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A simplified Track Assembler I/O for the Muon Trigger Track Finder

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Abstract

One of the architectural concerns in the present design of the Muon Trigger Track Finder (MTTF) is the large number of inputs to the Track Assembler (TA). In the TA block, input track segment pairs from many Extrapolation Units (EU) are associated into tracks. The relative contribution of these inputs to the assembled tracks is studied with simulated track patterns for low and high p_t muons over the entire η, ϕ acceptance of the CMS barrel. A pruning of the EUs is proposed which does not alter the performance of the Track Finder and minimizes the interconnections between azimuthal wedges.

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1 Introduction

The design and expected performance of the Track Finder (TF) of the Muon Trigger (MTRG) chain in the CMS barrel are thoroughly studied in [1, 2, 3].

The Muon Barrel (MB) detector [4] is partitioned in five *wheels* consisting of twelve azimuthal *wedges*, for a total of sixty *sectors*. A MB *sector* approximately covers 30 degrees in ϕ and 0.3 units of pseudo-rapidity. It consists of four *muon stations*, interleaved with iron, located at radial distances between 4 and 7 metres from the beam line. Each muon station has RPC and Drift Tube (DT) chambers.

In the MTRG architecture there is a dedicated TF processor for each MB sector. The processor combines track segments delivered by the DT chambers into tracks and calculates p_t, ϕ and η. Each TF sector processor outputs two muon tracks, selected by p_t and quality, to the next trigger stage, the *wheel sorter*. The block diagram of the TF system is shown in Fig. 1.

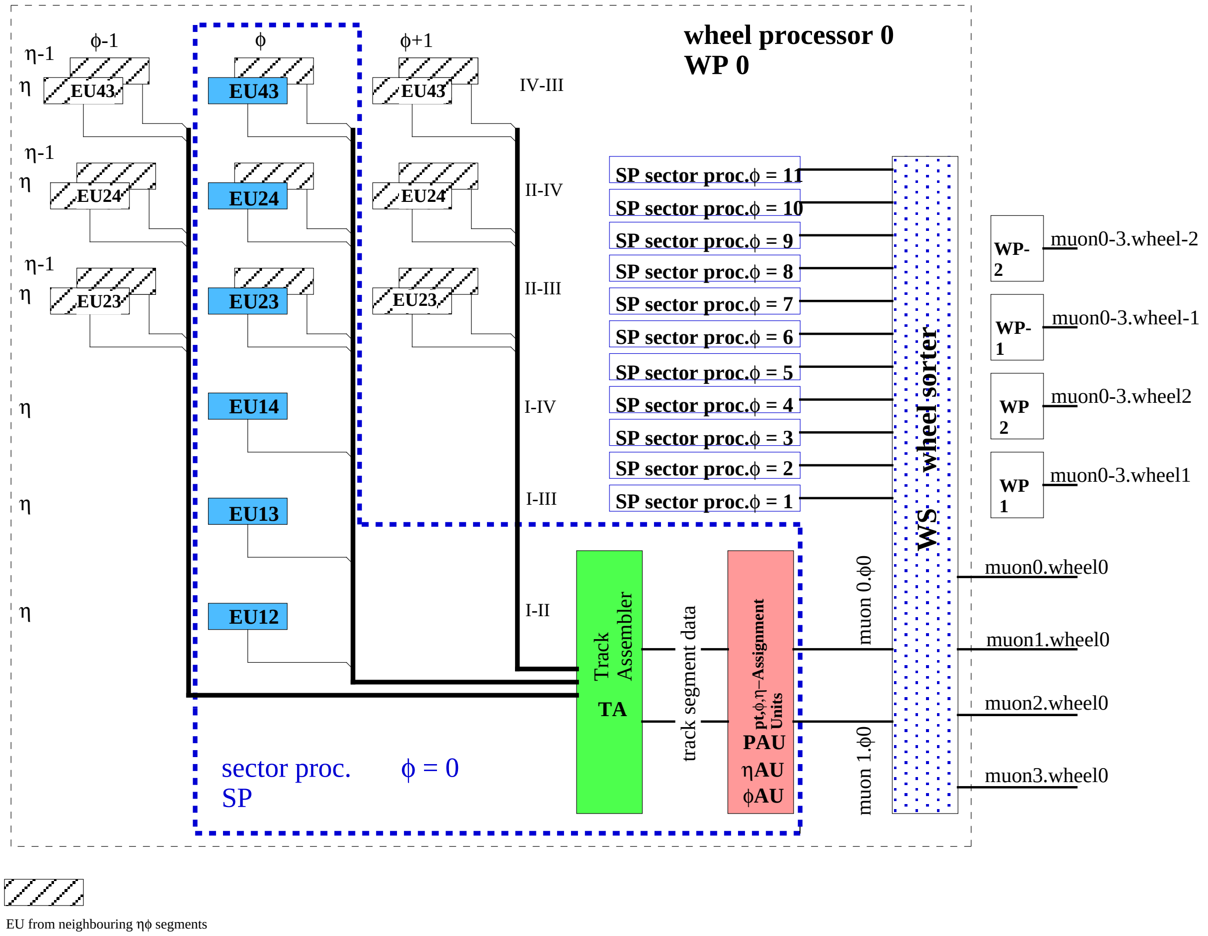

Figure 1: Block diagram of the Track Finder processor (from [2]).

In a sector processor the DT trigger data are processed in three stages: by the Extrapolation Units (EU), by a *Track Assembler* (TA) and by a p_t-ϕ-η Assignment Unit (AU). An EU looks for the occurrence of a matching pair of track segments between predefined sets of DT chambers. The TA of a TF sector processor assembles full tracks from the pairs of segments delivered by the EUs and selects at most two track candidates.

A limiting factor of the sector processor design is the number of EUs to be connected to the TA. In the current approach the TA I/O count is so large that the hardware implementation becomes problematic ([3]).

In this note we propose to reduce the number of EUs connected to a sector TA. The proposal is described in section 2. The triggering performance with the proposed simplified TF processor is compared to the baseline design in section 3. Implications on the overall TF system architecture are described in section 4.

2 Simplification of the Track Assembler I/O

Basic blocks of the TF processor are the *Extrapolation Units* (EU). Starting from a given DT segment, an EU looks whether a segment exists in one of the next DT chambers. Each sector of the muon detector has six dedicated EUs, performing the extrapolations from station 1 to 2, 1 to 3, 1 to 4, 2 to 3, 2 to 4, and 4 to 3. Extrapolations from station 3 are unfeasible, due to the very small bending angle in that region.

For the aim of this note, the important feature is that the extrapolation procedure is not limited to within a sector: for instance, an EU12, from a source segment in station-1 of a given sector, looks for a segment, that matches the extrapolation prediction, not only in station-2 of that same sector but also in station-2 of adjacent sectors in ϕ and η (labelled in fig. 1 as $\phi-1, \phi+1, \eta-1, \eta+1$). Thus, an EU12 of a sector in the central η wheel inspects 9 station-2 chambers: 3 in the same wheel (in the same sector of station-1 and in the two sectors azimuthally adjacent) and 3 in each of the adjacent η wheels. Each DT chamber delivers 2 segments, thus the EU performs a total of 18 comparisons with the extrapolation prediction, for each one of the two segments of station-1. Accordingly, an EU12 of a sector in an external η wheel inspects 6 station-2 chambers, since inspecting the wheel opposite to the flight direction in the Rz projection is not needed.

All segment-to-segment associations found by the EUs are processed by the Track Assembler (TA) which tries to connect consecutive associations into a track, and delivers the two best tracks to the next stage. In order to process tracks crossing sector boundaries, a sector processor receives also information from the EU23, EU24, EU43 extrapolators of the neighbouring sector processors. A TA of an external (central) wheel has then inputs from 21 (30) EUs, as shown in the block diagram of Fig. 1. Each EU delivers two associations to the TA for a total of at least 24 bits per EU in the current design. The TA I/O pin count becomes therefore very large, thus making the hardware realisation difficult.

We propose to reduce the number of EUs connected to a TA, with no change to EU functionality. In this simplified design, the TA of a given sector has inputs from the 6 EUs of that sector and EU23, EU24, EU43 of the adjacent η wheels, but it has no inputs from the EUs of adjacent ϕ sectors, i.e. a TA of an external (central) wheel has inputs from 9 (12) EUs only. Fig. 2 shows the connections between sector processors for the present baseline design compared to the proposed simplified design. The proposal is motivated by the following considerations:

- i) a DT segment consists of up to eight points along a track; it was shown in [5] that two correlated segments between two subsequent stations provide a determination of the track parameters which matches the trigger requirements: in particular for the low-p_t regime there are three possible p_t determinations: the bending angle measurement provided by each one of the two DT segments, and the bending angle measured from the azimuthal position difference between the two segments;

- ii) for high-p_t muons (straight tracks), the information from EUs of adjacent ϕ sectors is not needed for most of the azimuthal acceptance of the sector. No difference in TF performance between baseline and simplified is then expected. However, a straight track would seem to change azimuthal sector when it is close to the sector border: the azimuthal borders of a sector are ”fuzzy”, since the muon stations do not line up, in order to guarantee hermeticity. Even so, two correlated segments are generated in at least one of the sectors. Note that this regime is already reached for p_t of about 25 GeV, since the displacement from a straight track in going from a station to the next is smaller than the azimuthal coverage of one BTI ([4]) unit.

- iii) due to the strong field in the coil, low p_t muons ($3.5 < p_t < 4$ GeV) have a sizeable angle of impact with respect to the perpendicular on MB1 and their path unavoidably goes across azimuthal sector borders. However, the properties of these tracks are essentially determined from the DT measurements in the inner stations (station-1 and station-2), which are treated by the EU12 units, which, as previously underlined, also extrapolate across sector boundaries:

The above considerations suggest that, although the TA I/O count is drastically pruned in the simplified design, the performance of the Muon Trigger Track Finder should not be significantly affected.

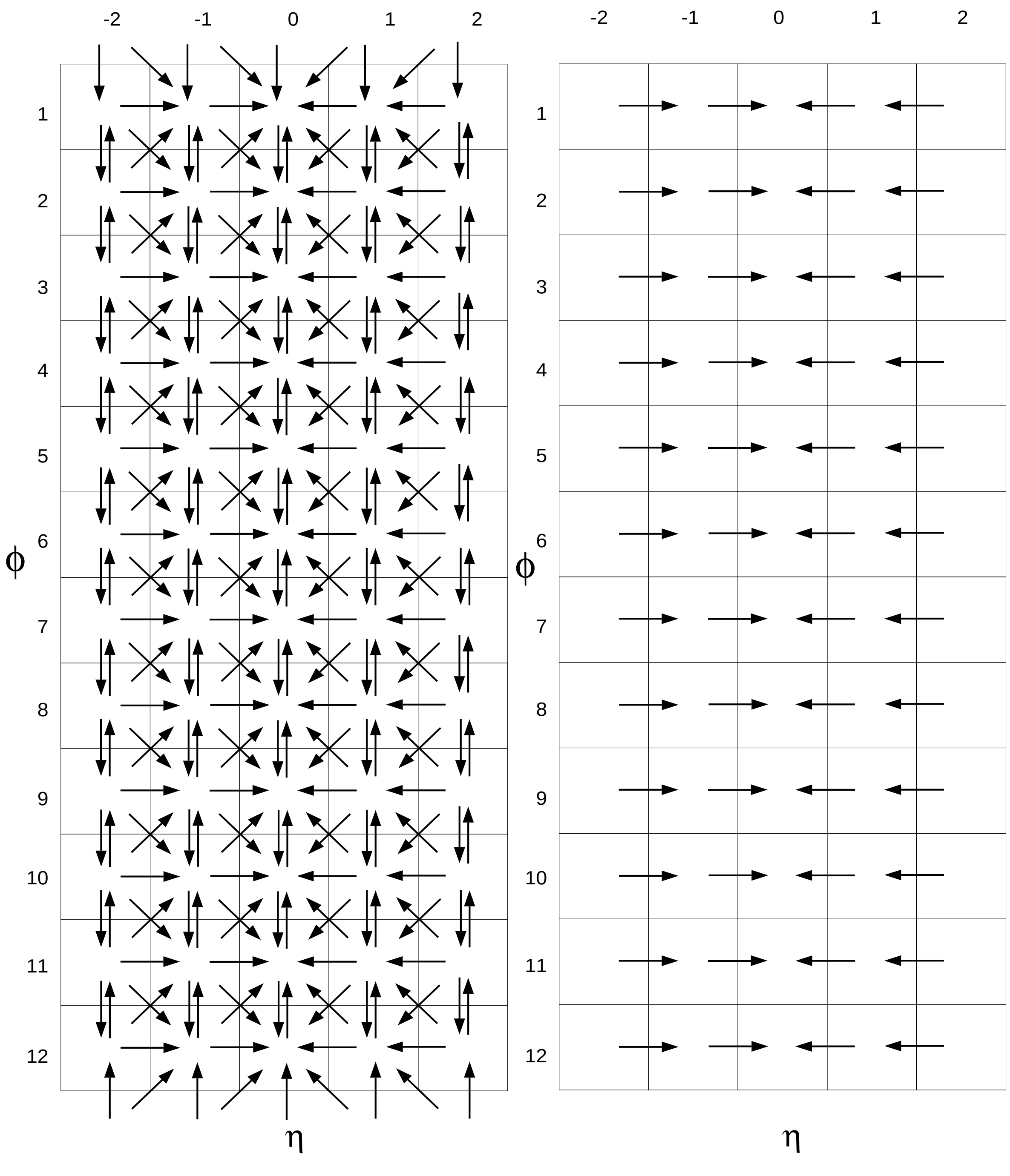

Figure 2: Connections between sector processors for the present baseline design (left figure) compared to the proposed simplified design (right figure). Each square represents one Track Finder sector processor, and each line represents the output of the EU23,EU24,EU43 extrapolators of a processor going to the Track Assembler of another processor.

3 Comparison with the baseline design

A detailed comparison between baseline and simplified design has been carried out with simulated muon tracks at three p_t values (4, 25, 200 GeV) and with simulated muon tracks uniformly distributed in p_t from 6 to 100 GeV. While fixed p_t samples are used to determine the relative impact of EU segment-to-segment associations for known track patterns, the continuous sample in p_t is used for discovering possible pathological patterns. The generated muons are uniformly distributed in azimuth and pseudo-rapidity. The trigger primitives of simulated muon tracks have been generated using the CMSIM113 package [6], and then processed with the TF simulation software [5].

3.1 Track Finding Efficiency

In Fig. 3,4 the TF efficiencies are shown for baseline and simplified design, for the same data sample. No difference is observed and we can set an upper limit of $< 6 \times 10^{-4}$ on the relative inefficiency of simplified with respect to baseline TF. More detailed information can be obtained by looking at specific track patterns. In table 1 the

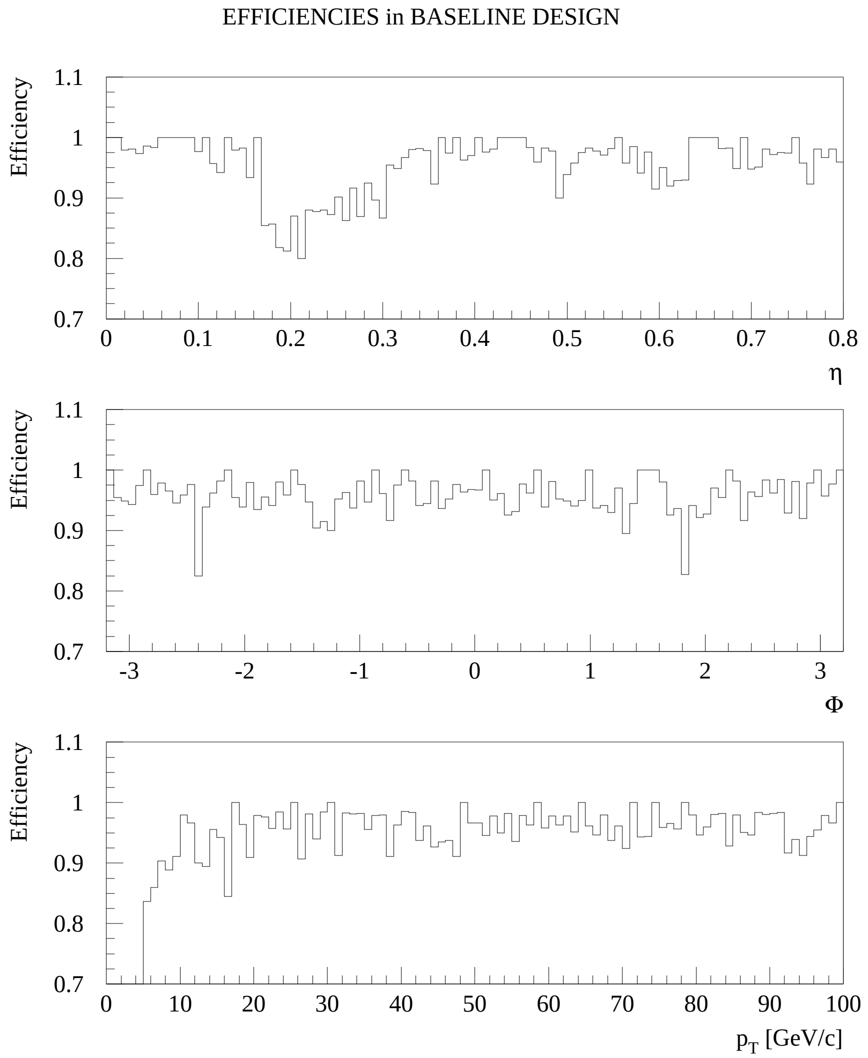

Figure 3: Track finding efficiency in the baseline design

relative probability is given for a muon track to produce a given multiplicity of segment-to-segment associations as found by the EUs in the simplified design. Only tracks with at least one DT segment are considered. The study is limited to η in the range of -0.8 to 0.8. When all four DT segments are found along a track, six EU associations are generated.

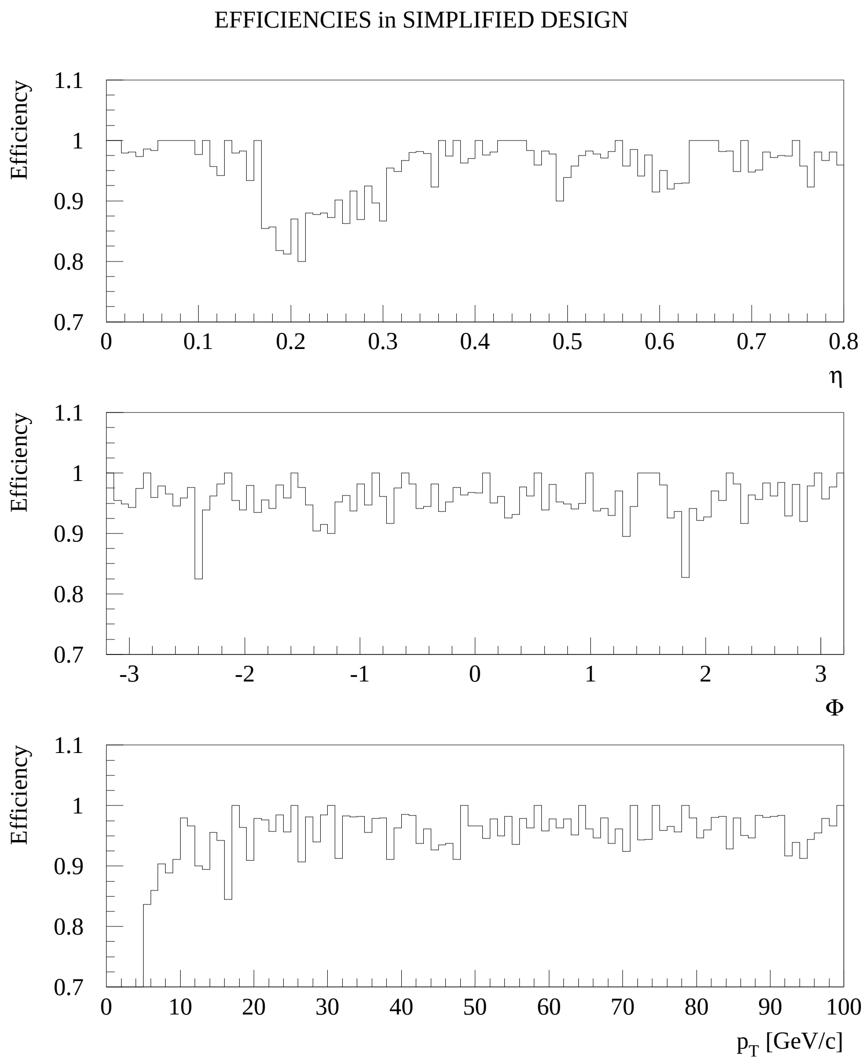

Figure 4: Track finding efficiency in the simplified design

E.U. associations (simplified TF)	number of DT segments	Relative Probability (%) (p_t=4 GeV)	Relative Probability (%) (p_t=25 and 200 GeV)
0	1	24.0±1.3	–
0	2	3.2±0.4	–
1	2	67.6±2.2	4.5±0.4
3	3	5.1±0.6	35.5±1.1
6	4	–	60.0±1.4

Table 1: Relative probability that a muon track produces a given multiplicity of segment-to-segment associations, found by the Extrapolation Units, in the simplified design. Only tracks with at least one DT segment are considered.

We observe that:

- Muons with p_t exceeding 25 GeV have a large probability of generating six associations. The 4.5% of muons having only two DT segments are at the sector border azimuthally. One association is enough to fulfil the trigger requirements.
- Lower-p_t muons of 4 GeV rarely reach out to station-4 and tend to produce just one valid association of two DT segments. When no association is found, it is mostly because there is only one DT segment; in a very small fraction of cases there are two DT segments, but those are one each in two neighbouring MB1 stations (inner then outer superlayer hit).

Therefore, adding the information from EU23,24,43 of neighbouring ϕ sectors, as in the baseline design, cannot improve the efficiency, although it may improve the system redundancy at the azimuthal sector borders. This is better seen in Fig.5, 6,7, where the ratio between baseline and simplified TF efficiencies is plotted as function of ϕ in a sector (0 at sector centre) and as function of the number of DT stations used in assembling the track. For p_t=4 GeV, the TF performance is unchanged. For the higher p_t cases, close to the sector border the simplified TF uses less stations, although the integral efficiency remains unchanged in azimuth.

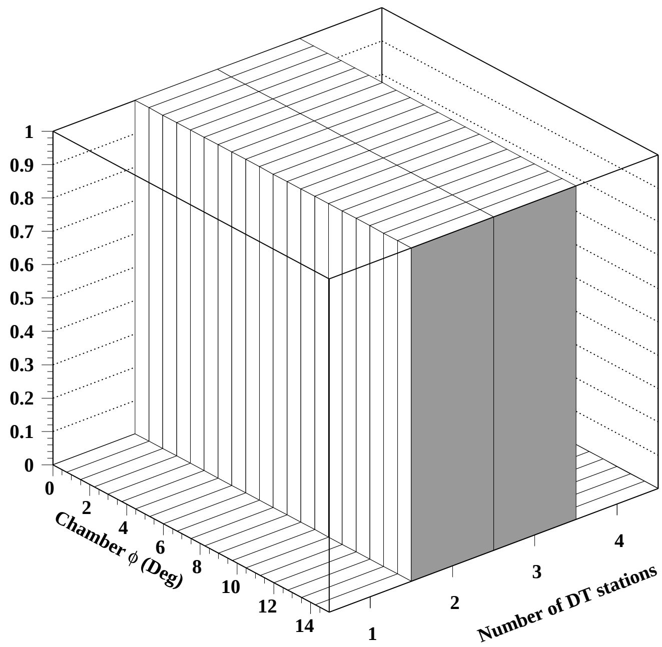

Figure 5: Ratio between baseline and simplified TF efficiencies plotted as function of ϕ in a sector (0 at sector centre) and as function of the number of DT stations used in assembling the track for muons with p_t=4 GeV.

A missing DT segment for high-p_t tracks at sector azimuthal borders is more likely in the simplified TF due to the

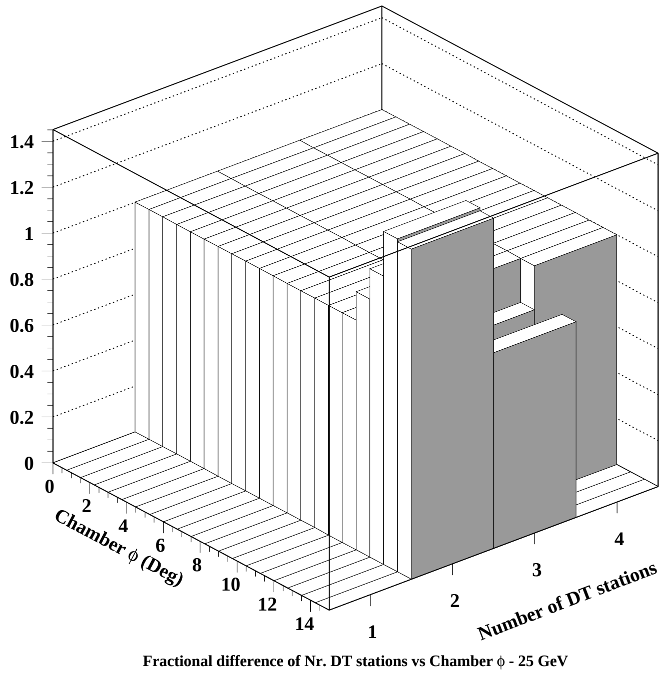

Figure 6: Ratio between baseline and simplified TF efficiencies plotted as function of ϕ in a sector (0 at sector centre) and as function of the number of DT stations used in assembling the track for muons with p_t=25 GeV.

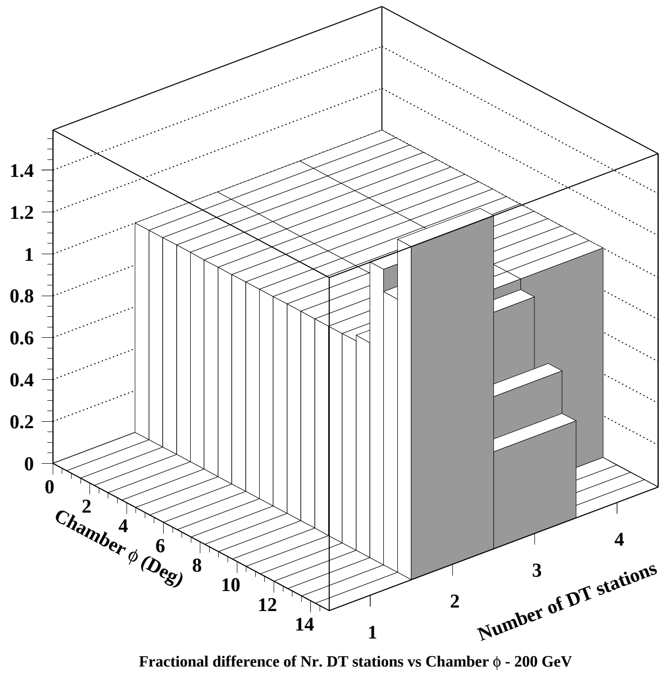

Figure 7: Ratio between baseline and simplified TF efficiencies plotted as function of ϕ in a sector (0 at sector centre) and as function of the number of DT stations used in assembling the track for muons with p_t=200 GeV.

peculiarity of the EU43 extrapolation which proceeds in reversed direction. A straight track at sector azimuthal border, because muon chambers are not lined up, is very likely to have at least one segment in the adjacent ϕ sector. When this segment is in station 4, the EU14, EU24 in the sector are activated, together with the EU43 in the adjacent sector, which is not used in the simplified TF sector processor. In Fig. 8,9,10 the distributions in number of DT stations used for assembling the muon tracks are shown superimposed for the two designs. For p_t=4 GeV they coincide. For the larger p_t cases, station-4 clearly appears to be less frequently used in the simplified design.

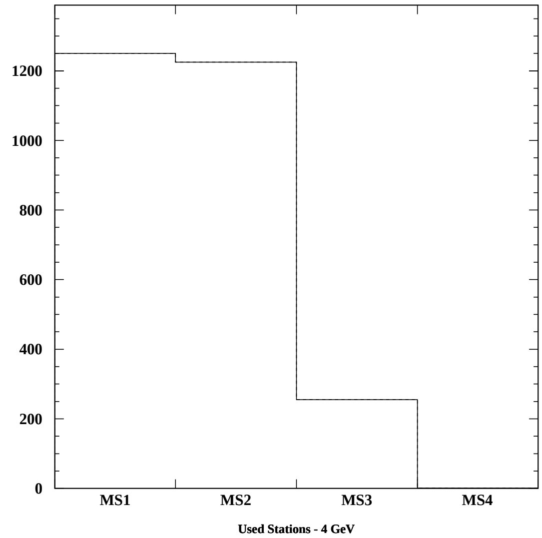

Figure 8: Distributions in number of DT stations used for assembling the muon tracks for the baseline (full line) and the simplified (dashed) TF, superimposed. Simulated muons with p_t=4 GeV.

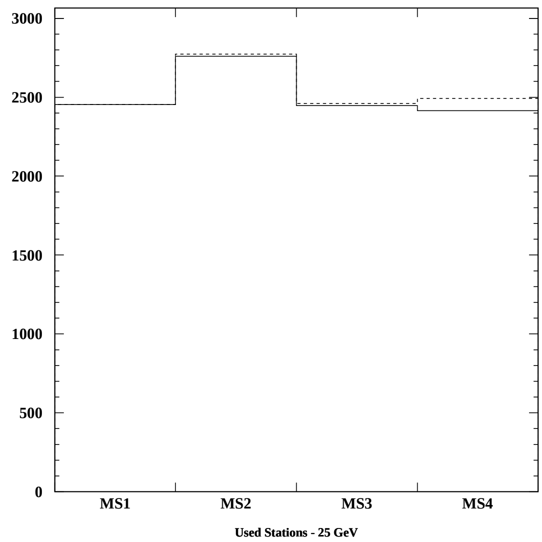

Figure 9: Distributions in number of DT stations used for assembling the muon tracks for the baseline (full line) and the simplified (dashed) TF, superimposed. Simulated muons with p_t= 25 GeV.

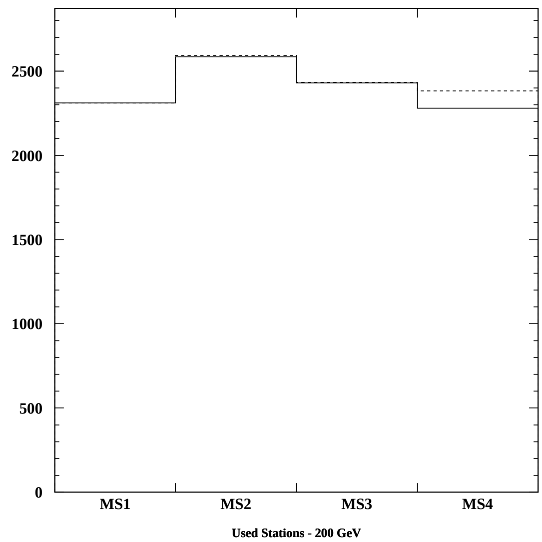

Figure 10: Distributions in number of DT stations used for assembling the muon tracks for the baseline (full line) and the simplified (dashed) TF, superimposed. Simulated muons with p_t= 200 GeV.

3.2 P_t Assignment

The p_t value that the TF algorithm assigns to a track is the same for most tracks in both designs, because possible differences in p_t assignment are limited to the small fraction of cases where the simplified TF uses less segments. The p_t distributions are compared (superimposed) in fig. 11 for the samples generated with fixed p_t. No difference is observed. However, we expect that the fraction of tracks changing p_t value depends on p_t and the difference

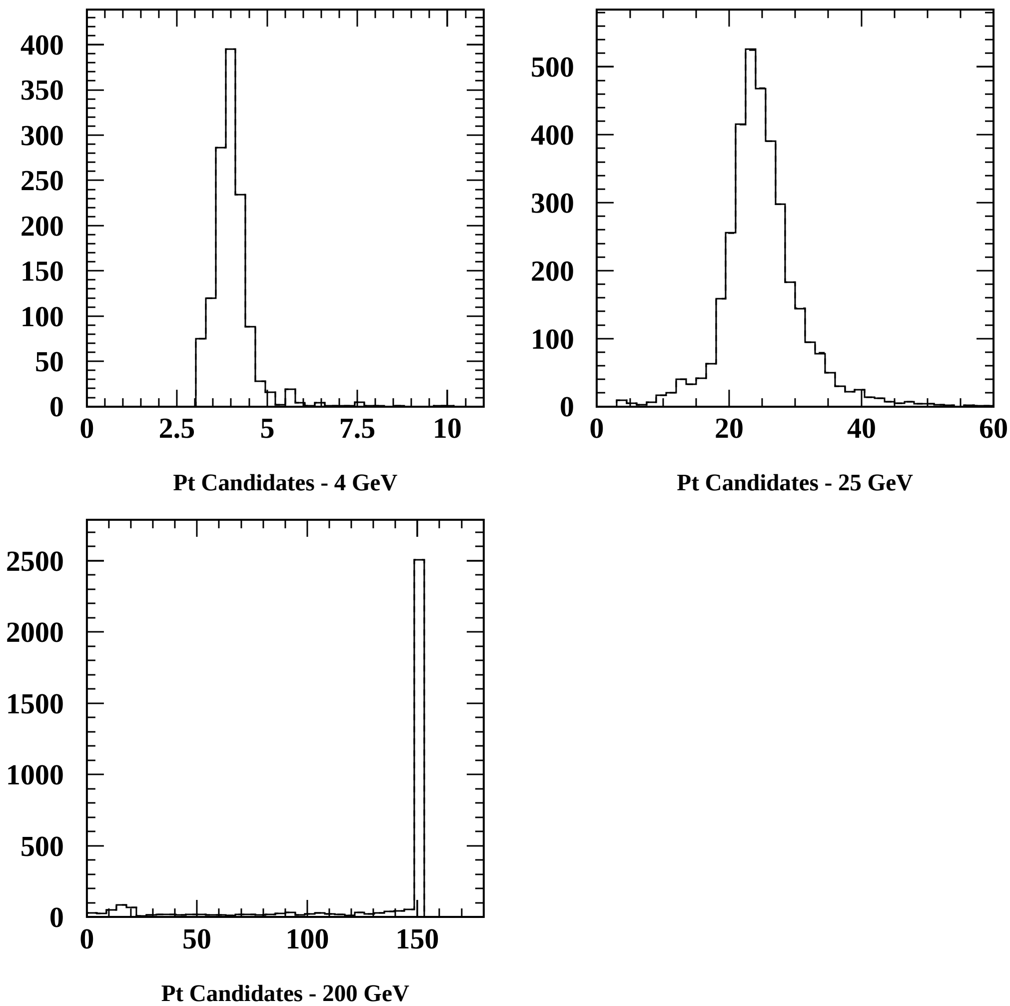

Figure 11: Assigned P_t distributions for simulated muons with p_t = 4,25,200 GeV. Distributions for baseline and simplified TF are superimposed. The p_t assignment table extends up to 150 GeV.

could be significant for some particular track patterns. In order to estimate the magnitude of the effect we use the continuous sample of muon tracks with uniform p_t distribution from 6 to 100 GeV: $(1.4 \pm 0.2)\%$ of the tracks change p_t and fig. 12 shows the observed fractional change in assigned p_t as function of p_t. For the vast majority of the sample the assigned p_t changes by less than 1%. Large error bars are generated by single events with large deviations: they constitute about 0.1% of the sample. More statistics is needed for investigating these specific patterns.

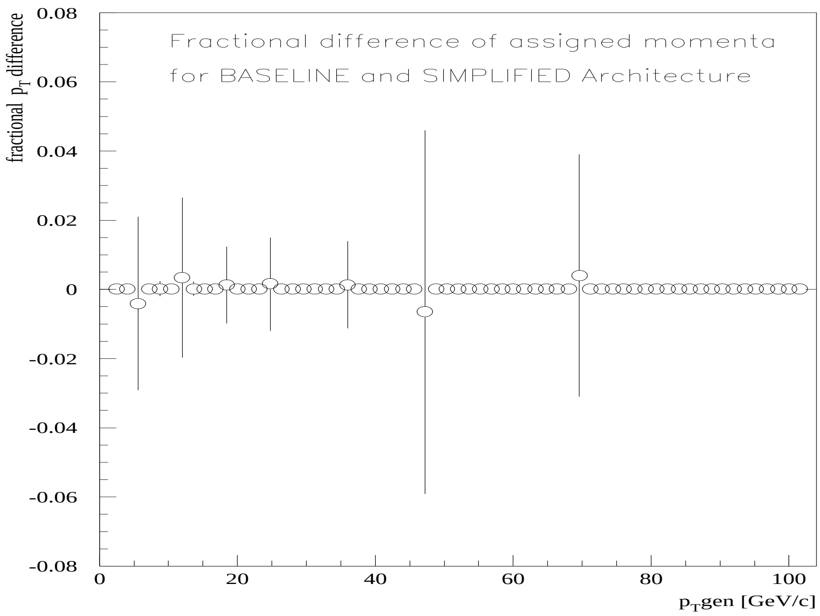

Figure 12: Fractional change in assigned p_t between baseline and simplified TF design as function of p_t.

3.3 System Robustness

Because of noise in a chamber or failure of its local trigger components, one could be forced to discard one station. The effect of one missing station in a sector on track finding efficiency in that sector for simplified and baseline TF designs is shown in tab. 2. We observe that there is no additional inefficiency of simplified TF with respect to baseline TF. Besides the extreme case of 4 GeV where mostly only station 1 and 2 are hit, the efficiency loss is what is expected for 2 correlated segments out of four muon stations, with station 2 being slightly more important. The weaker redundancy in the simplified TF at the sector azimuthal border previously expected turns out to be compensated by the possibility for both of the adjacent sectors to detect the border track.

p_t (GeV)	Fractional loss in track finding efficiency (%)							
	NO MS1		NO MS2		NO MS3		NO MS4	
	base	simpl	base	simpl	base	simpl	base	simpl
4	83.1 ±0.3	83.1±0.3	83.8±0.3	83.8±0.3	7.8±0.1	7.76±0.1	0.	0.
25	15.6±0.1	15.6±0.1	23.6±0.1	23.6±0.1	12.6±0.1	12.6±0.1	12.3±0.1	12.3±0.1
200	17.4±0.1	17.4±0.1	24.9±0.1	24.9±0.1	16.0±0.1	16.0±0.1	14.1±0.1	14.1±0.1

Table 2: Loss in track finding efficiency in a sector when one DT station is missing in that sector, for baseline and simplified TF. Errors are binomial.

The same level of random noise rejection can be obtained in either design. If a spurious segment-to-segment association is generated by an EU, it is processed in the same way by either baseline or simplified TF sector processor. However, the simplified design has the advantage that the spurious association goes in input to just one or two sector processors, since it is not distributed to the adjacent ϕ sectors.

4 Implications on the TF System Architecture

In the baseline design, the overall TF system is organised by wheels. TF sector processors belonging to the same wheel are grouped and they provide inputs to the wheel sorter. Clearly this is optimised for the baseline TA design where communication between processors of adjacent sectors in the same wheel is more important than communication across wheels (Fig. 2).

In the simplified scheme the TA does not need inputs from EUs of adjacent sectors in the same wheel. Therefore it seems more natural that the basic unit be a ”wedge”: a wedge is the ensemble of the sectors covering the same ϕ in the different eta wheels, i.e. a 30 degrees longitudinal slice of the muon barrel. A wedge does not need to communicate with adjacent wedges in ϕ. It is an independent unit and more wedges could be grouped into blocks without block-to-block interconnections, which is an advantage also for the mechanical organisation of the system.

In the baseline design the four best muons per wheel are sorted, for a total 20 muon candidates in the CMS barrel.

In the simplified scheme, assuming the system was organised by wedge, one could think of sorting the best two muons of the wedge. There are three supporting arguments for such a choice:

- i) there are no physics processes that produce more than two muons in the same wedge of 30 degrees
- ii) each wedge-sorter is independent of any other one
- iii) it becomes easier to require correlations between muons and/or other trigger components.

The total output would then be 24 muon candidates in the CMS barrel.

5 Conclusions

We propose to reduce the number of Extrapolation Units (EU) connected to the Track Assembler (TA) of a Track Finder (TF) sector processor. In this simplified design, the TA of a given sector has inputs from the 6 EUs of that sector and EU23, EU24, EU43 of the adjacent η wheels, but it has no inputs from the EUs of adjacent ϕ sectors. Therefore a TA of an external (central) wheel has inputs from 9 (12) EUs only, to be compared with 21(30) EUs in the baseline scheme. The proposal takes advantage of the key feature in the EU design that the extrapolation procedure is not limited to within a sector: for instance, an EU12, from a source segment in station-1 of a given sector, looks for a segment, that matches the extrapolation prediction, not only in station-2 of that same sector but also in station-2 of adjacent sectors in ϕ and η.

Simulation studies have been carried out and the TF performances for baseline and simplified design compared. The results show no deterioration both in track finding efficiency and in p_t assignment. Furthermore, the simplified system preserves a good level of robustness against one of the muon stations becoming unusable.

The proposed simplification, besides reducing the TA I/O count by nearly a factor of two, has also very beneficial implications on the overall TF system architecture for the CMS barrel muon detector.

References

[1] **CMS Note 1997/091**, A.Kluge and T.Wildschek, *"The Hardware Muon Track Finder Processor in CMS - Specification and Method"*.

[2] **CMS Note 1997/092**, A.Kluge and T.Wildschek, *"The Hardware Muon Track Finder Processor in CMS - Architecture and Algorithm"*.

[3] **CMS Note 1997/093**, A.Kluge and T.Wildschek, *"The Hardware Muon Track Finder Processor in CMS - Prototype and Final Implementation"*.

[4] **CMS TDR 3, CERN/LHCC 97-32**, CMS Collaboration, *"The Muon Project - Technical Design Report"*.

[5] **Dissertation, Technische Universitaet Wien,1997**, T.Wildschek, *"An algorithm for Track Finding in the CMS Muon Trigger"*.

[6] **http://cmsdoc.cern.ch/cmsim/cmsim.html** CMS Simulation Package CMSIM