CMS Endcap Muon Track Finder firmware algorithm description

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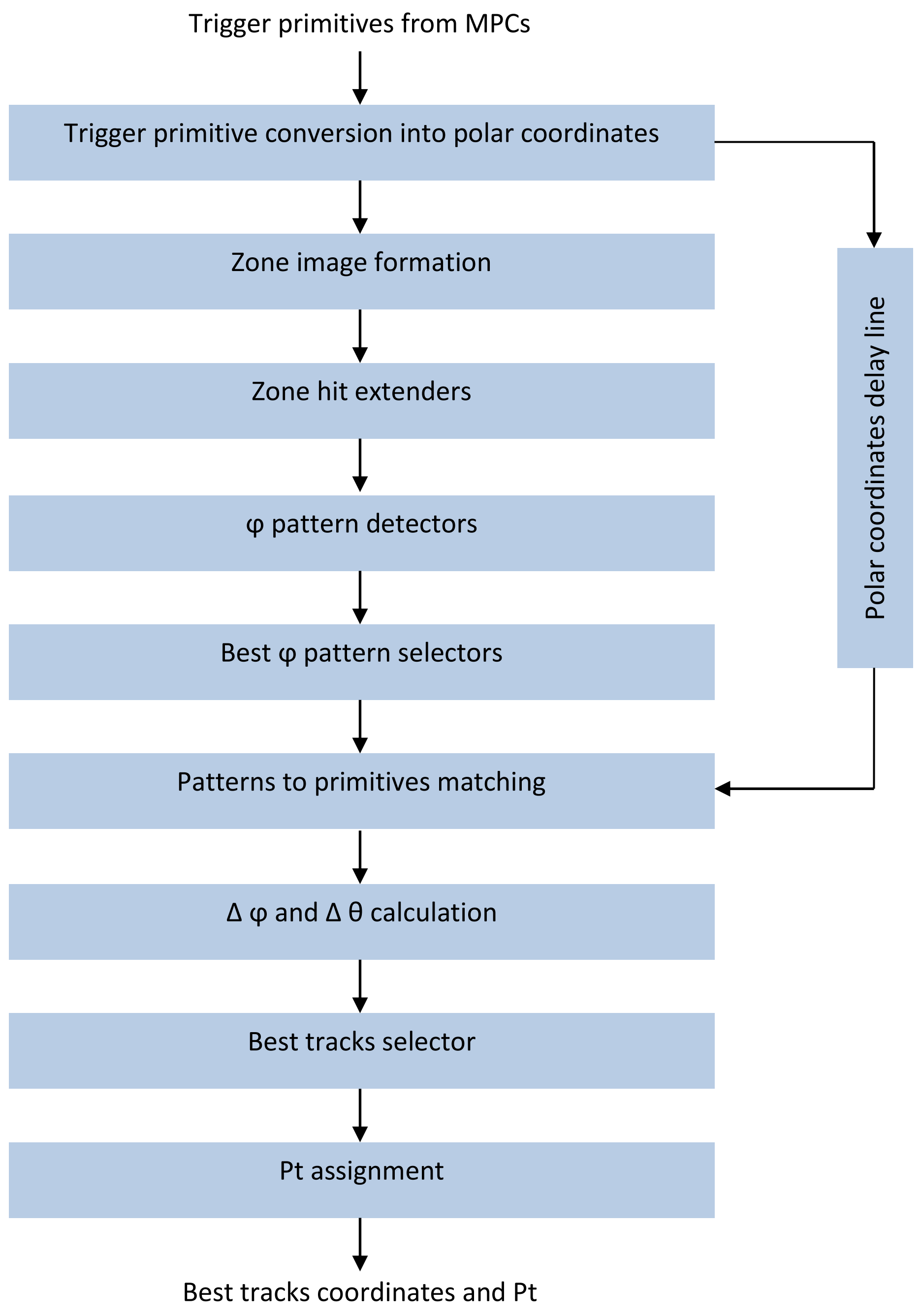
The block schematics below shows the structure of the algorithm.


Trigger primitives from MPCs
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Trigger primitive conversion into polar coordinates

Trigger primitives (also known as Local Charged Tracks, or LCTs) arrive from Muon Port Cards (MPCs) via 3.2 Gbps optical links. Each chamber in Muon Endcap sector can send up to two LCTs. LCTs from each chamber are processed by a separate coordinate conversion unit. Therefore, the total count of these units matches the count of chambers in 60 degree sector. The version of the algorithm currently implemented only processes chambers from its own sector, so the count is 45. The final version will also process 9 chambers from a neighboring sector, to take sector overlap into account. This will bring the count of chambers and coordinate conversion units to 54.

Each LCT contains information listed in Table 1.

Name	**Description**
Quality	LCT quality code
Wiregroup	Key wiregroup number
Half-strip	Key half-strip number
CLCT pattern	CLCT pattern

Table 1. LCT data fields

Trigger primitive conversion unit converts these values into polar coordinates (φ and θ). These coordinates are computed relative to 60 degree Muon Endcap sector. In addition to φ and θ coordinates, the unit outputs "φ hit image". This is a set of bits that represent chamber cross-section in φ dimension. Each bit in this "image" corresponds to 0.53333 degree angle in φ. The bits corresponding to φ coordinates of detected LCTs are set to one; the rest of the bits are zeros. Coordinate φ output is calculated with much better precision, 0.016666 degree. Θ output is calculated with the precision of 0.285 degree.

Zone image formation

This unit is responsible for the creation of the Endcap Muon sector image inside the FPGA logic. This is accomplished by representing each layer of chambers in φ direction using flip-flops. In θ direction, the sector is separated into four zones. The zone separation allows for avoiding ambiguity in assigning the detected φ patterns to chambers later. Figure 1 shows the zones in θ dimension. Θ zone boundaries are 0-41, 42-49, 50-87, and 88-127. The sector image is formed by simply ORing the φ hit image outputs of trigger primitive converters. The φ hit image output for each chamber is inserted with proper φ offset according to chamber's geometrical position.

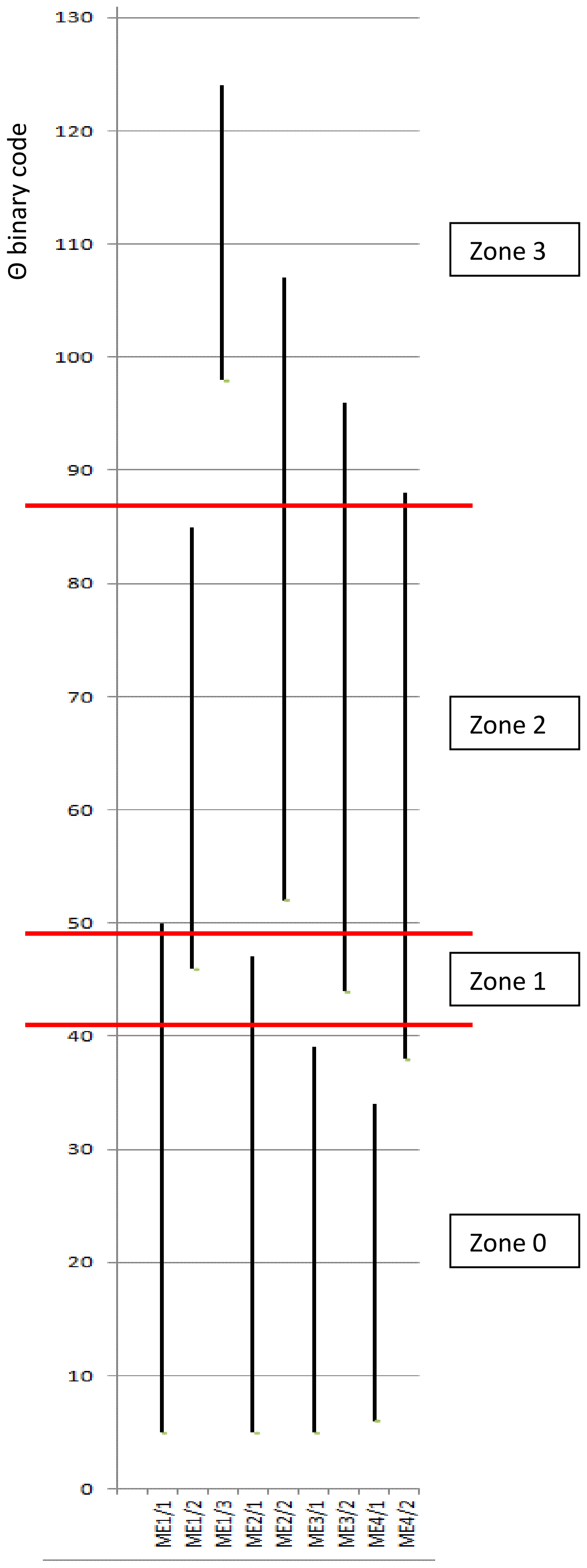


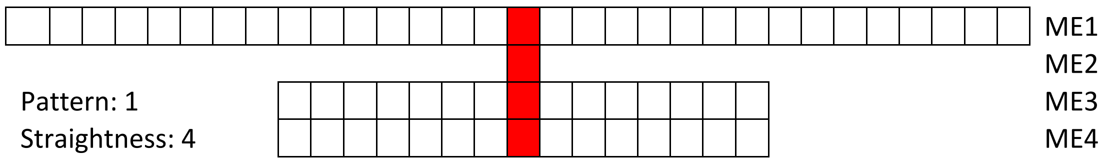
Figure 1. Chamber coverage and zones in θ view

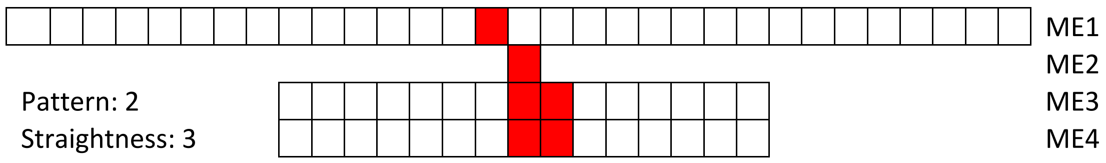
Zone hit extender

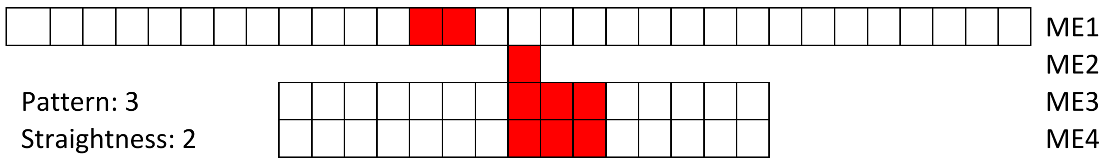
Due to various factors, the LCTs created by a particular track may arrive to Track Finder with a delay up to two bunch-crossings (BXs). In order to build a track from such delayed LCTs, the algorithm must consider LCTs from three consecutive BXs. To allow for that, each hit in the sector image must be extended to occupy 3 BXs. Such extended hits overlap in time, so the pattern detectors can later identify complete track patterns. Zone hit extender unit contains this time extension logic.

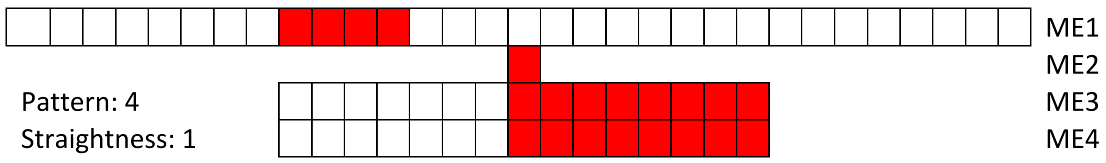
ϕ pattern detectors

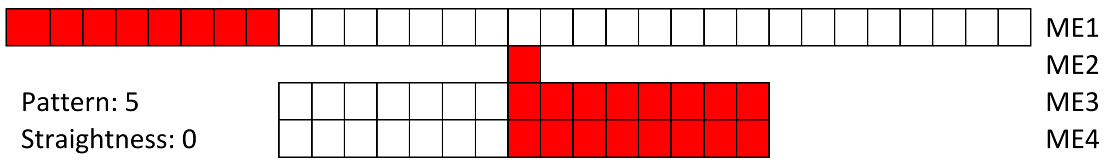
The task of φ pattern detectors is to detect the track patterns in φ cross-section of the sector, and determine their quality. The quality is higher for the straighter tracks, and for tracks with hits in more layers. The diagrams below show the patterns recognized by pattern detector.











Note that patterns 2, 3, 4, 5 also have mirrored twins, so the total count of patterns is 9. Not all hits shown in red have to be found, but the more – the better. The pattern quality is formed as shown in Table 2.

Bit number	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Contents	S2	ME1 hit	S1	ME2 hit	S0	ME3 or ME4 hit

Table 2. Pattern quality code contents. Sx are straightness code bits

This quality code scheme gives higher priority to tracks having the following characteristics:

- Containing ME1 hit, then ME2 hit, then ME3 and/or ME4 hits
- Containing more station hits in any stations
- Straighter tracks

Φ pattern sorter

φ pattern sorter (sort_sector module) selects best three patterns in each zone. This is done in three stages: first, the best pattern is selected and then removed from consideration, then the second best, and finally the third best. Output ph_q carries best ranks, output ph_num carries their location (φ pattern number).

Segment matching module

After the best φ patterns have been found, they need to be matched to the track segments received from chambers. Module match_ph_segments is responsible for that. Each of the best φ patterns detected in previous steps can only come from certain subset of chambers. Segment matching module compares φ coordinate of the detected pattern with the φ coordinates of all segments coming from those chambers. It also takes into consideration the segments delayed by 1 and 2 clocks. This is necessary because some track segments may arrive with a certain delay.

Δ ϕ and Δ θ calculation module

The matching segments for each of the track candidates are used to calculate φ and θ differences between segments. Segments from each station are compared with segments from any other station. This module is also checks that θ differences in each track candidate are not exceeding the maximum allowed difference. If one of the segments is not lining up in θ dimension with the rest of the segments, it's removed from the track, and the track's rank is reduced to reflect the change. Module name is deltas_sector.

Best track module

The best_tracks module receives parameters of all 12 track candidates, as well as φ and θ differences. This module performs the following functions:

- Remove track duplicates (ghosts). Some of the segments can be used to build multiple tracks, usually very close to each other. The module is looking for the tracks that share at least one segment. If such tracks are found, the track with lower rank is considered ghost and removed.
- Select best three tracks according to ranks of the candidates.

PT LUT address formation

The parameters of the best three tracks are used to form the 30-bit address for PT LUT memory. The address formation logic is fairly complex due to various optimizations involved in using the very limited address bits in a best possible way. See source code for details.