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CMS Muon Trigger Preliminary specifications of the baseline trigger algorithms

CMS Muon Trigger Group

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Abstract

This document contains the specifications of the CMS baseline Muon Trigger algorithms. After listing basic requirements and their justifications the algorithms of all Muon Trigger components are described. List of the technical notes and other documents related to the Muon Trigger simulation and design is appended.

1. Introduction

The aim of this document is to provide a comprehensive list of specifications of the CMS baseline Muon Trigger algorithms. Most of the information is extracted from the CMS Technical Proposal and numerous technical notes in order to collect in one place all relevant information. The present specifications provide the basis for further simulation studies with the aim of refining its details. They provide the basis for the design studies, prototype developments and beam tests to be carried out in 1996-98. These specifications are preliminary and may be modified as a result of the foreseen tests and technical developments.

Basic requirements for the Muon Trigger system together with their justifications are listed in Sec. 2. Algorithms of all Muon Trigger components are described in Sec. 3. Detailed information on the physics performance of the algorithms can be found in the technical notes listed at the end of the document.

2. Requirements

The basic tasks of the CMS Muon Trigger are:
- muon identification,
- transverse momentum measurement,
- bunch crossing identification.

It has to fullfil the following requirements.

Geometrical coverage: up to $|\eta|$=2.4, in order to cover the entire area of the muon system.

Latency: < 3.2 μs. Total trigger processing, including 2 × 120 m cables (1.2 μs) to the control room, should stay within the length of the tracker pipelines equal to 128 bunch crossings. This implies that the trigger algorithms cannot be too complicated.

Trigger dead time: not allowed. Every bunch crossing has to be processed in order to maintain high efficiency crucial for many physics channels with low cross section.

Maximal output rate: < 15 kHz for luminosities < 10^{34} $s^{-1}cm^{-2}$. Maximal second level input rate is 100 kHz. Uncertainty in estimates of cross sections and luminosity variations during a single run requires large safety margin. We design the average first level output rate not to exceed 30 kHz which should be shared amongst muon and calorimeter triggers. About 3-6 kHz is assumed for the single muon trigger. This implies rejection factor of ~1:100000 at the highest luminosity.

Background rejection: trigger rate due to background should not exceed the rate of prompt muons from heavy quark decays. This is necessary to maintain the rejection factor stated above. The prompt muon rate is irreducible except for channels where the isolation criterion can be applied (see below).

Low p_t reach: should be limited only by muon energy loss in the calorimeters. It is equal to about 4 GeV in the barrel and it decreases with $|\eta|$ down to ~2.5 GeV. This is required mainly by b-quark physics at $L = 10^{33}$ $s^{-1}cm^{-2}$.

The highest possible p_t cut: ~50-100 GeV. Expected threshold needed to keep the single muon trigger rate to be 3-6 kHz at $L = 10^{34}$ $s^{-1}cm^{-2}$ is 15-20 GeV. Uncertainty in estimates of cross sections and background levels requires large safety margin. Increasing the threshold from 15-20 GeV to 50-100 GeV reduces the rate by two orders of magnitude.

Isolation: transverse energy E_t deposited in each calorimeter region of $\Delta\phi \times \Delta\eta$ = 0.35 × 0.35 around a muon is compared with a threshold. This function is needed to suppress the rate of background and prompt muons form heavy quark decays when triggering on muons not accompanied by jets. This is particularly useful in channels like h,A,H→μμ, h,A,H→ττ, tt→WW and gluino decays.

Output to the Global Trigger: up to 4 highest p_t muons in each event. In principle only 3 muons are necessary for the Global Trigger to perform single- and multiobject cuts including the three-muon trigger. Delivering 4 muons we reduce the probability that a low p_t isolated muon will not be selected because of the presence of higher p_t nonisolated muons. This way we also reduce the probability of accepting ghosts instead of real muons.

3. Muon trigger components

The muon trigger system consists of the following items:

- Pattern Comparator Trigger (PACT) based on Resistive Plate Chambers (RPC)
- Drift Tube (DT) Trigger - containing Bunch and Time Identifier (BTI) and Track Correlator (TC)
- Cathode Strip Chamber (CSC) Trigger
- Track Finder (TF) - Regional Trigger
- Muon Sorter
- Global Muon Trigger

Functional relations between the components are shown in Fig. 1. Cumulative latency is given in bunch

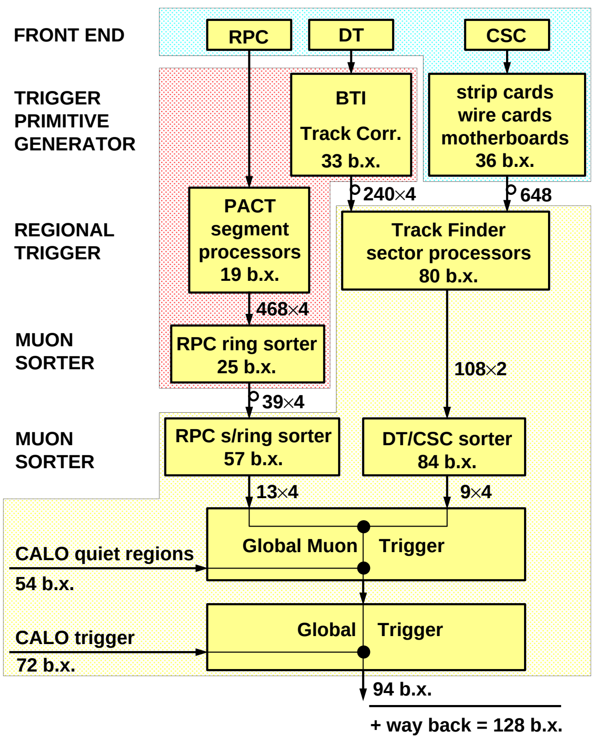


Fig. 1. Functional scheme of the Muon Trigger.

crossing units (bx). Three shaded backgrounds show the location of the electronics: at the chamber, in the experimental hall and in the control room respectively. The number of links is given. Optical links of 1 Gbit/s are indicated by circles. Most of the RPC trigger electronics is placed in the experimental hall, but an option is being considered to move a large part of it to the control room. This would increase the number of expensive optical links but make the system more reliable and easier to maintain.

DT and CSC electronics first process the information from each chamber locally. As a result one vector (position and angle) per muon station is delivered. Vectors from different stations are collected by the Track Finder which combines them to form a muon track and assign a transverse momentum value. This information is shipped to the Muon Sorter.

In the case of RPC there is no local processing apart from synchronisation and cluster reduction. Hits from all stations are collected by PACT logic. If they are aligned along a possible muon track, a p_t value is assigned and the information is sent to the Muon Sorter.

The Muon Sorter selects 4 highest p_t muons from each subsystem in several detector regions and sends them to the Global Muon Trigger. The Global Muon Trigger compares the information from TF (DT/CSC) and PACT (RPC). So called quiet bits delivered by the Calorimeter Trigger are used to form an isolated muon trigger. The 4 highest p_t muons in the whole event are then transmitted to the Global Trigger. Finally transverse momentum thresholds are applied by the Global Trigger for all trigger conditions.

3.1. RPC Pattern Comparator Trigger algorithm

The trigger is based on 4 RPC planes. There is one RPC plane in each muon station except MB1 and MB2. These stations contains additional planes referred to as MB1' and MB2'. They are used to trigger on low momentum muons ($p_t < 6$ GeV) which cannot reach MB3 and MB4. In the baseline design RPC cover the η-range up to $|\eta|$=2.1, but the space for a possible installation of chambers is left up to $|\eta|$=2.4 in case of upgrade. RPC are read out by strips covering $\Delta\eta \approx 0.1$ and $\Delta\phi = 5/16°$ each. If the signal is shared by more than 2 strips the cluster size is reduced by removing strips on the cluster edge. For low p_t muons, when the resolution is limited by multiple scattering, the strips are grouped by 2, 4 or 8, depending on the momentum.

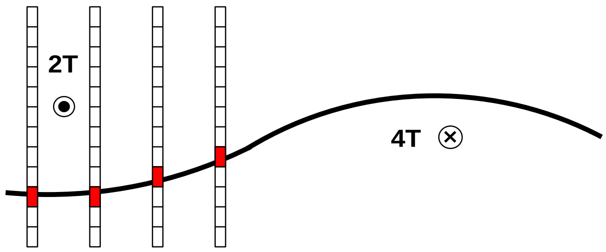


Fig. 2. PACT idea

The basic logical unit of PACT is called *segment*. It covers $\Delta\eta \approx 0.1$ rapidity unit times $\Delta\phi = 2.5°$. It is defined by 8 strips in a reference muon station. As the reference station we have chosen MF2 and the first RPC plane in MB2. Each *segment processor* is equipped with a Pattern Comparator (PAC) chip which compares patterns of hits from 4 RPC planes with predefined *valid patterns*. The valid patterns are first obtained from simulation and will be corrected later using real reconstructed muon tracks. Because a given pattern can be created by muons from a certain p_t range we assign a maximal p_t value to it. The pattern must consist of at least 3 hits from different planes. If it consists of 4 different plane hits a *3/4 quality bit* is set to 1. Otherwise it is set to 0. This bit is used further to select the best muon candidates (see Sec. 3.5.) becuase a missing hit can cause overestimation of the muon momentum. Full information delivered by each segment processor is described in Tab. 1. This information is further processed by the Muon Sorter.

Tab. 1. Information delivered by PACT segment processor (≤1 track per segment)

variable	bits	unit / precision
η	6	~0.1 η unit
ϕ	8	2.5°
muon sign	1	—
p_t	5	nonlinear scale
3/4 quality bit	1	—

3.2. Drift Tube Trigger algorithm

Each of 4 muon stations in the barrel is equipped with 12 layers of Drift Tubes. They are arranged in 3 quartets called *superlayers* (SL). Two of the superlayers measure the $r\phi$ coordinate, one measures η. Tracks in each SL are recognised by Bunch and Track Identifier (BTI) using generalised meantimer technique. Signals from 4 DT layers are connected to clock driven shift registers. Shifting time in the registers compensates the drift time, thus 4 signals are aligned in a fixed time after the particle passage, approximately equal to the maximal drift time. This enables bunch crossing identification. Cases when only 3 aligned hits are found are also accepted but they are called *Low Quality Triggers* (LTRG) and they set the *H/L quality bit* to 0. *High Quality Triggers* (HTRG), based on 4 aligned hits, set the H/L quality bit to 1. In case of more than 1 track candidate an arbitrary one is delivered but HTRG has preference over LTRG.

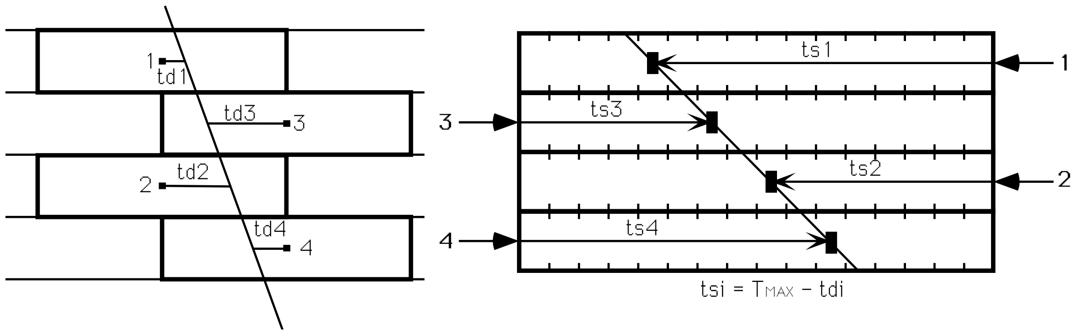


Fig. 3. Bunch and Track Identifier (BTI)

A single tube is 40 mm wide (drift direction) and the distance between planes of tubes is 13 mm. The maximal drift time with a drift velocity of 50 μm/ns is about 400 ns. The clock cycle of 25 ns and the drift velocity determine the position measurement unit to be equal to 1.25 mm. A lever arm of at least 22 mm gives an angular precision better than 60 mrad. A single BTI unit is connected to 2+2+2+3 tubes in 4 layers respectively covering a spacial range of 80 mm and an angular range of $\pm 45.7°$. Hence 6+6 bits are needed to express the measured position+angle. The acceptance for 3 hit tracks is slightly wider than $\pm 45.7°$ but the efficiency decreases with the angle approaching 0 at $\pm 56°$.

Tab. 2. Information delivered by DT BTI (≤1 track per BTI)

variable	bits	unit / precision
track position x	6	1.25 mm
track angle ψ	6	60 mrad
H/L quality bit	1	—

Track pairs from inner (SL_I) and outer (SL_O) ϕ-superlayers are combined by the *Track Correlator* (TC). It compares their angles, ψ_I and ψ_O, with the angle ψ_{COR} defined by the positions x_I and x_O with precision of 10 mrad. If the correlation is successful then ψ_{COR} and x_{COR} are transmitted and *CORR quality bit* is set to 1. Otherwise CORR=0 and HTRG is chosen. If both tracks have the same quality the one from SL_I is taken. Each TC serves 5 SL_I and 15 SL_O in order to match the BTI angular acceptance. It selects up to 2 candidate BTI pairs using H/L bit and deviation from radial direction $\Delta\psi_r$ which should be smaller for higher p_t tracks. HTRG has preference over $\Delta\psi_r$ for the first candidate, and vice versa for the second one. If a second trigger comes right after the first one, only one track is transmitted and the overlap flag OVLP is set to 1. The MULT flag informs if there are other tracks to be transmitted. TC also receives information from the θ-superlayer. It is used together with H/L bits from ϕ-superlayers to determine two trigger quality bits TRG0 and TRG1. The described algorithm flow is the standard one, but other choices are available using programmable control bits.

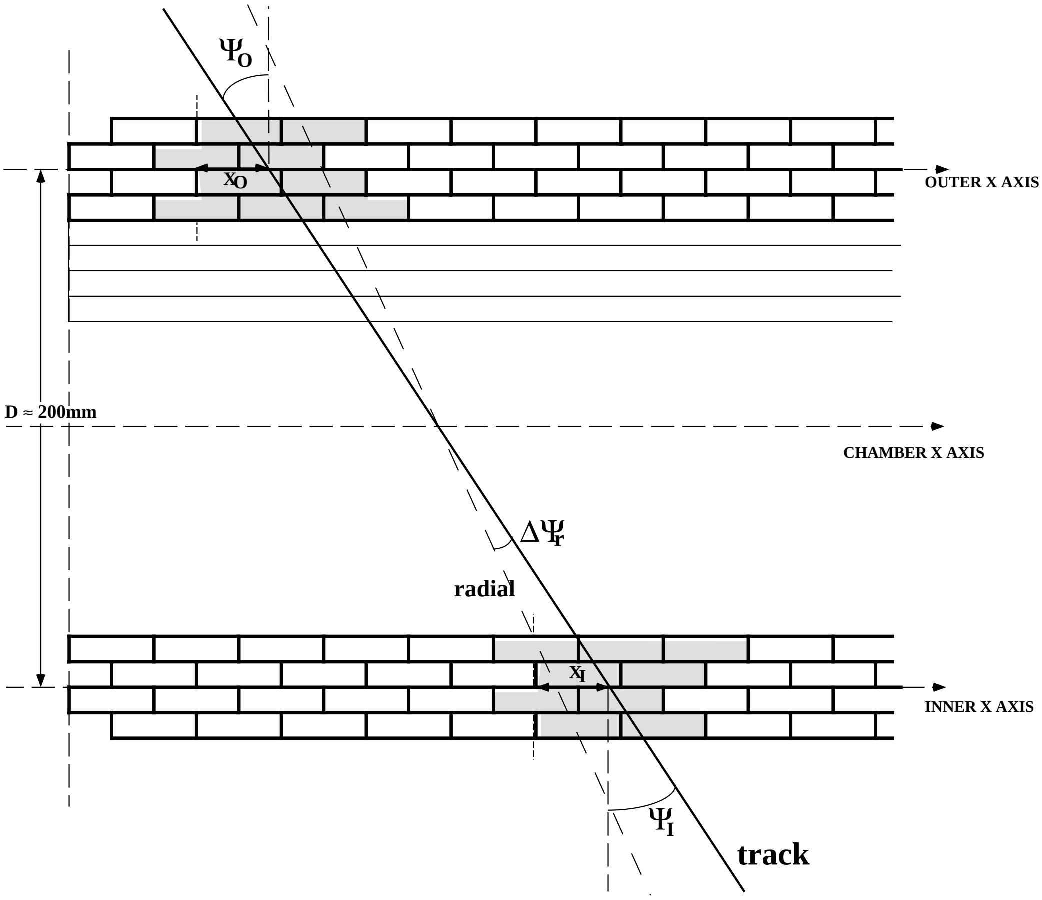


Fig. 4. Track Correlator (TC)

TC outputs from one chamber are collected by *Trigger Server*. It selects up to 2 candidates having smallest $\Delta\psi_r$. In addition, positions of all tracks detected by BTI in θ-superlayers are coded in 32 bits with 8 cm resolution.

Tab. 3. Information delivered by DT Trigger Server: ϕ-projection (≤2 tracks per chamber)

variable	bits	unit / precision
track position $\phi(x)$	11	2.5 mm
track angle ψ	8	10 mrad (if CORR=1) 60 mrad (if CORR=0)
quality bits: CORR, MULT, OVLP, TRG(1:0)	5	—

Tab. 4. Information delivered by DT Trigger Server: η-projection (per chamber)

variable	bits	unit / precision
position of triggered BTIs	32	8 cm

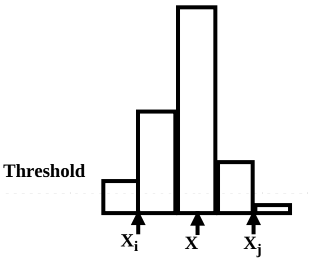
3.3. Cathode Strip Chamber Trigger algorithm

Endcap muon stations are equipped with Cathode Strip Chambers. Each chamber consists of six detecting layers. They are read out by radial strips and wires perpendicular to them, except MF1/1 where the wires are tilted by 22°. An alternative solution with 3+3 layers of 10°-stereo strips (parallel to the chamber edges) is also considered. The strip width $\Delta\phi$ varies from 2.0 to 4.3 mrad and the length $\Delta\eta$ from 0.35 to 0.60 η units. The wires are ganged in groups of $\Delta\eta \approx 0.02$-0.04 (i.e. 25-50 mm). Signals from strips and wires are first processed independently by electronics attached to the chambers.

Typical signal is shared by a few strips. The first task of the strip electronics is to find the center of the cluster with a half strip precision. Details of this algorithm are still under discussion. Currently two possibilities are being envisaged (Fig. 5):

- algorithm 1 working on discriminated signals, calculating the cluster center from strips on the cluster edge,
- algorithm 2 using a net of analog comparators looking for the highest signal and its neighbours.

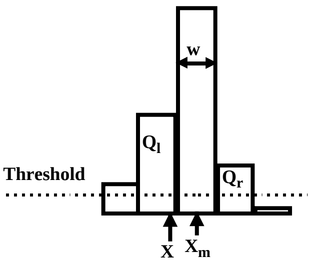
Algorithm 1:



$$\mathbf{X = 1/2\ (X_i + X_j).}$$

where:
X - hit coordinate
X_i, X_j - coordinates of cluster edges

Algorithm 2:



$$\mathbf{X = X_m\text{, for one strip;}}$$
$$\mathbf{X = X_m - w/4,\ \text{if}\ Q_l > Q_r;}$$
$$\mathbf{X = X_m + w/4,\ \text{if}\ Q_r > Q_l.}$$

where:
X_m - strip coordinate with max. charge;
w - strip width ;
Q_l, Q_r - the charge on left and right strips of the cluster.

Fig. 5. Algorithms to achieve half-strip resolution

One CSC strip card handles 16 strips $\times$ 6 layers. The strip signals are brought into coincidence within *roads* within a time bucket of 100 ns for the local strip trigger. For p_t in the range 10 - 100 GeV the road is 4 $\times$ half strip wide. For low p_t, between 2.5 and 10 GeV, the half strip signals are grouped by 4 (to the width of two strips) and the road is 4 $\times$ double strip wide. Having 6 layers in a chamber this gives $2\times4\times6=48$ bits. One or two missing hits in a road are allowed, i.e. 4/6 (4 out of 6) and 5/6 patterns are accepted in addition to 6/6 ones. The best pattern in a road and then the best one on a entire strip card is found by *priority encoding*. First 6/6 patterns take priority over 5/6 and 4/6, then low bend-angle (high p_t) take priority over high bend-angle (low p_t). This mechanism also enables some tuning of the system by assigning higher or lower priority to selected patterns. Assuming about 100 roads per one half-strip, each road having 22=1+6+15 (for 6/6+5/6+4/6) patterns, one needs 11 bits to specify one of 2048 roads. Another 5 bits are needed to select one of 32 half-strips on the card. The 11+5=16 bits specifying the highest priority pattern in a given strip card are transmitted to the motherboard card.

The main task of the wire card is to recognise the bunch crossing. It is not straightforward because signals from six layers are spread within 50 ns interval due to the drift time. A possible algorithm is shown in Fig. 6.

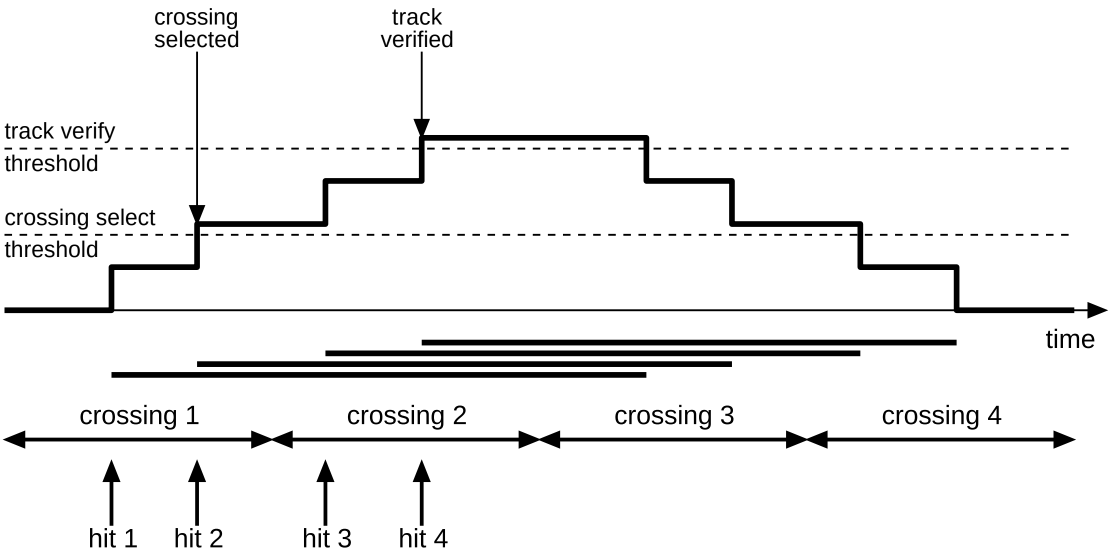


Fig. 6. Bunch crossing assignment algorithm for CSC.

We use each hit in a CSC layer to produce a t_w long pulse. The pulses that are assigned to a road are added together. If a second hit is added to the first, the pulseheight goes over the crossing select threshold and a candidate track in this crossing is stored. However, the existence of a track assigned to this crossing is not established until 2 more additional hits are found in this road within the t_w time window established by the earliest hit. If this occurs, the pulseheight exceeds the track verification threshold and the track is confirmed and assigned to the original crossing where the crossing select threshold was passed. Even if the verification (by passage of the 4-hit threshold) happens in the subsequent crossing to the establishment of the candidate track (by passage of the 2-hit threshold), the track is still assigned to the crossing where the candidate was originally found. The length of the time window t_w depends on parameters of the chamber+electronics. Currently chosen values are 50 ns for MF1/1 and 75 ns for MF1/2-MF4. Again 16 bits are enough to transmit the information about the track to the motherboard.

A motherboard performs the following basic functions:

- Converts (via look up tables) strip card information into number of hits N_h, position ϕ, bend angle ψ and probability P. The algorithm of assigning the probability is not yet defined.
- Converts wire card information into number of hits N_h, position η and probability P.
- Requires coincidence between track segments seen by strips and by wires.
- Resolves overlaps with neighbour chambers in ϕ.
- Applies alignment corrections to muon track segments.
- Transmits the information to the Track Finder.

Tab. 5. Information delivered by CSC motherboard: ϕ-projection ($\leq$2 tracks per chamber)

variable	bits	unit / precision
track position ϕ	11	3-4 mrad
track angle ψ_ϕ	8	10 mrad
quality information based on N_h and P	not yet defined	—

Tab. 6. Information delivered by CSC motherboard: η-projection (≤2 tracks per chamber)

variable	bits	unit / precision
track position $\eta(r)$	8	25-50 mm
track angle ψ_η	8	50-100 mrad
quality information based on N_h and P	not yet defined	—

It is foreseen to send up to two tracks from a motherboard. However, having in mind possible technical difficulties one should check this requirement by simulation of appropriate physics channels and background. If the stereo option is chosen, the motherboard should match the information from U and V strip layers. Trigger electronics for the radial strips option is simpler but it has a possible drawback: in case of more than one track crossing one chamber it is difficult to decide which strip track segment should be matched with each wire track segment. The best place to solve this ambiguity is the motherboard. Several possible ways are considered:

- use information available at the motherboard like number of hits etc.
- make coincidence with RPC strips which are ~6 times shorter then those of CSC
- make coincidence with an additional plane of CSC pads

Other alternatives are:

- solve ambiguities in the Track Finder hoping that the extrapolation of ghosts will fail
- solve ambiguities in the Global Muon Trigger comparing with track candidates from RPC

3.4. Track Finder algorithm

The main task of the Track Finder is to combine track segments delivered by DT and CSC from different stations into full muon tracks and assign p_t values to them. Its basic unit called *sector processor* covers $\Delta\phi=30^o$ and $\Delta\eta=0.35$. It matches track segments from different stations by an extrapolation method. Having 4 muon stations several station→station extrapolations can be done in parallel. In the barrel they are: 1→2, 2→3, 4→3, 1→3, 2→4, and 1→4. The extrapolation is based on position ϕ and bend angle ψ of a track segment. The bend angle ψ is used as a starting direction and as a measure of p_t to find the track curvature. In the barrel the $p_t(\psi)$ relation is unique but in the forward region it depends also on η. A pair of track segments is considered as matched if the extrapolation of the first one coincides with the position (and possibly the angle) of the second one within a given accuracy.

The next step is to combine all matched pairs into a full track. At least two matched track segments are required. Resulting track candidates are checked whether they are not caused by the same real muon. The last step is to assign unique ϕ, η and p_t to the track. The p_t is calculated as a function of the bend angle between two stations ϕ_i-ϕ_j. In the forward region also the η information must be used. The resulting values are then transmitted to the Muon Sorter. A single sector processor can deliver up to 2 tracks. They are selected using p_t and quality bits.

The presented algorithm works well in the barrel, but it has some difficulties in the forward region. They are caused by the fact that the knowledge of η is required for the extrapolation. It can be measured by CSC, but in case of η/ϕ ambiguities described in the previous section one does not know which η should be used to extrapolate which ϕ track segment. Several possibilities are being investigated:

- make an extrapolation in the η-projection only — this extrapolation is linear and can be done independently of ϕ, in addition a pointing to the interaction point can be checked
- match the two projections asking for track segments from the same sets of chambers — this works only in some regions of the detector
- combination of the two above methods

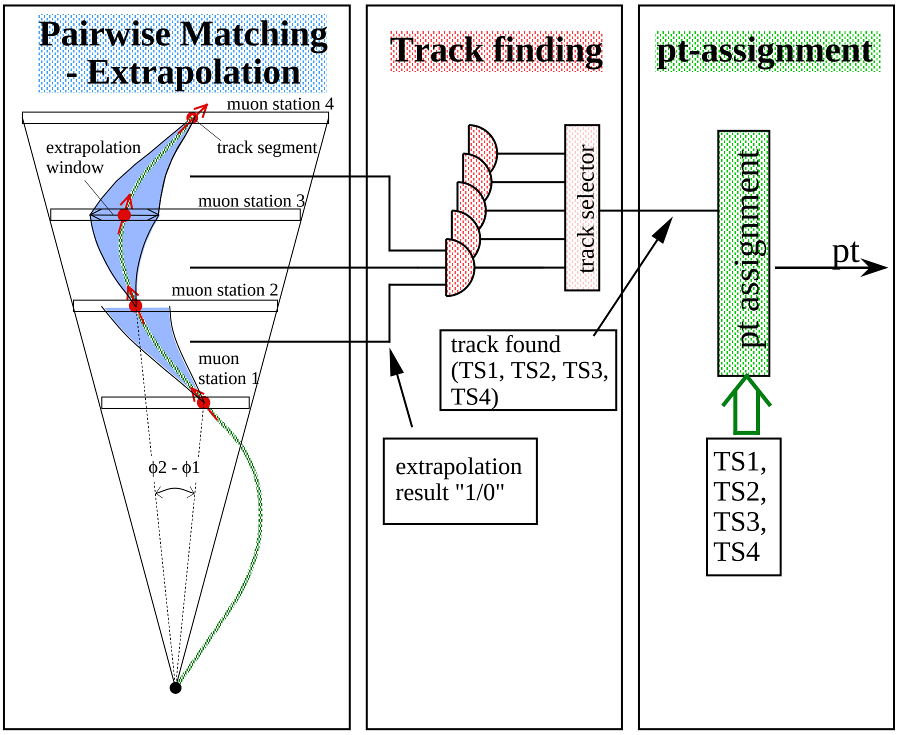


Fig. 7. Track Finder principle

Tab. 7. Information delivered by Track Finder (≤2 tracks per sector)

variable	bits	unit / precision
η	6	~0.1 η unit
ϕ	8	2.5°
muon sign	1	—
p_t	5	nonlinear scale
quality bits	2	—

Even more difficult situation is in the barrel/endcap transition region where some track segments come from DT and others from CSC. In this region the extrapolation from CSC to DT is ambiguous. Extrapolation from DT to CSC cannot be done, because it requires η coordinate which cannot be delivered by DT for $|\eta|>0.85$ due to the limited BTI acceptance ($\psi_{max}=45.7°$ corresponds to $\eta_{max}=0.86$). Several possible solutions are considered:

- use ϕ_{MF2}-ϕ_{MF1} to get rid of the ambiguity in CSC→DT extrapolation
- assume that the track has high p_t to get rid of the ambiguity in CSC→DT extrapolation

(this degrades slightly the performance at low p_t)

- make CSC→DT extrapolation with “wide window” containing ambiguities; in case of >1 candidate pairs select one with better p_t match or better quality bits
- make DT→CSC extrapolation with a “wide window” containing η-uncertainties; in case of >1 candidate pairs select one with better p_t match or better quality bits
- use only DT or only CSC taking advantage that at least two stations of one kind are crossed by each track

Yet another problem in this region is the presence of magnetic field up to ~0.9 T in MB1 and MB2. It causes an increase of the drift time and in consequence reduction of the ϕ-BTI efficiency below 70%.

3.5. Muon Sorter algorithm

Muon sorting. The Muon Sorter receives the information from the PACT or TF in a form described in Tab. 1 and Tab. 1 respectively. One single sorter chip accepts up to 8 muons on the input and delivers up to 4 muons on the output, sorted according to their p_t applying the ghost suppression described below. Muons having the same p_t are sorted according to their quality bits. The output data has the same format as the input. A lack of muon is indicated by p_t=0. The sorting chips are arranged in a form of a tree sorting out the 4 highest p_t muons among all candidates in several detector regions (see Fig. 8). In the case of PACT the first step of sorting is done already at 468 *Trigger and Readout Boards* (TRB) grouping 12 segment processors each. Their outputs (4 per TRB) are further processed by 33 (or 39 in the case of upgrade) *ring sorters*, each covering a *ring* of $\Delta\eta\approx 0.1$ and $\Delta\phi=360°$. Then the rings are grouped by 3 into 11 (or 13) *superrings* of $\Delta\eta\approx 0.35$ and $\Delta\phi=360°$. Thus 11×4 (or 13×4) muons are delivered to the Global Muon Trigger. The TF sectors are grouped into 9 regions of $\Delta\eta\approx 0.5$ and $\Delta\phi=360°$ thus providing 9×4 muons on the Muon Sorter output. This segmentation is, however, still a subject to optimisation.

Tab. 8. Information about each muon handled by the Muon Sorter
(≤8 tracks on input, ≤4 tracks on output)

variable	bits	unit / precision
η	6	~0.1 η unit
ϕ	8	2.5°
muon sign	1	—
p_t	5	nonlinear scale
quality bit	2	—

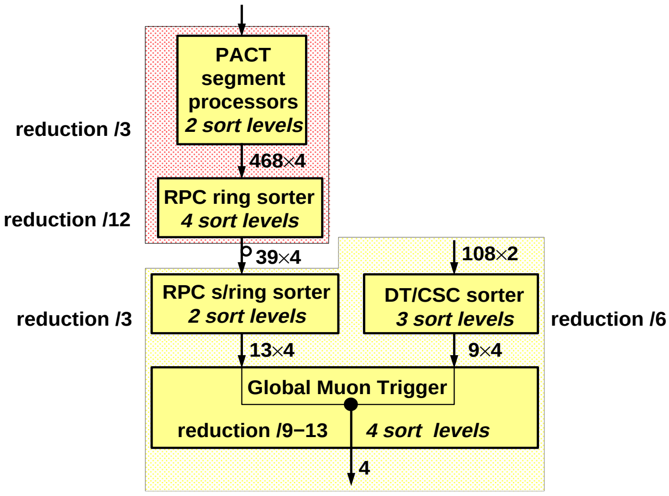


Fig. 8. Muon Sorter tree

Neighbour ghost suppression. Both RPC PACT segment processors and DT/CSC sector processors have some overlap with their neighbours in order to deal with tracks crossing their boundaries. It may happen that the same muon is found by two neighbouring processors. Therefore the muon candidates should be checked whether they are not coming from neighbouring segments or sectors. It should be done as early as possible in order to reduce the probability to select a ghost instead of a real muon. In the case of DT/CSC the possible ghosts are suppressed by the Track Finder. In the case of RPC the ghost suppression algorithm requires that there should be at least one empty segment in ϕ and/or η between two muons. Otherwise only the muon with higher quality bit should be taken, regardless of its momentum. This is because a ghost with only 3 hits has typicaly higher momentum then the corresponding track based on 4 hits. If the quality bits are equal, the candidate with higher p_t should be selected. Details of the implementation of this algorithm are not yet fixed. The ghost suppression can take place inside the sorter ASIC at every sorting level.

Another possibility is to arrange the sorting tree in such a way that neighbouring segments meet each other at late stage of sorting, when the ghost suppression is done by a dedicated logic (possibly FPGA).

3.6. Global Muon Trigger algorithms

The following sequence of actions is performed by the Global Muon Trigger.

3.6.1. Final muon sorting

The 4 highest p_t muons in the whole event are selected. From the logical point of view this is the last step of the Muon Sorter and the algorithm is as described in the previous section. It is placed in the Global Muon Trigger because it might be an advantage to perform it after the RPC and DT/CSC matching. This is because the matching can suppress some ghosts which otherwise could be selected instead of real muons. Simulation study on this subject should be done.

3.6.2. Preprocessing

There are some operations which should be performed on the data coming out of the Muon Sorter. They are specific to particular subsystems but performing them only on the selected muons can save a lot of hardware. These operations can be considered as a preparation for further Global Muon Trigger action.

The ϕ, η, and p_t conversion. RPC and DT/CSC subsystems have different segmentations and therefore they can use different ϕ and η scales. The p_t scales can also be different because the performance of the two subsystems depends on p_t in different ways. The p_t coding may even depend on the detector region. Therefore the data from both subsystems should be converted by lookup tables to common scales, before they are compared to each other.

Muon sign validation. Both RPC and DT/CSC subsystems use one bit for the muon sign. However, due to limited momentum resolution, it is meaningful only up to a certain p_t value, depending on η. In case the muon sign will be used in some trigger condition, an additional bit should be created saying whether the sign information for a given muon is meaningful or not. It can be done by a lookup table having η and p_t on the input.

3.6.3. Matching RPC and DT/CSC information

The information coming from the two subsystems should be combined before the final trigger decision. At the end of the sorting tree each of them deliver up to 4 muon candidates in several detector regions with their η, ϕ, signs, p_t and quality bits. First the spatial coordinates should be checked to determine whether the two candidates can be attributed to the same physical muon. Let us consider two cases.

Candidate is seen by only one subsystem. A decision should be taken whether this candidate should be considered as a real or a fake muon. It should be based on (in order of preference):

- quality bits: if they are high a real muon case is more probable
- background level at the given detector region: in a high background region a fake muon is more probable
- p_t of the candidate: it is more harmful for physics to lose high p_t muons; probability of low p_t fake muon is much higher
- current running conditions: one should trade off efficiency against fake muon rate

Candidate is seen by both subsystems. A decision should be taken which momentum estimate should be chosen. It should be based on (in order of preference):

- quality bits: their high value indicates a more reliable estimate
- background level at the given detector region: the two subsystems have different response to background, e.g RPC are more sensitive to uncorrelated hits whereas DT/CSC can be affected by correlated

background (additional tracks).

- p_t of the candidates: DT/CSC are more precise at high p_t, but they can underestimate p_t, RPC are less precise but they can only overestimate p_t.
- current status of each detector in a given region: e.g. noisy chambers can cause p_t overestimation.

In any track recognition system there is a trade-off between the track recognition efficiency and the number of accepted fake tracks. Tightening cuts one can reduce the number of fake tracks for the expense of efficiency loss. Having two different subsystems one can improve the efficiency/fakes balance. Less correlated the subsystems are, better improvement can be achieved. This is because the characteristics of fake tracks in the two subsystems are different.

The above criteria are at the moment only qualitative but they should be quantified by detailed simultaneous simulation of all the subsystems. Only then they can be turned into workable algorithms.

3.6.4. Isolated muon trigger

This is the last operation of the Global Muon Trigger. The isolated muon trigger algorithm checks whether there was a significant energy deposit in a calorimeter around a given muon. So called *quiet bits* delivered by the calorimeter trigger are used for this purpose. A quiet bit is assigned to each *calorimeter region* of $\Delta\phi \times \Delta\eta = 0.35 \times 0.35$ and it is set if the transverse energy E_t deposited in this region is below a threshold. Details of this algorithm are currently under study. Possible use of MIP information from the calorimeter trigger is also being envisaged.

3.6.5. Multimuon and other triggers

After preparing the information about all individual objects the Global Trigger performs all foreseen cuts and selections. Among them there are a di-muon trigger, possibly three-muon trigger, muon-electron trigger and other combined triggers. The cuts might be asymmetric, e.g. two different thresholds might be required for the two muons in a pair to pass the two muon trigger. Since multiobject triggers belong to the Global Trigger domain they will not be discussed in detail here.

4. Technical Notes and other documents related to the Muon Trigger

An HTML version of this list can be found at
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