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Muon Trigger Rates

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Abstract

Results of the Pattern Comparator Trigger simulation are presented. The stability of the trigger algorithm is discussed. Single muon trigger rates for the CMS version 9 (mid 94) are shown. Contributions of various sources like prompt muons, π, K decays, neutrons and gammas are compared.

Introduction

The CMS first level muon trigger is based on three kind of detectors: Cathode Strip Chambers (CSC), Drift Tubes (DT) and Resistive Plate Chambers (RPC). This note summarises results of the simulation of the Pattern Comparator Trigger (PACT) to be used with RPC's. The title is however general, because adding CSC's and DT's to the trigger system can only improve it. Therefore presented results can be treated as a kind of lower limit on the overall trigger performance.

The calculations have been done for the CMS version 9, presented in the ***CMS Status Report*** '94 [1]. More details on the PACT can be found in [2, 3].

1 Simulation software

Rates at the vertex have been calculated using PYTHIA [4, 5]. Tracking through the CMS detector has been performed by CMSIM/GEANT [6]. For the hadronic shower development and punchthrough production the GHEISHA program has been used [4]. Neutral particle fluxes have been obtained with FLUKA [7]. Muon trigger algorithm has been simulated with program MTRIG [8].

2 Pattern Comparator Trigger algorithm

2.1 Stability of the algorithm

The PACT algorithm is based on four detector planes equipped with strips of $\Delta\varphi = 1/3°$and $\Delta\eta \approx 0.11$, i.e. 1-4 cm $\times$ 20-90 cm. A muon track creates a pattern of hit strips. The processor compares this pattern to predefined patterns. The trigger signal is generated if the pattern belongs to the set of valid patterns.

In order to prepare a set of valid patterns for a given p_t we simulate single muons in a certain $|\eta|$ interval. The obtained pattern distribution has usually a long tail of rare patterns due to multiple scattering and energy losses (see an example in Tab. 1). We cut it at, e.g. 98% of events. In addition a pattern to be selected must appear in at least e.g. 2 events.

Table 1: Example set of patterns for p_t = 50 GeV, $1.5 < |\eta| < 1.6$. Each 4-hit pattern is denoted by three numbers: $\Delta\varphi_{4-3} = \varphi_{MF4} - \varphi_{MF3}$, $\Delta\varphi_{3-2} = \varphi_{MF3} - \varphi_{MF2}$, $\Delta\varphi_{2-1} = \varphi_{MF2} - \varphi_{MF1}$, expressed in one strip units.

4-3	3-2	2-1	events	Σ %	4-3	3-2	2-1	events	Σ %
-1	0	0	4399	45.22	-2	0	1	2	99.89
-1	-1	0	2527	71.20	-1	-1	-1	2	99.91
-2	0	0	1997	91.72	-3	0	1	1	99.92
-1	0	-1	677	98.68	0	0	1	1	99.93
-1	-1	1	50	99.20	-2	-8	-6	1	99.94
-2	0	-1	27	99.48	-2	0	2	1	99.95
-2	-1	0	13	99.61	-4	-2	-2	1	99.96
0	-1	0	8	99.69	-2	-1	-1	1	99.97
0	0	0	8	99.77	1	1	1	1	99.98
-1	0	1	5	99.83	-1	-1	-8	1	99.99
0	-1	1	4	99.87	-2	-1	1	1	100.00

Since the "98%" and "2 events" are rather arbitrary numbers, the following questions arise:

- Are "98%" and "2 events" the optimal values ?
- Is the algorithm stable, i.e. how the results change if we use e.g. "95%" and "10 events" cuts?

In order to check it we calculated trigger efficiency and purity of cuts in four cases:

relative cut	absolute cut
95%	2 events
98%	2 events
99%	2 events
98%	10 events

Although the calculations have been done for the full rapidity range here we show results only for $1.5 < |\eta| < 1.6$ as an example. Efficiency curves are shown in Fig. 1. In the low p_t part curves for different options are almost indistinguishable. Only expanded high p_t part shows some differences. The relative cut of 95% causes substantial fluctuations. The 98% curve is already quite stable. On the other hand the absolute cut at 10 events causes that the efficiency slowly approaches the plateau and therefore 2 events cut is preferable. Hence we have chosen "98% / 2 events" cuts for further analysis.

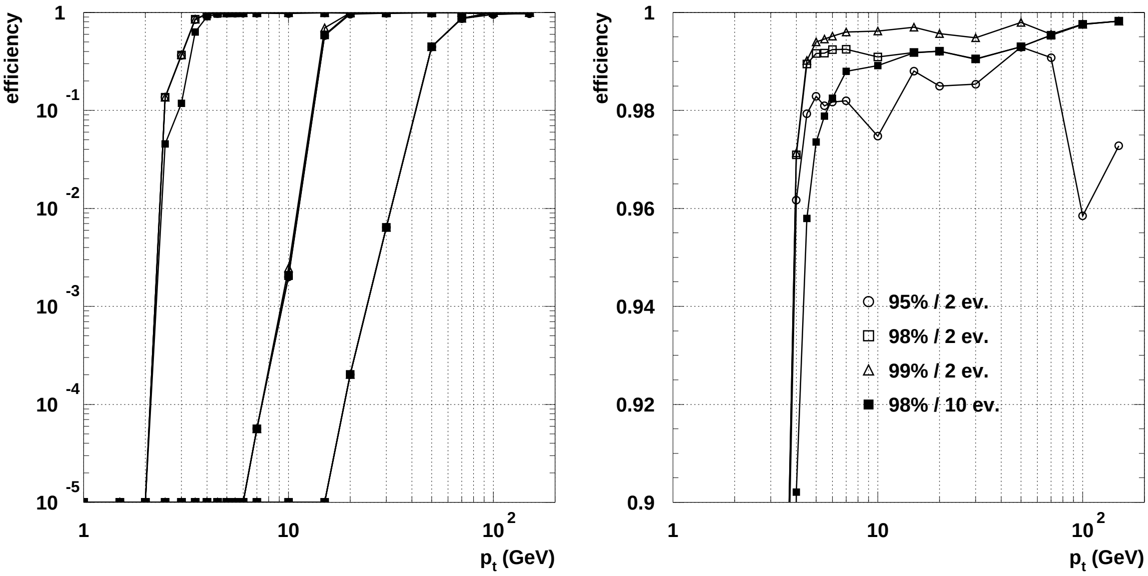

Figure 1: Comparison of efficiency curves for various cuts ($1.5 < |\eta| < 1.6$).

The cut purity is defined as a fraction of triggered muons with p_t truly above p_t^{cut} to all triggered muons (see [9] for details). It is shown in Fig. 2 for the four sets of algorithm parameters. One can observe large fluctuations, especially at high p_t. They reflect the fact that one cannot change the trigger threshold in a smooth way. Adding one pattern to the set of valid patterns moves the p_t cut by a small but finite value. One can also observe that the variation of the purity due to changes in the algorithm parameters are negligible in comparison to the intrinsic fluctuations. That means that the algorithm is stable, i.e. small changes do not effect its performance.

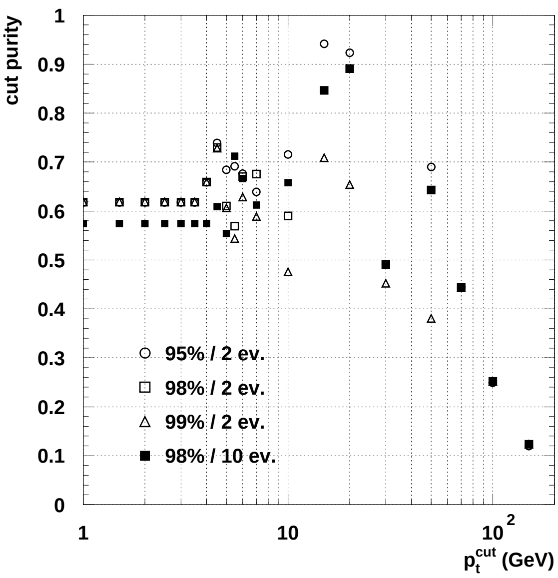

Figure 2: Momentum cut purity ($1.5 < |\eta| < 1.6$).

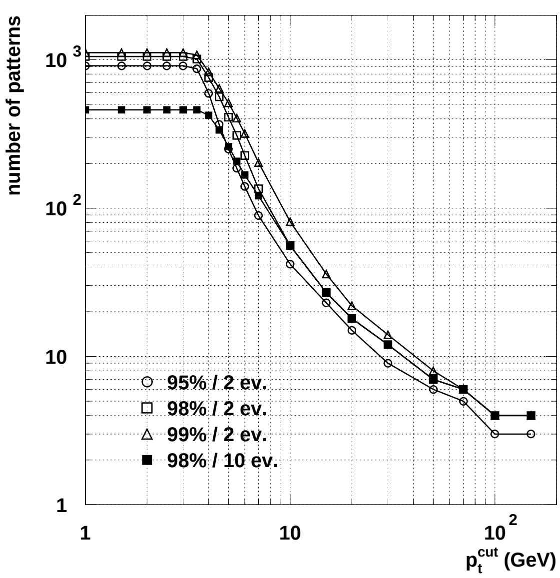

Figure 3: Number of patterns ($1.5 < |\eta| < 1.6$).

Finally Fig. 3 shows the number of patterns for each variant of the algorithm. Again the dependence is rather weak which means that also requirements on electronics do not depend strongly on the details of the algorithm.

2.2 Performance of the PACT

The first level muon trigger in CMS does not apply a momentum cut itself but sends the information about the p_t to the global trigger. Simulated results of the p_t measurement done by PACT are shown in Fig. 4. Muons with several p_t values have been generated and passed through the trigger algorithm. The answer is denoted on the ordinate. One can observe that the trigger optimisation is different from that of the momentum measurement. For the momentum measurement one would require a narrow Gaussian distribution centered at the nominal p_t value, thus points on Fig. 4 should be close to the diagonal on its both sides. In case of trigger the measurement is just a preparation for later cut, thus all the points should lie above diagonal, possibly close to it.

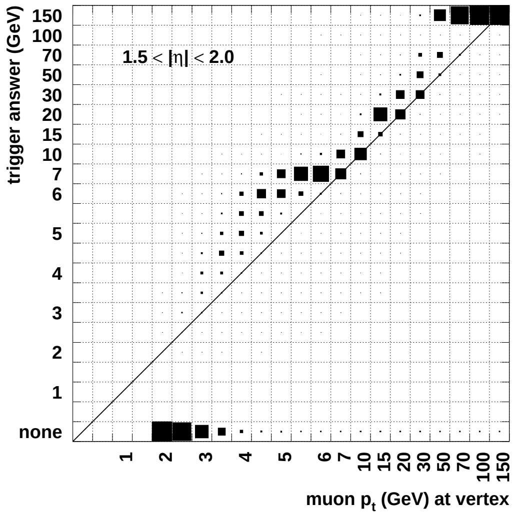

Figure 4: The trigger answer for a muon with a given p_t.

Fig. 5 shows maps of the trigger cut purity [9]. Differential one (a) indicates the purity in a given bin of η and p_t^{cut}. As expected the trigger performance slowly degrades at high η and p_t^{cut}. Small degradation below $p_t^{cut} = 10$ GeV in the barrel (low η) is due to change in the algorithm: at low p_t one can not use four muon stations because of limited range of muons. One can also observe a complicated structure around $\eta = 1 - 1.5$ which reflects complicated geometry of the barrel/endcap corner.

Fig. 5 b is obtained by integrating the previous one over η. In other words it shows the average purity up to a given η_{max}. For example, if we limit the trigger coverage to $|\eta| < 2$ the purity is above 60% up to 70 GeV.

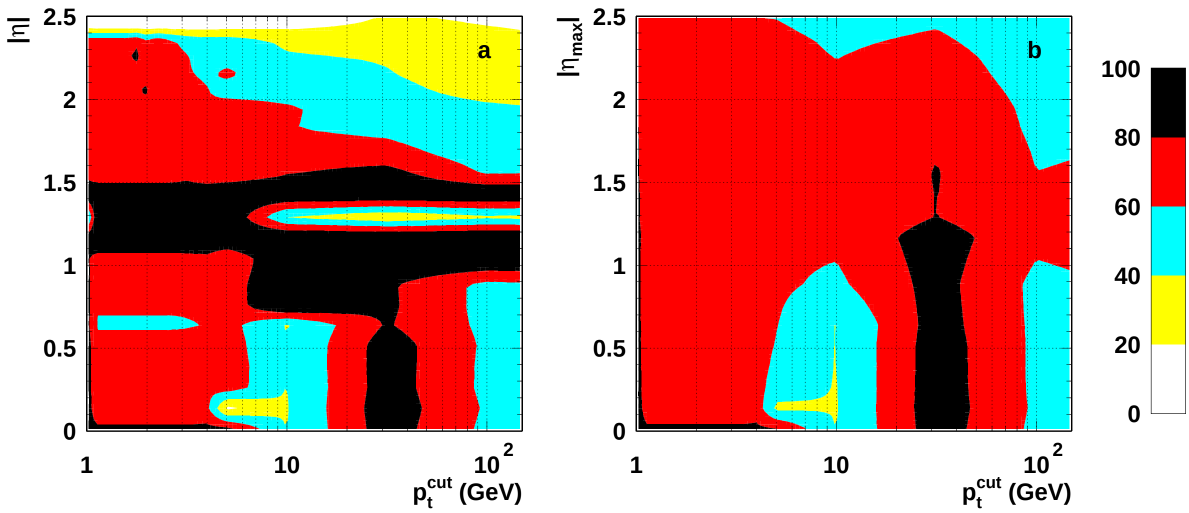

Figure 5: Differential (a) and integral (b) map of the trigger cut purity.

3 Prompt muon rates

Prompt muon rates are presented in Fig. 6. The dashed line corresponds to the rate at the vertex, mainly due to b and c quark decays. The solid line represents the trigger rates due to those muons. At low p_t it saturates because muons of very low p_t are stopped in the calorimeters. At high p_t the trigger rate is higher than the primary one because of limited momentum resolution of the trigger: momentum of some muons with $p_t < p_t^{cut}$ is overestimated and therefore they pass the cut. The difference between the two curves demonstrates the quality of the trigger.

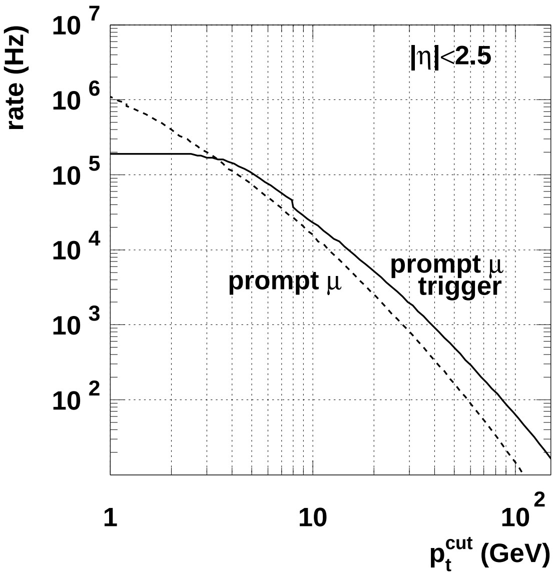

Figure 6: Muon trigger rates due to prompt muons (solid line) compared to muon rates at vertex (dashed line).

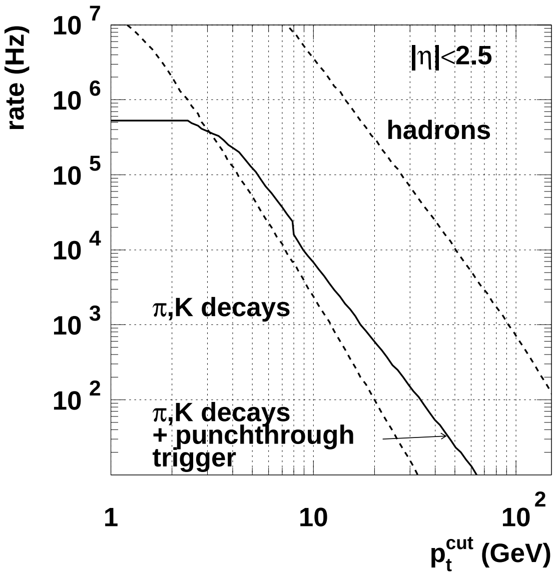

Figure 7: Muon trigger rates due to hadrons (solid line) compared to hadron rates at vertex and π/K decays (dashed lines).

4 Rates due to hadron decays and punchthrough

The hadron rate at the vertex is shown in Fig. 7 as an upper dashed line. Hadrons do not cause a trigger themselves but some of them decay into muons inside the tracker (lower dashed curve), some others can produce punchthrough. Total trigger rate due to both processes is indicated by the solid line.

5 Rates due to neutral particles and noise

In the muon system apart from the charged tracks there are also uncorrelated hits due to neutrons, gammas and noise. In high rate environment an accidental coincidence of such hits can cause a trigger signal. Moreover a coincidence of such a hit with hits of low p_t, curved muon track can look like more straight track and thus increase the apparent muon momentum.

In order to study the promotion effect we simulated 2 000 000 muons and 70 000 000 random hits of the following origin:

origin	amuont	source of information
n/γ	1-1000 Hz/cm^2 depending on η	Ref. [7]
intrinsic RPC noise	1 Hz/cm^2	experience from RD5 experiment
electronic noise	100 Hz/channel	arbitrary number

The total hit rate per cm^2 and per strip (more precisely per ring of 1080 strips) at the luminosity of 10^{34} cm^{-2} s^{-1} is plotted in Fig. 8. In the endcaps the rate is dominated by n/γ and obviously the rate per cm^2 rises very rapidly with rapidity. However the strips are smaller at high η and the rate per strip remains almost constant. One can also see it from the Table 2 which shows a few examples.

In the barrel, the assumed electronic noise is a dominant factor but it is still negligible in comparison to endcaps. The value of 100 Hz/channel was chosen arbitrarily but one can learn from Fig. 8 that if it was 10 times higher it would be comparable with n/γ rate in endcaps. Thus one can conclude that we should keep the electronics noise well below 1 kHz/channel.

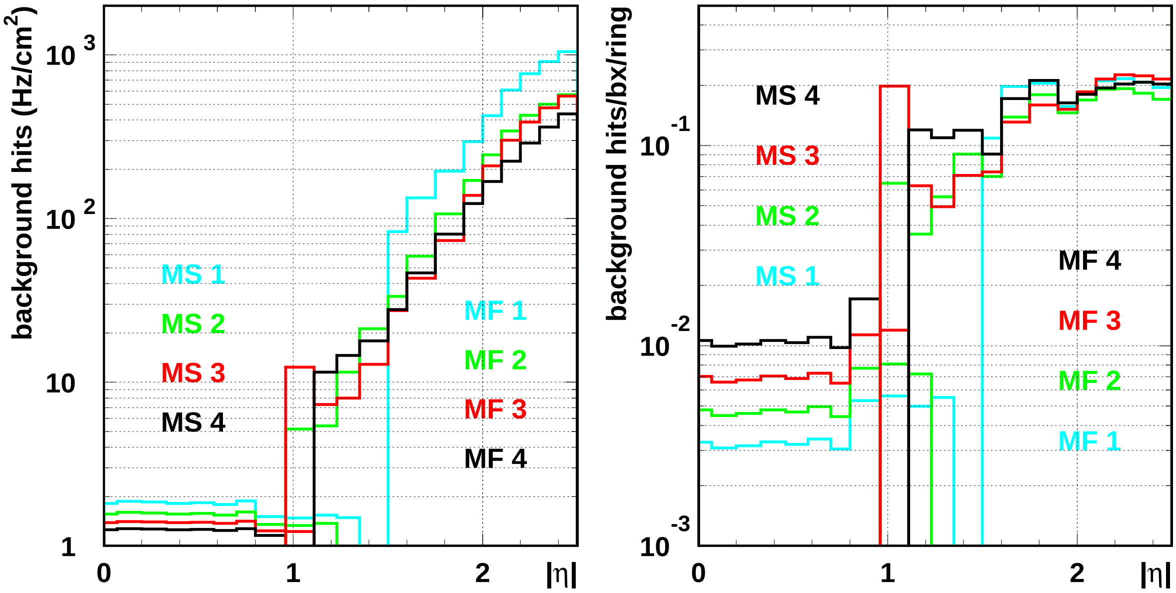

Figure 8: Rates of hits due to neutral particles.

Table 2: Examples of n/γ hit rates.

position		strip size in cm			flux	rate
η	MF	width	length	area	Hz/cm^2	Hz/strip
1.6	4	2.3	42	97	50	4800
	1	1.4	27	37	150	5600
2.4	4	1.0	17	17	400	6800
	1	0.6	11	7	1000	6500

Following Table 2 one can assume an average of 6 kHz/strip and estimate the number of n/γ hits per bunch crossing in the entire CMS:

$$200000\,\mathrm{strips} \cdot 6\,\mathrm{kHz/strip} \cdot 25\,\mathrm{ns/bx} = 30\,\mathrm{strips/bx}$$

Distribution obtained by precise simulation is shown in Fig. 9. The figure confirms that the average number of random hits per bunch crossing is 30.

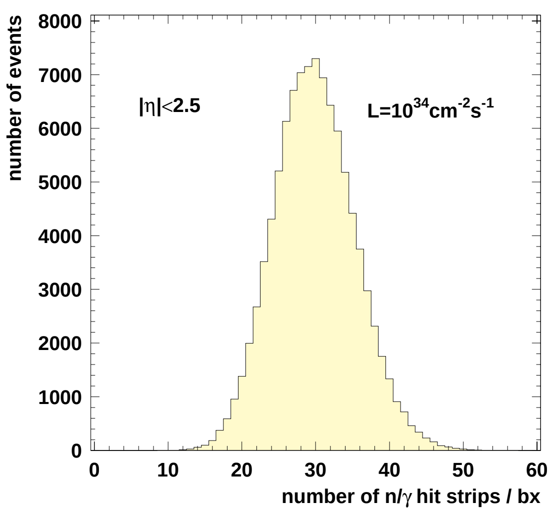

Figure 9: Distribution of n/γ hit multiplicity per bunch crossing.

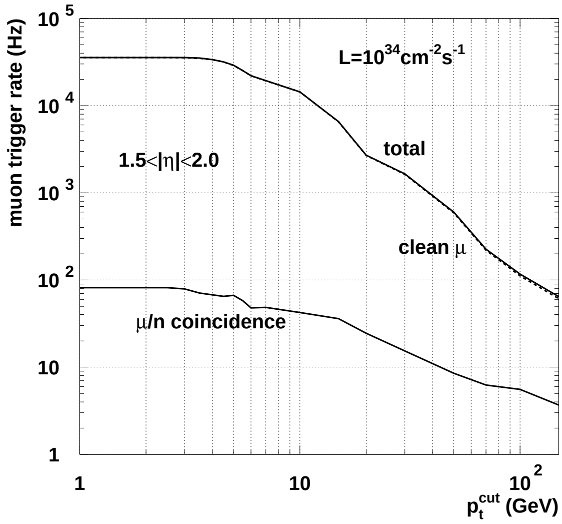

Figure 10: Trigger rates due to "clean" and promoted (marked by "μ/n") muons.

These random hits can increase the trigger rate due to promotion effect described above. This additional rate is presented in Fig. 10 (curve marked "μ/n"). It turns out to be negligible with the "clean" muon rate (dashed curve).

The trigger rate due to accidental coincidences of n/γ hits is plotted in Fig. 11 (curve denoted by "n"). The way it was calculated is described in detail in [10].

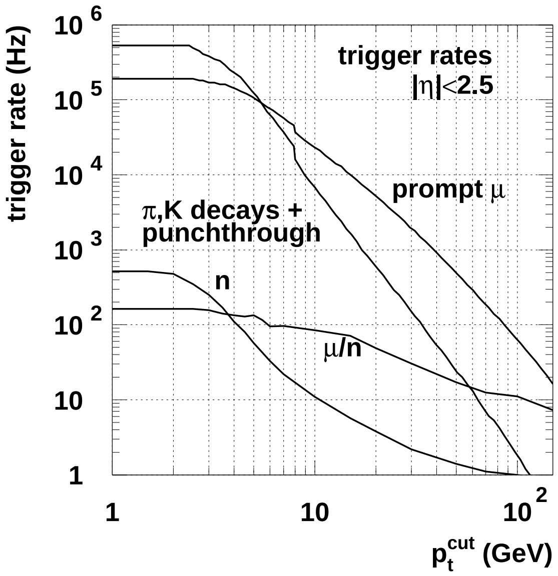

Figure 11: Comparison of various contributions to the trigger rate at luminosity 10^{34} cm^{-2} s^{-1}.

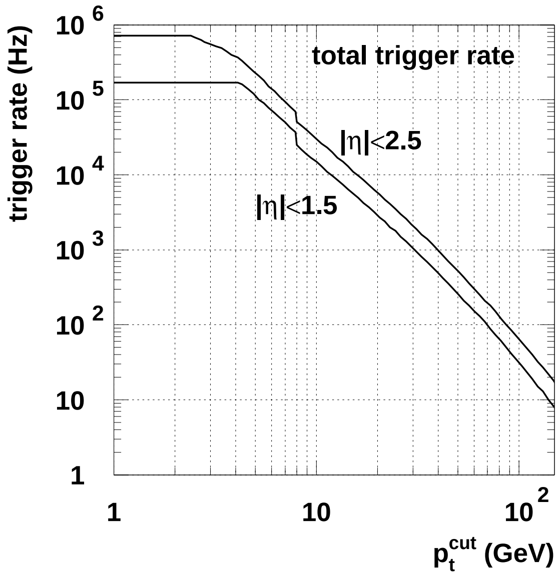

Figure 12: Total single muon trigger rate.

6 Total single muon trigger rate

Various contribution to the trigger rate are compared in Fig. 11. Rate of random hit coincidences recognized by the trigger as muons is marked by "n" . Increase of the muon rate due to coincidence of muon track with random hits ("promotion" effect) is indicated by "μ/n". It is seen that rate due to charge particles dominates at all momenta.

Finally, the total single muon trigger rate is presented in Fig. 12. Two curves correspond to the rapidity limit $|\eta| < 2.5$ and $|\eta| < 1.5$ respectively. It is seen that the output trigger rate can be maintained by adjusting rapidity range and the momentum cut.

7 Trigger momentum thresholds

The p_t thresholds should be adjusted in such a way that the overall trigger rate does not exceed the limit of capability of the CMS event filter processor farm. The full available bandwidth of 100 kHz should be shared among various triggers. Thus the maximal rate allowed for the single muon trigger is of the order of 3 kHz. Optimal p_t cuts for luminosities 10^{32}, 10^{33} and 10^{34} cm^{-2}s^{-1} are 4.5, 10 and 25 GeV respectively as can be read from Fig. 13.

A large uncertainty in the estimation of physics rates, background and noise level force us to make the system very flexible with large safety margins. Therefore there should be a possibility to apply a p_t cut as high as 100 GeV. On the other hand a double muon trigger allows us to use much lower thresholds than those for the single muon trigger. In fact the lowest possible cut is determined by the muon energy loss in the calorimeters. Taking all this into account we can conclude that the first level muon trigger should provide adjustable p_t cuts in the range from 2.5 up to 100 GeV. Fig. 13 shows that the Pattern Comparator Trigger is fully capable of that.

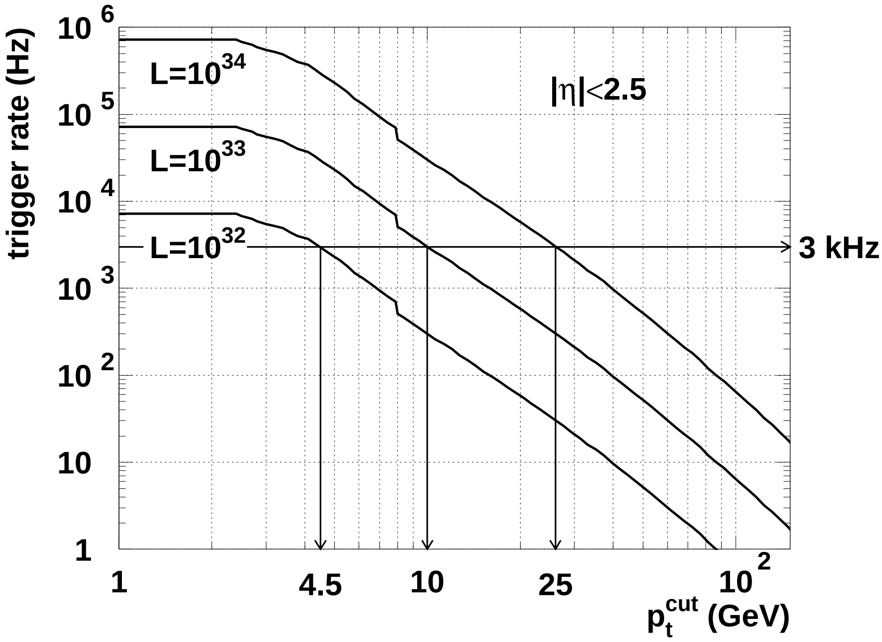

Figure 13: Muon rates and corresponding trigger cuts for various luminosities in CMS.

Acknowledgment

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