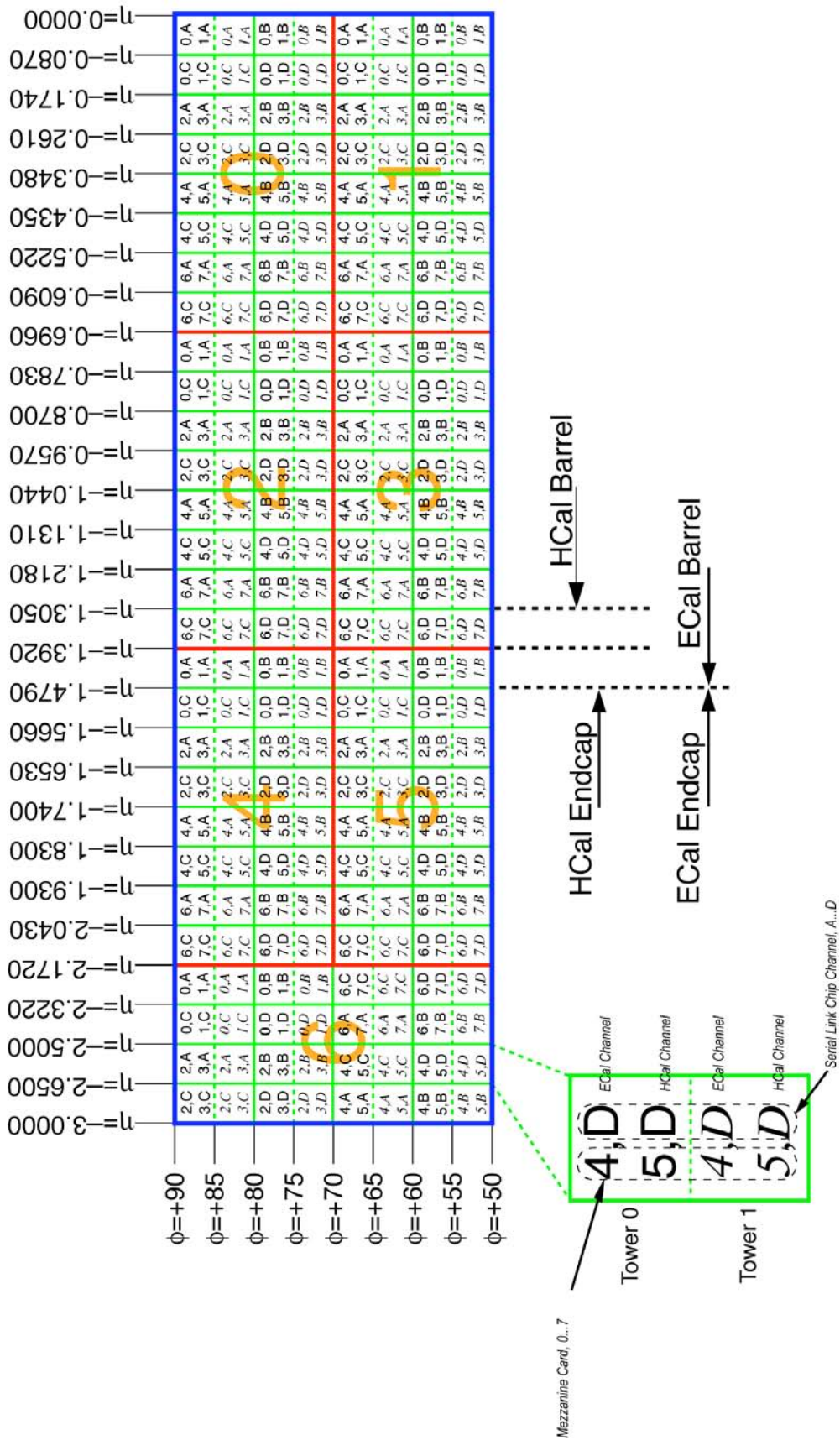
Figure 3: Channel map for crate zero, showing the coverage of the receiver card, each mezzanine card, and each serial link chip channel. Crates 1-7 will have an identical layout, crates 9-17 will be a mirror image, with the $\eta=0$ axis the axis of symmetry. HF mapping is shown in Figure 5.
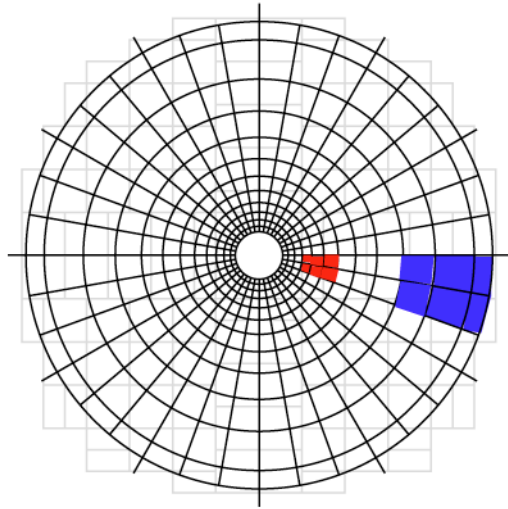
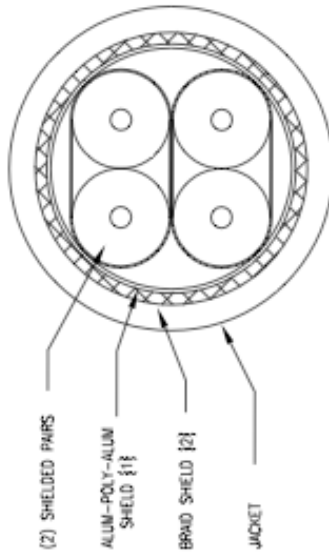**Figure 4:** HF Segmentation showing individual trigger towers.

Figure 5: HF tower segmentation. Each differently shaded band represents two Jet/Summary Cards, 18 in total. Crate numbers are shown to the left or right for each block of 8 HF towers.

E01	E02	E03	E04	E05	E06	E07	E08	E09	E10
PC	PC	PC	PC	PC	PC	PC	PC	PC	PC
Turbine 4U	Turbine 4U	Turbine 4U	Turbine 4U	Turbine 4U	Turbine 4U	Turbine 4U	Turbine 4U	Turbine 4U	Turbine 4U
Patch panel	Patch panel	Patch panel	Patch panel	Clock Crate / Patch panel	Patch panel	Patch panel	Patch panel	Patch panel	Patch panel
Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U
Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange
RCT00	RCT09	RCT01	RCT10	RCT02	RCT11	RCT03	RCT12	RCT04	RCT Hot crate
Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U
Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange
RCT17	RCT08	RCT16	RCT07	RCT15	RCT06	RCT14	RCT05	RCT13	Patch panel
Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U
Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange
48V Supplies	48V Supplies	48V Supplies	48V Supplies	48V Supplies	48V Supplies	48V Supplies	48V Supplies	48V Supplies	48V Supplies
Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U	Fan tray 2U
Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange	Heat exchange
Air deflector 2U	Air deflector 2U	Air deflector 2U	Air deflector 2U	Air deflector 2U	Air deflector 2U	Air deflector 2U	Air deflector 2U	Air deflector 2U	Air deflector 2U

Figure 6: Layout of RCT racks in row E on the second floor of the underground counting room in USC55 as viewed from the front of the racks. The front side faces the HCAL racks and the rear side faces the ECAL racks according to document [11]. The diagram is to scale and includes additional heat exchangers, fan trays, and power supplies. The numbers E01-E10 above the racks are the rack numbers, and the numbers on the racks are the crate numbers as in Figure 2.

PRELIMINARY

PHYSICAL

(2) SHIELDED PARALLEL PAIRS

24 AWG SOLID SILVER PLATED COPPER

.094 NOM DIAMETER FOAM POLYOLEFIN (.037 NOM WALL)

PARALLEL PAIR

.001 ALUMINIZED POLYESTER, SPIRAL, FOIL OUT, 20% MIN OVERLAP, HEAT SEALED

("1" PRINTED ON ONE, "2" PRINTED ON OTHER)

CABLING: TWISTED TO ROUND WITH RIGHT HAND LAY

OVERALL SHIELD [1]: .002 ALUM-POLYESTER-ALUM, SPIRAL, 20% MIN OVERLAP

OVERALL SHIELD [2]: 36 AWG TINNED COPPER BRAID, 85% MIN COVERAGE

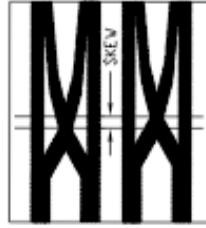JACKET: .025 NOM WALL PVC, BLACK

DIAMETER: .315 NOM

PRINT LEGEND: SPECTRA-STRIP SKEWCLEAR® 2 PAIR 24 AWG
(PENDING UL) (UL) 75°C CL2 CSA AWM I/II A 75°C 300V FT-4

ONE LEG'S EYE DIAGRAM

SKEW

100 ps / div TYPICAL

OTHER LEG'S EYE DIAGRAM

(2) SHIELDED PAIRS

ALUM-POLY-ALUM SHIELD [1]

BRAID SHIELD [2]

JACKET

ELECTRICAL

IMPEDANCE: 150 ± 10 Ω (DIFFERENTIAL TDR)

CAPACITANCE: 28 pF / M NOMINAL

PROP DELAY: 4.29 ns / M NOMINAL

SKEW (WITHIN PAIR) ≤ 200 ps / 25 M (DIFFERENTIAL EYE DIAGRAM METHOD, SHIELD GROUNDED)

1.0625 Gb 2^7-1 PRBS INPUT THRU Z MATCHING PADS, OUTPUT THRU Z

MATCHING PADS TO SAMPLING 'SCOPE. DELAYS MEASURED @ 50% CROSSINGS

USING CURSORS. SEE FIGURE.

CROSSTALK: BETTER THAN -45 dB @ 1 GHz (0.6 % VOLTAGE, REF)

ATTENUATION (NOMINAL): 0.31 dB / M @ 531 MHz
0.46 dB / M @ 1062 MHz
0.69 dB / M @ 2125 MHz

USING 150 Ω ADAPTERS

APPROVALS

UL / CSA: UL CL2 CSA FT4 75°C PENDING

ALL DIMENSIONS ARE INCHES UNLESS OTHERWISE NOTED

REVISION	CHANGES
1	FOAM, HEAL SEAL SHIELD, TEST METHODS

AMPHENOL SPECTRA-STRIP OPERATIONS
720 Sherman Ave Tel (203) 281-3200
Hamden CT. 06514 Fox (203) 281-5872

Rev 1

Sheet 1 of 1

DRAWN BY	PROD ENG	QA	MKT	P/ECN #

DRAWING NO. 160-2499-998

TITLE: (2) SHIELDED PAIRS, 150 OHM, 24 AWG SKEWCLEAR®