A Detailed Description of the Cluster Finding Scheme for the FMS Trigger

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Starting in the 2009 RHIC running period we are aiming to trigger on clusters in the FMS. A cluster is characterized by a central cell, with a high ADC value, surrounded by eight neighbors with greater-than-average ADC values. The trigger algorithm will aim to detect the central cell, form the sum of the ADC values of all nine cells and then apply a threshold cut to that sum.

The trigger will be implemented at Level 0, i.e. in the QT-DSM tree. In order to maximize the trigger efficiency it will be necessary to trigger on clusters that span boundaries within the electronics chain. Reconstructing clusters that span boundaries is relatively difficult to do in the QT-DSM tree so it seems sensible to arrange the connections between the FMS cells, the QT boards and the DSM boards in such a way as to minimize the probability of a cluster spanning boundaries. The scheme that is described here has therefore been optimized to minimize the number of clusters that are split between multiple layer-0 DSM boards. The scheme also makes it as easy as possible to reconstruct those clusters that do still span multiple layer-0 DSM boards. There are two negative consequences of this optimization. One is that it will not be possible to reconstruct clusters that span the boundary between large and small cells. The other is that it will not be possible to reconstruct clusters that span the boundary between the North and South sides of the large-cell array. It should be noted that the small-cell array, and the two halves of the large-cell array, are physically distinct and separately enclosed with material in the boundary region. As a result there are currently no plans to analyze such clusters, so this is not considered to be a serious effect.

FMS Cell to QT Card Assignment Scheme

The FMS cells are assigned to QT cards using a geometrical scheme composed of a large set of simple rectangles. The assignment of FMS cells to the 4 QT8 cards within each QT card has been done using a “striping” scheme, where the stripes run along the length of the rectangles. This scheme is shown in Figure 1.

- All of the FMS cells that connect to the DSM tree are shown in Figure 1.
- The cells contained within a thin solid line are all connected to one QT card.
- Within each QT card the thick solid line marks the locations of clusters that are totally contained by that QT card.
- In 3 of the 4 quadrants the stripes, indicating which QT8 card a cell is assigned to, are shown in light and dark gray.
- In the upper right quadrant the stripes are shown in shades of blue and yellow.
- In this quadrant each QT card has a label from A to J. The 4 stripes in each QT card (representing the 4 QT8 cards) are labeled from 0 to 3. In the rest of this document individual QT8 cards are referred to using these reference numbers, e.g. A(1), E(0), etc….

- Finally, the cells are separated out into 3 groups, indicating which QT card is connected to each of 3 layer-0 DSMS.

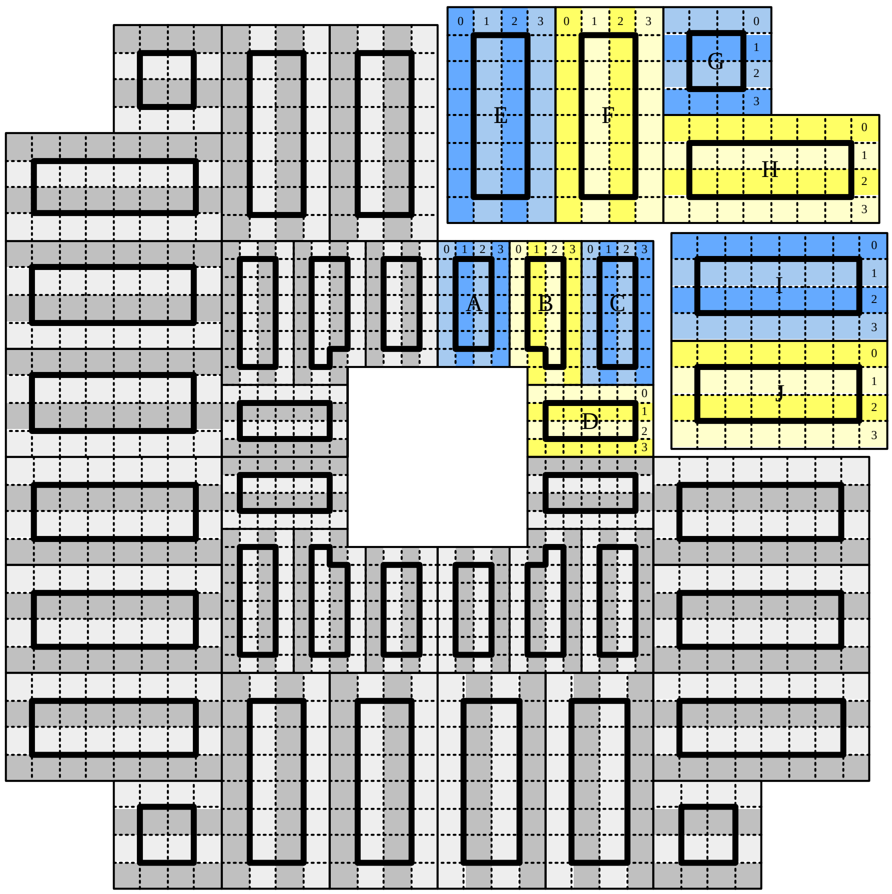

Figure 1: FMS Cell to QT and Layer-0-DSM Assignment Scheme

The output of each QT card, which is sent to the layer 0 DSM boards, contains the following information:

HTID	ID of cell with the highest ADC value	5 bits
HT	ADC value from cell with the highest value	5 bits
QT8(0:3)	Sum of the ADC values from each of the 4 QT8 cards	4 x 5 bits

Within each QT card the numbering scheme used to assign ID values to the 8 channels of each of the four QT8 cards is:

ID	QT8
0:7	0
8:15	1
16:23	2
24:31	3

Layer 0 DSM Tree Algorithms

In the layer 0 DSM boards a cluster is then reconstructed by summing together the QT8-sum, from the stripe that contains the highest cell, with the stripes on either side of it:

Cluster-sum = QT8-sum(stripe(HTID)) + QT8-sum(stripe-1) + QT8-sum(stripe+1)

This logic is relatively simple to code in VHDL. So long as all 3 stripes are within one layer 0 DSM it doesn't matter which QT card they come from. However, when the cell that contains the highest ADC value lies on the edge of a DSM's region, then things become more complicated. Data must be passed up to the layer 1 DSM board so the cluster can be completed there. In addition, if a cell is located where the orientation of the stripes changes, more than 3 stripes may need to be added together.

Table 1 shows the list of QT8 sums that need to be used to reconstruct a cluster located in any of the cells of the upper-right quadrant of the FMS, i.e. the colored part of Figure 1.

The columns in Table 1 are:

- DSM Board: The region of the FMS covered by this layer 0 DSM board
- QT: QT board reference letter from A to J
- HTID: ID of cell with the highest ADC value, which then forms the center of the cluster:
- Loc.: Geometric location of this cell (HTID) within the block of cells connected to this QT card:
    - TL = top left
    - LHS = left hand side
    - BL = bottom left
    - T = top
    - I = internal
    - B = bottom
    - TR = top right
    - RHS = right hand side
    - BR = bottom right
- List: A list of the QT8 sums that need to be added together to reconstruct this cluster. Only those QT8 sums that are available within this layer-0 DSM board are shown. If the cluster happens to lie on a boundary that the trigger will not span (e.g. the large-small cell boundary) then "Ignore – boundary" will be listed.
- No.: The number of cells that use this list.
- Action: A description of the action that is still needed to complete this cluster. This may include a list of QT8 sums from other layer 0 DSMS that need to be added in at layer 1. "Done" means that the cluster is complete. "Not applicable" means that the cluster lies on a boundary and is being ignored.

Table 1: QT8 Lists for Cluster Reconstruction in Upper-Right Quadrant of the FMS

DSM Board	QT	HTID	Loc.	List	No.	Action
Small-cell quadrant	A	0,6,8,14,16,22,24,30	T,B	Ignore – boundary	8	Not applicable
		1:5	LHS	A(0), A(1)	5	Add in A(0) from the next quadrant at layer 1
		9:13	I	A(0), A(1), A(2)	5	Done
		17:21	I	A(1), A(2), A(3)	5	Done
		25:29	RHS	A(2), A(3), B(0)	5	Done
	B	0,6,8,14,15,16,24	T,B	Ignore – boundary	7	Not applicable
		1:5	LHS	A(3), B(0), B(1)	5	Done
		9:13	I	B(0), B(1), B(2)	5	Done
		17:22	I	B(1), B(2), B(3)	6	Done
		23	B	B(1), B(2), B(3), D(0)	1	Done
		25:30	RHS	B(2), B(3), C(0)	6	Done
		31	BR	B(2), B(3), C(0), D(0)	1	Done
	C	0,8,16,24:31	T,RHS	Ignore – boundary	11	Not applicable
		1:6	LHS	B(3), C(0), C(1)	6	Done
		7	BL	B(3), C(0), C(1), D(0)	1	Done
		9:14	I	C(0), C(1), C(2)	6	Done
		15	B	C(0), C(1), C(2), D(0)	1	Done
		17:22	I	C(1), C(2), C(3)	6	Done
		23	B	C(1), C(2), C(3), D(0)	1	Done
	D	0,6,8,14,16,22,24,30	RHS, LHS	Ignore – Boundary	8	Not applicable
		1	T	C(1),C(2),C(3),D(0),D(1)	1	Done
		2	T	C(0),C(1),C(2),D(0),D(1)	1	Done

		3	T	B(3),C(0),C(1),D(0),D(1)	1	Done
		4	T	B(2),B(3),C(0),D(0),D(1)	1	Done
		5	T	B(1),B(2),B(3),D(0),D(1)	1	Done
		9:13	I	D(0), D(1), D(2)	5	Done
		17:21	I	D(1), D(2), D(3)	5	Done
		25:29	B	D(2), D(3)	5	Add in D(3) from the next quadrant at layer 1
Large-cell horizontal section	E	0:7,8,15,16,23,24,31	LHS,T,B	Ignore - boundary	14	Not applicable
		9:14	I	E(0), E(1), E(2)	6	Done
		17:22	I	E(1), E(2), E(3)	6	Done
		25:30	RHS	E(2), E(3), F(0)	6	Done
	F	0,7,8,15,16,23,24,31	T,B	Ignore – boundary	8	Not applicable
		1:6	LHS	E(3), F(0), F(1)	6	Done
		9:14	I	F(0), F(1), F(2)	6	Done
		17:22	I	F(1), F(2), F(3)	6	Done
		25	RHS	F(2),F(3),G(0),G(1),G(2)	1	Done
		26	RHS	F(2),F(3),G(1),G(2),G(3)	1	Done
		27	RHS	F(2),F(3),G(2),G(3),H(0)	1	Done
		28	RHS	F(2),F(3),G(3),H(0),H(1)	1	Done
		29	RHS	F(2),F(3),H(0),H(1),H(2)	1	Done
		30	RHS	F(2),F(3),H(1),H(2),H(3)	1	Done
	G	0:3,8,16,24	T,RHS	Ignore – boundary	7	Not applicable
		9:10	I	G(0),G(1),G(2)	2	Done
		11	LHS	G(0), G(1), G(2), F(3)	1	Done
		17:18	I	G(1), G(2), G(3)	2	Done
		19	LHS	G(1), G(2), G(3), F(3)	1	Done

		25:26	B	G(2), G(3), H(0)	2	Done
		27	BR	G(2), G(3), H(0), F(3)	1	Done
	H	0:4,8,16,24,31	T,RHS,BL	Ignore – boundary	9	Not applicable
		5:6	T	G(3), H(0), H(1)	2	Done
		7	TL	F(3), G(3), H(0), H(1)	1	Done
		9:14	I	H(0), H(1), H(2)	6	Done
		15	LHS	F(3), H(0), H(1), H(2)	1	Done
		17:22	I	H(1), H(2), H(3)	6	Done
		23	LHS	F(3), H(1), H(2), H(3)	1	Done
		25:30	B	H(2), H(3)	6	Add in I(0) at layer 1
Large-cell vertical section	I	0,7,8,15,16,23,24,31	LHS,RHS	Ignore – boundary	8	Not applicable
		1:6	T	I(0), I(1)	6	Add in H(3) at layer 1
		9:14	I	I(0), I(1), I(2)	6	Done
		17:22	I	I(1), I(2), I(3)	6	Done
		25:30	B	I(2), I(3), J(0)	6	Done
	J	0,7,8,15,16,23,24,31	LHS,RHS	Ignore – boundary	8	Not applicable
		1:6	T	I(3), J(0), J(1)	6	Done
		9:14	I	J(0), J(1), J(2)	6	Done
		17:22	I	J(1), J(2), J(3)	6	Done
		25:30	B	J(2), J(3)	6	Add in J(3) from the next quadrant at layer 1

Table 2 summarizes some information from Table 1. It can be seen that 88 out of the 295 total cells lie on a boundary and cannot be used for triggering. Half of these cells (42) lie on the outer edges of the array, i.e. the inner edge of the small cell array or the outer edge of the large cell array. The others lie on either the boundary between the large and small cells, or on the dividing line between the North and South sides of the large cell array. 179 of the remaining 207 cells (86%) produce clusters that can be fully reconstructed by the layer-0 DSM boards. These are the clusters listed as “Done” in Table 1. The rest (28) will be completed at layer 1. The last column of Table 2 has a count of the number of clusters whose reconstruction requires summing more than 3 stripes together. All of these clusters lie in the regions were the orientation of the stripes switches between vertical and horizontal. They make up around 10% of the 207 non-boundary cells.

Table 2: Statistics for each Layer 0 DSM

DSM Board	QT Boards connected to this DSM	Total Cells	Boundary Cells	Clusters internal to this DSM board	Clusters to be completed at layer 1	Clusters with more than 3 stripes
Small Cell quadrant	A, B, C and D	119	34	75	10	10
Large Cell horizontal section	E, F, G and H	112	38	68	6	12
Large Cell vertical section	I and J	64	16	36	12	0
Totals		295	88	179	28	22

Table 3 then shows which QT8 sums each layer 0 DSM board needs to pass up to layer 1 in order to complete those clusters that lie on the boundaries.

Table 3: QT8 Sums to be passed on to Layer 1

DSM Board	QT8 Sums passed to Layer 1
Small Cell quadrant	A(0) D(3)
Large Cell horizontal section	H(3)
Large Cell vertical section	I(0) J(3)

The layer 0 algorithm will therefore perform the following steps:

- Step 1: Receive the ID (HTID) and ADC value (HT) of the highest cell, and the 4 QT8 suns, from each of 4 (or 3) QT cards.
- Step 2: Compare the HT values and select the largest. If the HTID value indicates that the cell lies on a boundary and should be ignored (everything listed as

"Ignore – boundary" in Table 1) then that cell's HT value will be excluded from the comparison. In parallel with this comparison, start to compute the sums for all possible clusters.

- Step 3: Complete the sum of just the cluster that is centered (HTID) on the selected largest HT value. In parallel with completing the sum, compare the selected largest HT value to a threshold and set a bit if it exceeds that threshold.
- Step 4: Pass that sum, the identifying information, the necessary QT8 sums and the HT-over-threshold bit on to layer 1. The identifying information now contains the original 5 bits, to specify which channel in the QT card is the center of the cluster, and 2 more bits to specify which of the 4 (or 3) QT cards produced this data. Note that there are no plans to pass along the actual HT values themselves.

Table 4 shows how many bits need to be passed from each layer-0 DSM to its layer-1 DSM. The bit totals are all less than 32, which is the maximum that can be passed from one DSM to another, so there is no problem passing these bits.

Table 4: Output of Layer 0 DSM Boards

DSM Board	Output Data		
	Data	Bit Count	Bit Total
Small Cell quadrant	Cluster Sum ID 2 x QT(8) Sums HT	8 7 10 1	26
Large Cell horizontal section	Cluster Sum ID 1 x QT(8) Sum HT	8 7 5 1	21
Large Cell vertical section	Cluster Sum ID 2 x QT(8) Sums HT	7 7 10 1	25

<u>Layer 1 DSM Tree Configuration and Algorithm</u>

From Figure 1 it can be seen that there are 4 layer 0 DSM boards of each type (Small Cell quadrant, etc…), one in each of four quadrants. This makes 12 layer 0 DSM boards in total. Since there are no plans to trigger on clusters that span the boundary between large and small cells there is no immediate need to bring the large and small cell data together in the DSM tree. By the same logic, there is no need to bring the data from the North and South sides of the large-cell array together. The connections from the layer 0 DSM boards to the layer 1 DSM boards have therefore been made as simple and as tightly packed as possible. The 4 boards covering the small cells will all connect to one layer 1 DSM board. The 4 boards covering the North side of the large cell array will connect to a second layer 1 DSM board, and the 4 boards covering the South side of the array will connect to the third and final layer 1 DSM board. This is shown in Figure 2. The blue stripes highlight the FMS regions covered by the QT8 sums that need to be passed from layer 0 to layer 1 in order to allow boundary clusters to be completed.

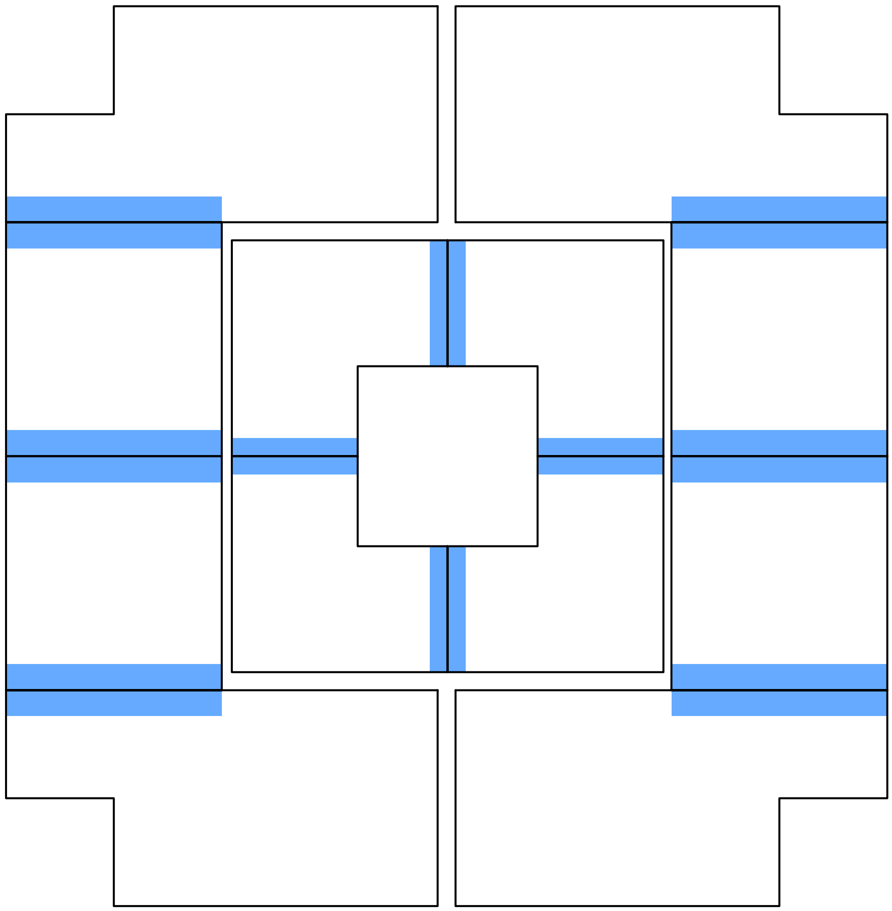

Figure 2: DSM Layer 0 to Layer 1 Assignment Scheme

The algorithm in the small cell layer 1 DSM board will be very slightly different from the algorithm in the large cell layer 1 DSM boards. The small cell layer 1 DSM board will receive data from all four quadrants so it can complete the small cell cluster analysis and pass along the final result to layer 2. There are two large cell layer 1 DSM boards, each covering two quadrants of the detector. They will each complete the analysis for their quadrants, leaving the task of completing the large cell analysis to the layer 2 DSM.

The layer 1 DSM algorithms will therefore perform the following steps:

- Step 1: Receive the sum and ID information for the cluster with the highest central cell from each of 4 layer 0 DSM boards (see Table 4). Also receive the QT8 sums necessary to complete clusters that lie on the internal boundaries (see Table 3), and the HT bit.

- Step 2: Check the ID information for each of the 4 clusters. If any of them lie on an internal boundary, then add in the necessary QT8 sum to complete that cluster. In parallel with these sums, the large cell DSMS will combine the 4 HT bits to produce 2 bits; one covering the top quadrant of the detector and the other covering the bottom quadrant. The small cell DSM will just pass through its HT bits, since each of them already covers one quadrant.
- Step 3: Compare the 4 completed clusters and select the one with the largest sum.
- Step 4: Pass that sum and its identifying information on to layer 2. In the small cell DSM the identifying information now consists of a 4-bit list, to identify which quadrant produced that cluster with the largest sum. In the large cell DSMS the identifying information consists of a 2-bit list, since each of those DSMS only covers two quadrants. Also pass along the HT bits to layer 2. Again, the small cell DSM will pass along 4 bits, while the two large cell DSMS will each pass along 2 bits.

The output from the layer 1 DSMS will therefore be as shown in Table 5. The bit totals are all 16 or less, so this data can fit onto one 16-bit output cable from each DSM. In preparation for future logic upgrades it probably would be useful to connect both output cables from each layer 1 DSM to the layer 2 DSM. This would leave just 2 inputs to the layer 2 DSM available for FPE and any other detector upgrades.

Table 5: Output of Layer 1 DSM Boards

DSM Board	Output Data		
	Data	Bit Count	Bit Total
Small Cell	Cluster Sum	8	16
	ID	4	
	HT	4	
Large Cell (North/South)	Cluster Sum	8	12
	ID	2	
	HT	2	

<u>Layer 2 DSM Algorithm</u>

The layer 2 DSM board will receive the data listed in Table 5 from the FMS small and large cell layer 1 DSMS. It may also receive data from the FPE and FHC detectors. The final logic that will be implemented here has not yet been decided on. However, the initial stages are finalized:

- Step 1: Receive the sum, ID and HT information from each of the three FMS layer 1 DSMS.
- Step 2: For the small cell data, compare the cluster sum to a threshold, and set a bit if that threshold is exceeded. For the large cell data, select the largest of the clusters received from the North and South sides, and then compare the selected cluster sum to a threshold. Set a bit if that threshold is exceeded. Also, combine and modify the large cell ID bit lists to finally indicate which quadrant contained

the selected largest cluster. At this stage the small and large cell data have the same format:

  - 1 bit indicating that the ADC sum for the largest cluster is over threshold
  - 4-bit list to indicate which quadrant contained that largest cluster. NOTE: only 1 of the 4 bits should ever be set
  - 4-bit list to indicate, for each quadrant individually, whether or not there was a high tower that exceeded a threshold. NOTE: since the quadrants are treated separately in the HT logic, any combination of these bits is possible.

- Step 3: Combine these bits for FMS to make the combinations that will be used for triggering. These combinations have not yet been defined.
- Step 4: Pass along this data to the last DSM and TCU, along with any bits from the FPE and FHC detectors.

The final details of this last algorithm will be decided later when the FPE (and possible FHC) logic has been determined.