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CMS DN -2015/017

The Compact Muon Solenoid Experiment

Detector Note

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16 June 2015 (v3, 05 February 2016)

Interface between the Muon Track Finders and the micro-Global Muon Trigger in the Upgraded CMS Trigger for 2016

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2016/02/05
Head Id: 319791
Archive Id: 247804:320607MP
Archive Date: 2016/01/26
Archive Tag: trunk

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Abstract

This document describes the interface between the upgraded muon track finders and the upgraded Global Muon Trigger for 2016. It includes a short description of the protocol used for transmission and gives details about the encoding of muon properties in the used 64 bit data format.

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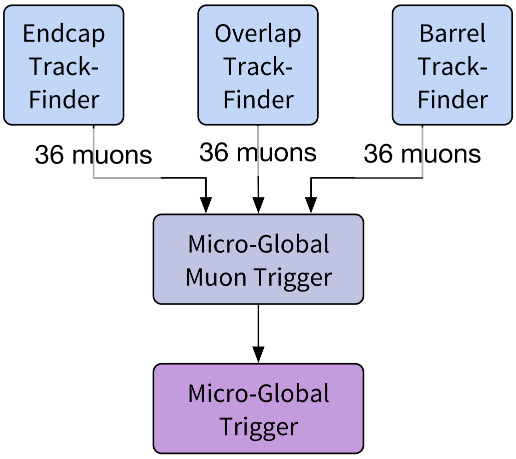

Figure 1: Interfaces of the μGMT. This document defines the interfaces from the track finders (TF) to the μGMT.

1 Context

As illustrated in Fig. 1, the micro-Global Muon Trigger (μGMT) will receive muon candidates from the regional muon triggers in the barrel, overlap and endcap regions, corresponding to $|\eta| < 0.83$, $0.83 <= |\eta| < 1.24$ and $|\eta| > 1.24$, respectively. The regional muon triggers independently find candidates in their η-region making use of both the data from the tracking chambers (Drift Tubes (DT) in the barrel and Cathode Strip Chambers (CSC) in the endcaps) and the Resistive Plate Chambers (which cover both barrel and endcaps). The μGMT will sort the received candidates, cancel out duplicates and send the resulting list of candidates to the micro-Global Trigger (μGT). Additionally the μGMT will receive energy deposits from the Calorimeter Trigger with a granularity of 2×2 towers which it will use to calculate isolation of the muon candidates. Isolation information will be attached to the muon candidates sent to the μGT. The present document deals with the interface between the Regional Muon Triggers and μGMT.

The Regional Sorters will be absorbed in the Global Muon Trigger. The individual Regional Muon Processor Cards (12 per regional muon trigger) will each send their 3 best muon candidates to the Global Muon Trigger over one fibre at 10 Gb/s. The Global Muon Trigger has to handle cancel-out of duplicate candidates at sector/wedge boundaries.

The Barrel Muon Track-Finder (BMTF) is organized in 12 wedges, each covering 30° of the entire barrel (5 adjacent sectors). Each processor card, corresponding to one wedge sends the three best muon candidates per wedge to the μGMT. The μGMT handles the cancel-out of duplicate muons at wedge boundaries.

The Overlap and Endcap Muon Track-Finders (OMTF and EMTF) are each organized in 6 sectors of 60° per endcap. Each overlap/endcap sector is aligned with two barrel wedges. Each of the 60° sectors is covered by one processor card. The best three muons found by the processor card are sent to the μGMT, which handles the cancel-out of duplicate candidates at sector boundaries.

The μGMT also handles cancel-out of duplicate candidates at the four boundaries between η-regions (endcap/overlap and overlap/barrel for both sides of the detector).

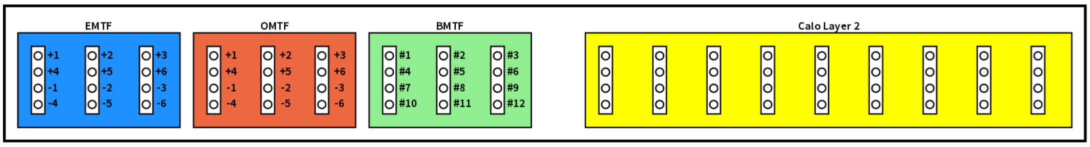

Figure 2: Proposed patch panel for the micro-Global Trigger and micro-Global Muon Trigger μTCA crates. The left hand side will be used for muon inputs while the right side is foreseen for calorimeter inputs.

2 Physical Implementation

The μGMT will be implemented using the MP7 micro-TCA board housed in a separate crate located in the same rack as the μGT. The board contains a Virtex-7 FPGA (XC7VX690T) with 80 GTH transceivers capable of running at up to 13.1 GHz. 72 of the transceivers are connected to 72 optical inputs and 72 optical outputs. The inputs from the regional muon triggers are expected to deliver data at 10 Gb/s. The MP7 has four MTP connectors containing 36 fibers each (the connector would allow for up to 48 fibers to be connected but only 36 are used). Two connectors are used for inputs, two for outputs. It is planned to use one of the input connectors for data from the regional muon triggers.

A patch panel will be employed to receive 12 individual fibers with LC connectors per Regional Trigger on its front side. The 36 individual fibers will be connected to one MTP connector at the rear of the patch panel. A trunk MTP-MTP cable will then connect the patch panel to one input of the μGMT. Another part of the patch panel will be used to receive data from the calorimeter trigger. An illustration of the patch panel is shown in Fig. 2.

3 Link Protocol

In order to avoid problems with link stability due to instabilities in the LHC clock, an asynchronous clock will be used for the transmission. The links will run at 10 Gb/s which is an industry standard supported by different types of transceivers (e.g. Xilinx GTX and Xilinx GTH). An 8 bit/10 bit encoding will be used which brings the usable bandwidth down to 8 Gb/s. It is planned to use a link protocol developed for the MP7 [**?**]. The link will internally accept data of 32 bits width at a rate of 240 MHz (192 bits at 40 MHz) which corresponds to 7.68 Gb/s. Data will be padded to reach 8 Gb/s and padding words will be dropped on the receiver side. The link protocol further protects data with a CRC check sum that is calculated over an orbit.

It is expected that the link sends these padding words and the CRC check sum during the entire BX range 3550-3554 as defined by TCDS. This range is contained in the so-called “dark gap” during which TCDS supresses all triggers.

4 Muon Candidate Format

Each input link for the μGMT will transmit 3 muons per bunch crossing. Muons will be encoded using 64 bits and thus sent in two 32 bit words over two 240 MHz clock cycles, c.f. table 1.

- 62 data bits:
    - p_T: transverse momentum, 9 bits
    - qual: 4 quality bits
    - η: Pseudorapidity, 9 bits

Table 1: Muon data sent over one bunch-crossing, each row shows one 32 bit word, thus, two rows represent one muon.

0	BX0	ϕ	H/F	η	qual	p_T		
	31	30	22	21	12	8		0
1	SE	track addresses					VCH	CH
	31	30					1	0
2	B0	ϕ	H/F	η	qual	p_T		
	31	30	22	21	12	8		0
3	B1	track addresses					VCH	CH
	31	30					1	0
4	B2	ϕ	H/F	η	qual	p_T		
	31	30	22	21	12	8		0
5	Res.	track addresses					VCH	CH
	31	30					1	0

  - H/F: Halo bit for EMTF; fine-eta bit for BMTF
  - ϕ: azimuthal angle, 8 bits
  - CH: charge bit (1 = negative, 0 = positive)
  - VCH: Valid charge (1 = valid, 0 = not valid)
  - track addresses: information on track segments used to construct given track, up to 29 bits
- 5 control bits (sent once per bunch crossing):
  - BX0: Bunch crossing zero bit (1 = bunch crossing zero of orbit; 0 = else)
  - SE: Synchronization error (1 = error; 0 = OK)
  - B0/1/2: Three lowest bits of bunch crossing counter

5 Coding of data bits and scales

In the upgraded muon system the scales for η, ϕ and p_T will all be linear as well as common to the three track-finder systems. In contrast the H/F bit as well as the track addresses can have track-finder-specific meaning. The 4 quality bits will be split in two parts where the two most significant bits use a common scale among track-finders while the two remaining bits have track-finder specific meaning.

The following coordinate system is used for the η and ϕ coordinates:

- CMS is north of centre of LHC; right handed system with origin in collision point
- Horizontal x-axis pointing to centre of LHC (south),
- Vertical y-axis pointing upwards,
- Horizontal z-axis horizontal pointing to west, parallel to beam, parallel to B-field.
- Global $\phi = 0^\circ$ corresponding to x-axis, $\phi = 90^\circ$ corresponding to y axis. The track-finder systems transmit relative ϕ coorindates where $\phi = 0^\circ$ lines up with the lower sector or wedge boundary of the individual processor. For details, see section 5.1.
- $\eta = 0$ in x-y plane, $\eta > 0$ for positive z-axis

The regional track-finders determine a muon's spatial coordinates at a to-be-determined reference plane. The current proposal is to continue to use the current definition:

Table 2: Given in this table are the scale definitions of muon candidates transmitted to the μGMT: Name of the parameter, number of bits, the unit (value of the least significant bit), the integer range used and a comment.

Parameter	n_{bits}	Unit u	Range	Comment
p_T	9	0.5 GeV	$0 \ldots 511$	0: empty candidate; $(bit\_value - 1) \times u$ p_T is defined at 90% efficiency as in the legacy trigger.
quality	4			to be defined
η	9	0.010875	$-230 \ldots 230$	2's complement. $bit\_value \times u$ gives the centre of the bin.
H/F	1			Indicates halo-muon when sent by endcap track-finder or η-fine bit when sent by barrel track-finder.
ϕ_l	8	$2\pi/576$	see Sec. 5.1	2's complement. $bit\_value \times u$ gives the lower edge of the bin.
charge sign	1			1: negative, 0: positive
valid charge	1			1: charge sign is valid, 0: charge sign cannot be determined
track address	29			see Sec. 5.7
BC0	1			per link
Sync error	1			per link
BX 0/1/2	3			3 least significant bits of the bunch-crossing counter. Per link.

- For the barrel a cylinder going through the center of the second muon station.
- For the endcaps a plane going through the center of the second disc of muon chambers.

5.1 Phi scale

The scale used internally by the μGMT is a 10 bit scale with a range from 0 to 575 and thus a stepsize of $2\pi/576$. The track-finder systems will transmit the muon's local phi value (ϕ_l) with a relative coordinate in an 8 bit scale, encoded in 2's complement and with the same stepsize of $2\pi/576$. The μGMT will then apply offsets (configurable per link) to calculate the global ϕ coordinate that corresponds to the standard CMS coordinate system. Fig. 3 shows the global coordinate system in conjunction with the coordinate systems that apply for the track-finders. Two conventions are necessary as the BMTF processors take one DT wedge of 30° into account, while the EMTF and OMTF use the 60° sectors of the CSC system. In both cases, the lower boundary of the wedge / sector corresponds to $\phi_l = 0°$

- The BMTF transmits a signed value encoded in 2's complement. The range expected is -8 to 56 (corresponding to -5° to 35°), where the first and last 8 values (corresponding to 5° each) are overlapping with the previous and next processor.
- The EMTF and OMTF also transmit a signed value encoded in 2's complement. The expected range is -16 to 100 (corresponding to -10° to 62.5°), where the first 16 and last 4 values (corresponding to 10° and 2.5° respectively) are overlapping with the previous and next processor.

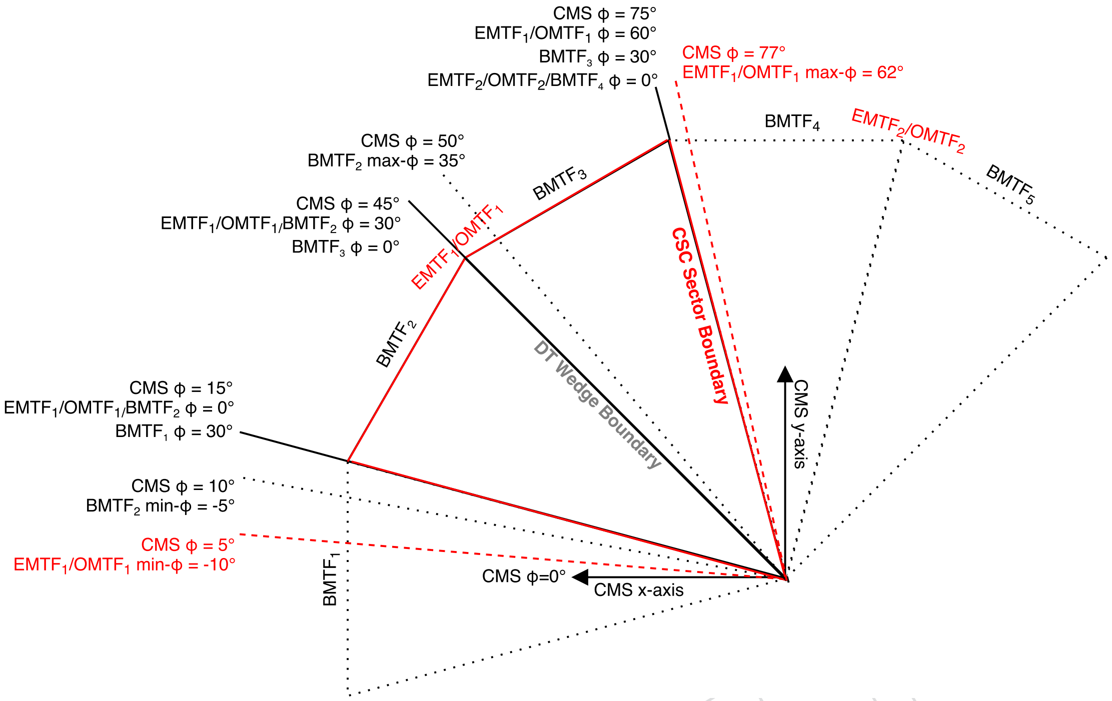

Figure 3: Proposed relative ϕ-scale for the track-finders starts counting at the edge of the processed wedge or sector. The range is different for BMTF as it processes 30° wedges, and OMTF/EMTF which process the 60° sectors.

5.2 Eta scale

The η scale used in the upgraded muon system will be homogeneous across track-finder systems and linear. It is encoded using two's complement in 9 bits with a range from -230 to 230 in steps of 0.010875. If the H/F bit is cleared for muons from the barrel track-finder, the η coordinate could not be determined exactly and has to be treated separately in the μGMT.

5.3 H/F bit

The Halo or Fine bit (H/F) has different meaning, depending on the track-finder. In the barrel track-finder it is used to encode whether the η coordinate could be determined precisely (H/F = 1) or not (H/F = 0). In the endcap track-finder the bit encodes whether the muon candidate is a halo muon (H/F = 1) or not (H/F = 0). For the overlap track-finder the bit has no meaning and is ignored by the μGMT.

5.4 pT scale

The p_T scale is linear and common to all track-finders. It is encoded as an unsigned integer of 9 bits with a stepsize of 0.5 GeV. The range is 0 to 255 GeV. A value of 0 indicates an empty candidate. The highest bin contains the overflow.

5.5 Charge and charge valid bit

The valid charge bit signifies validity of an assigned charge, it is cleared for high-p_T muons in the track-finders and forwarded to the μGT. The charge bit is 0 for positive charge and 1 for negative charge (charge = $(-1)^{sign}$).

5.6 Quality scale

The quality of a muon track is encoded in 4 bits that are split in half. The 2 most significant bits follow a common scale between track-finders that will also be forwarded to the uGT. The remaining two least significant bits can be encoded in a track-finder specific scale. However it is expected that the 4 bit quality scale follows an ordering, i.e. that higher quality signifies a "better" muon.

5.7 Track addresses

The track addresses are encoded in 29 bits. They are dependent on the algorithm used by the track-finders and, as such, system-specific.

5.7.1 Barrel Muon Track-Finder

Each Barrel Muon Track-Finder processor receives up to four track segments per station from each TwinMUX card which processes data from one sector. A track segment can consist of a combination of DT and RPC hits.

The general track finding logic will not change significantly with regard to the algorithm used for LHC Run-1, so it is possible to adapt the encoding chosen for the legacy system. In the legacy system this could be compressed to 7 bits, however in the upgraded system this information can be transmitted uncompressed saving encoding and decoding logic. A detailed documentation of the track addresses and the cancel-out logic can be found in 6.1.

5.7.2 Overlap Muon Track-Finder

No track address information is foreseen to be transmitted to the μGMT from the overlap muon track-finder.

5.7.3 Endcap Muon Track-Finder

MISSING

6 Track address based cancel-out

6.1 Barrel Muon Track-Finder

Address-based cancel-out for BMTF muons relies on the fact that muons sent by the track-finder for a given wedge N are certain to have at least all but one of their constituting track segments in wedge N, i.e. the track-finder algorithm extrapolates muon tracks only a maximum of one step into a neighbouring wedge.

The BMTF receives four track segments per station from the TwinMUX. For historical reasons these four track segments are grouped into two sets: Track segments (0, 1) and track segments (2, 3). The track-address uniquely identifies the track segments used for the construction of a track in the BMTF. For this, the wheel and wedge of each track segment are identified relative to the reference point of the track: The reference point for a particular track is defined by the wheel and wedge containing the track-segment from the station closest to the interaction point.

In the BMTF to uGMT interface the reference point is encoded by the originating track-finder processor (implicitly encoded in the link number) that corresponds to the reference wedge

Table 3: Wheel encoding: The first bit serves as a sign bit.

Wheel Label	Binary encoding	Hexadecimal encoding
-2	`0b110`	`0x6`
-1	`0b101`	`0x5`
-0	`0b100`	`0x4`
+0	`0b000`	`0x0`
+1	`0b001`	`0x1`
+2	`0b010`	`0x2`
None	`0b111`	`0x7`

Table 4: Encoding of track addresses for BMTF within the 32 bits of the second muon word described in table 1.

Res.	Selector	Wheel#	Res.	Station 1	Station 2	Station 3	Station 4	Res.
30	26	22	19	17	15	11	7	3 2

while the wheel is encoded in the track-address word. The constituents are then addressed relative to this reference. To uniquely identify the track constituents one needs:

- Wheel number *w*
- Track segment encoding *t*:
  - 4 x 1 bit to select track segment set (0, 1) or (2, 3) for each station
  - 2 bit for station 1
  - 3 x 4 bit for stations 2, 3, and 4
- Reference wedge (not explicitly encoded, given by link number)

The wheel number is encoded in two parts. Bit 3 indicates the “side” of the detector (i.e. positive or negative) while bits 1 and 2 encode the number. For bit 3 the code ‘1’ means negative and ‘0’ means positive.

The track addresses are split into three distinct fields. The first field contains four bits for each station indicating whether the track segment used is a member of the track segments (0, 1) or (2, 3). The following fields indicate whether the first or second track segment within such a set was used for each station separately. These fields are described in more detail in the following.

For the station 1 the encoding `0x2` and `0x1` for first and second track segment of a given set and `0x3` for “no segment used” was agreed on. (For the first station the reference point – i.e. the central wedge and wheel with lower $|\eta|$ – are used.)

Constituting track segments from stations 2-4, are identified by the following addressing scheme: For each station a 4 bit number is used that identifies wheel and wedge relative to the reference point as shown in Fig. 4. In the direction of the beam, higher numbers identify the wheel closer to the central wheel (e.g. `0x2` vs. `0xA`). For the azimuthal direction, higher numbers correspond to larger ϕ values (e.g. `0x1` vs. `0x5`). Within a station the two possible numbers encode whether the first or second track segment of a given set was used for a particular track (e.g. `0x0` vs. `0x1`). The code `0xF` is used to signify “no segment used” for a particular station.

Table 5: Coding of the selector field shown in table 4.

Station 1 selector	Station 2 selector	Station 3 selector	Station 4 selector
26	25	24	23

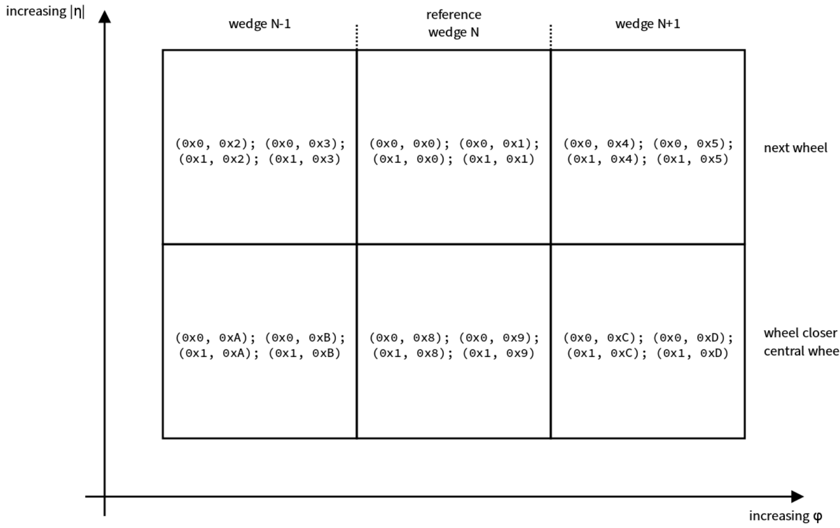

Figure 4: Track segment encoding for wedge N in one station. Each field corresponds to a given wheel and wedge. The four sets of numbers refer to the address encoding for one of the four track segments in that wedge.

The encoding within the input muon words is illustrated in table 4 with the detailed coding of the selector field described in table 5.

It has been agreed that a single matching track segment will indicate a duplicate track.

6.1.1 Duplicate Track Example

An illustration of this example is shown in Fig. 5.

Track found by track-finder for wedge N: $w =$`0x1`, $s =$`0x2`, and $t =$`0x29CF`
This would mean a track originating from wheel +1 ($w =$`0x1`), having been constructed from the first track segment (`0x2`) of the first set (`0x2=0b0010`) in station 1, from the second segment in wheel 1 and wedge N (`0x9`) of the first set (`0x2=0b0010`) in station 2, and from the first segment in wheel 1 and wedge $N + 1$ (`0xC`) of the second set (`0x2=0b0010`) in station 3. No track segment from station 4 was used (`0xF`).

Track as found by track-finder for neighbour wedge $N + 1$: $w =$`0x1`, $s =$`0x3`, and $t =$`0x3F88`
The track was also found in wheel 1 → $w =$`0x1`, but without track segments from stations 1 (`0x3`) and 2 (`0xF`). In station 3 the first segment in wheel 1 and wedge $N + 1$ (`0x8`) of the second set (`0x3=0b0011`) is the same segment as used by the first example. The track segment from station 4 is the first segment in wheel 1 and wedge $N + 1$ (`0x8`) of the first set (`0x3`).

The track segment used in station 3 is the first segment of the second set in wheel 1 and wedge $N + 1$ in both track-finders. The tracks are therefore flaged as duplicates.

References

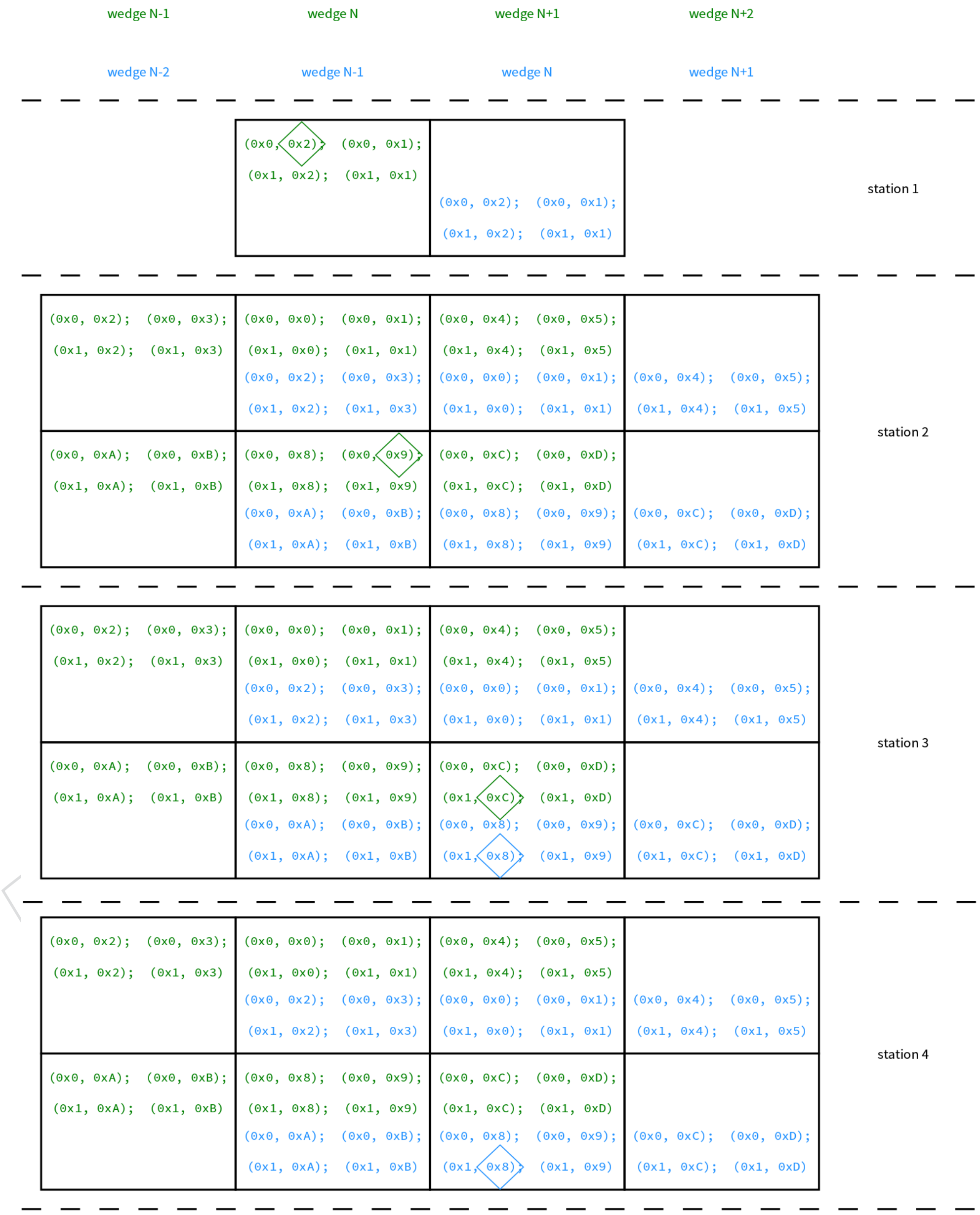

Figure 5: Illustration of the example. The two tracks are duplicates because of the shared track segment in station 3.