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Muon trigger for heavy ion physics

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Abstract

Trigger capability for dimuon events is discussed. The acceptance and low momentum reach are calculated. The rates of muon trigger caused by prompt muons, hadron decays and hadronic punchthrough are examined. A trigger strategy for Pb-Pb collision is proposed to ensure high efficiency for the signal and acceptable background rates. Possible modifications for lighter ions are briefly discussed.

1 Introduction

Properties of the dense matter produced in heavy ion collisions can be studied by observing the formation of bound states of heavy quarks, like J/ψ, ψ', ψ'', ϒ, ϒ', ϒ''. Their decay into muons provides a rather clean experimental signature. These objects are relatively light (3-10 GeV) and hence the produced muons have rather low p_t. Therefore it is extremely important to have low threshold for muon trigger and reconstruction. This is illustrated in Fig. 1, where the number of collected $\Upsilon \longrightarrow \mu^+\mu^-$ events is presented as a function of trigger threshold p_t^{cut}. The very strong dependence of available statistics on the p_t^{cut} is clearly visible.

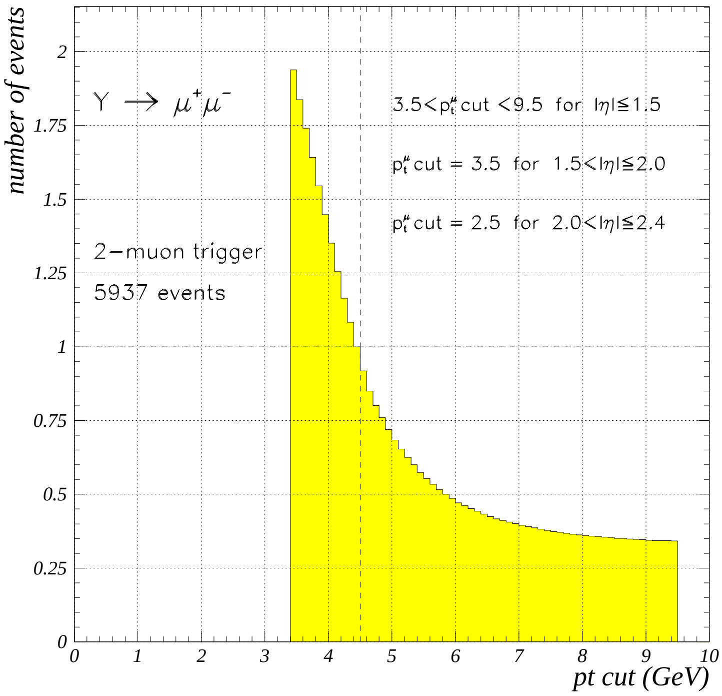

Fig. 1. Expected number of $\Upsilon \rightarrow \mu^+\mu^-$ events as a function of trigger threshold p_t^{cut}, normalised to p_t^{cut}=4.5 GeV

For this reason among the requirements for the CMS muon trigger one finds [1]:

- Low p_t reach should be limited only by muon energy loss in the calorimeters.

In the next section we discuss what is the low p_t reach of the CMS muon system according to the current design.

2 Acceptance for low p_t muons

In this paper we study the performance of the Pattern Comparator Trigger (PACT) based on Resistive Plate Chambers (RPC). This trigger searches for a patterns of hits in 4 RPC planes along a possible muon track. In the endcaps the RPC planes are placed in 4 muon stations, one plane per station. In the barrel two algorithms are used. High p_t muons (p_t > 5 GeV) are required to give hits in 4 RPC planes (denoted as MS1, MS2, MS3, MS4) placed in different muon stations. Low p_t muons ($p_t \leq 5$ GeV) also need to give hits in 4 RPC planes, but this time placed only in the first two muon stations (MS1, MS1', MS2, MS2'). In order to account for chamber inefficiency and dead areas, a coincidence of 3 out of 4 planes is enough to give a trigger.

The range-limited minimal value of the trigger threshold p_t^{min} which can be obtained in CMS is plotted in Fig. 2 as a function of |η|. Because of Landau fluctuations of the energy lost by muons, different p_t^{min} values are obtained for different required efficiencies. Because the detector design is not yet completely frozen, one can expect some minor changes in the amount of absorber (for example due to cables and services just behind the coil crostat), however these should not be bigger than one nuclear interaction length λ. The effects of a +1λ increment in depth is indicated in the figure as a kind of error bar. For comparison the total momentum p^{min} is also plotted in Fig. 3.

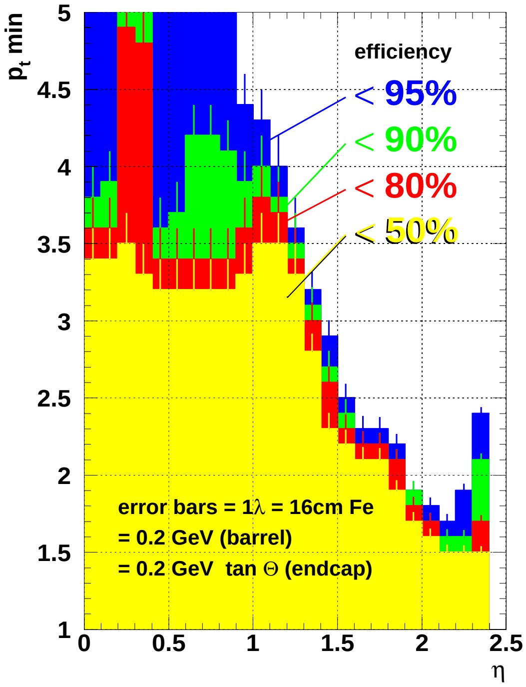

Fig. 2. Minimal muon trigger threshold p_t^{min} for various required efficiencies as a function of muon pseudorapidity.

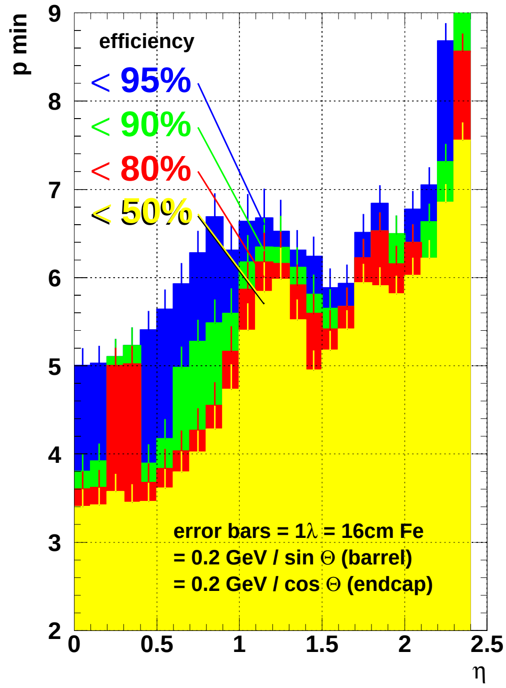

Fig. 3. Total momentum corresponding to the minimal muon trigger threshold as a function of muon pseudorapidity.

There is a region at |η|≈0.3 with particularly low efficiency. This is due to the gap between the central and next neighbouring wheels of the CMS barrel. The gap is needed mainly for cables and services of inner detectors and calorimeters. In the current design it is 20 cm wide. On top of that, one should add 2×4 cm of dead RPC edge. There are efforts at present to reduce these numbers, but it seems that the absolute lower limit is 14+2×2 cm. The effect of this gap on the muon trigger acceptance is better seen in Fig. 4. The trigger acceptance (coincidence of 3 out of 4 planes required) for muons with $4.5 < p_t < 5.0$ GeV is plotted for low and high p_t algorithms separately as well as for the logical OR of the two. The full acceptance table is given in Fig. 5.

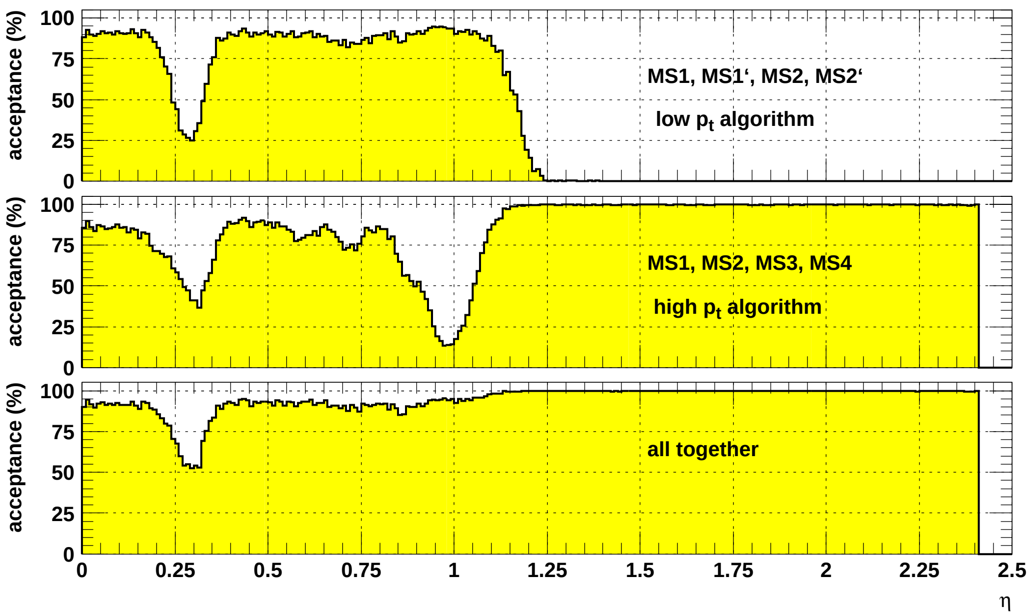

Fig. 4. Muon trigger acceptance (coincidence of 3 out of 4 RPC planes required) for muons with $4.5 < p_t < 5.0$ GeV for a central gap of 20 cm, plus dead RPC edges of 4 cm on each side of the gap.

92	92	80	82	94	93	92	91	87	92	94	99	100	99	100	100	99	100	99	100	100	100	99	100	100
91	90	74	81	93	93	92	90	89	93	95	99	99	99	99	100	99	100	100	100	100	100	100	99	100
92	91	69	78	93	92	92	90	90	93	94	99	100	99	99	100	99	100	99	100	99	99	100	99	100
91	90	66	77	92	91	90	89	90	94	95	99	99	99	100	99	99	100	99	99	100	100	100	99	100
91	90	56	73	91	91	91	90	88	93	95	99	99	100	99	99	99	99	99	100	99	99	99	99	100
89	90	55	71	91	92	90	87	89	95	95	99	99	99	99	100	100	99	99	100	99	100	100	99	
90	89	53	69	91	90	88	88	88	93	95	98	99	99	100	100	100	100	100	99	100	99	100	100	100
91	89	54	74	91	92	90	90	90	94	94	98	99	99	99	100	100	99	99	99	99	99	99	99	100
92	88	49	72	90	92	88	88	90	92	93	98	99	99	99	100	99	99	99	99	99	99	99	99	100
91	88	50	72	90	91	88	89	89	91	91	96	99	99	100	99	99	99	100	99	100	100	99	99	100
90	90	50	72	92	90	88	87	88	90	89	93	99	99	99	99	99	99	99	99	99	99	99	99	100
92	87	52	75	91	92	87	86	88	88	84	91	99	99	99	100	100	99	99	99	99	99	99	99	90
89	86	53	75	89	91	89	88	87	85	78	83	97	99	99	99	99	99	99	99	99	99	99	99	100
86	82	54	76	90	89	87	88	86	80	71	73	95	99	99	100	99	99	100	99	100	99	99	99	91
77	74	54	78	89	87	84	86	84	72	58	60	91	99	99	99	99	99	99	99	99	99	99	99	100
66	57	47	71	83	80	80	82	81	64	42	40	83	98	99	100	99	99	99	99	99	99	99	99	100
47	34	33	65	73	73	69	75	72	53	29	25	69	97	99	100	99	99	99	99	99	99	99	98	100
28	14	19	44	53	55	51	62	59	39	19	12	49	96	99	99	99	99	99	99	99	99	99	98	91
15	2	8	23	29	29	30	41	43	28	11	4	33	94	99	99	99	99	99	99	99	99	99	98	95
7		1	6	9	10	14	23	24	17	6	2	17	88	98	99	99	99	99	99	99	99	99	98	87
1				2	2	3	8	10	8	3	1	8	77	97	99	99	99	99	99	99	99	99	97	90
							1	3	2	1		3	64	94	99	99	99	99	99	99	99	99	97	83
									1			1	47	91	99	99	99	99	99	99	99	99	97	90
													28	84	99	99	99	99	99	99	99	99	97	90
													16	76	98	99	99	99	99	99	99	99	95	100
													11	66	94	98	98	99	99	99	99	99	95	87
													8	53	88	96	96	98	99	99	99	99	94	55
													5	36	70	90	91	97	99	99	99	98	93	66
													2	22	44	72	74	94	99	99	99	98	90	81
														10	17	38	42	79	98	99	99	97	89	69
														3	4	10	9	57	95	98	98	96	85	75
														1	1			23	83	97	98	94	84	85
																		3	53	92	96	93	81	50
																			16	74	91	90	76	25
																			1	37	82	83	70	37

Fig. 5. Acceptance table of the muon trigger in present CMS setup (central gap of 20 cm, plus dead RPC edges of 4 cm on each side of the gap).

Keeping in mind all the above mentioned uncertainties one can conclude that the lowest “triggerable” muon p_t is about 4 GeV in the barrel and it decreases down to ~2 GeV in the endcaps, if an efficiency of 90% for muon is required. One can, however, reduce p_t^{min} in the barrel down to ~3.5 GeV relaxing the requirement on the efficiency down to 80%. Relaxing it further down to 50% allows us to trigger on muons with p_t ~3.2 GeV. This can be better seen from Fig. 6a.

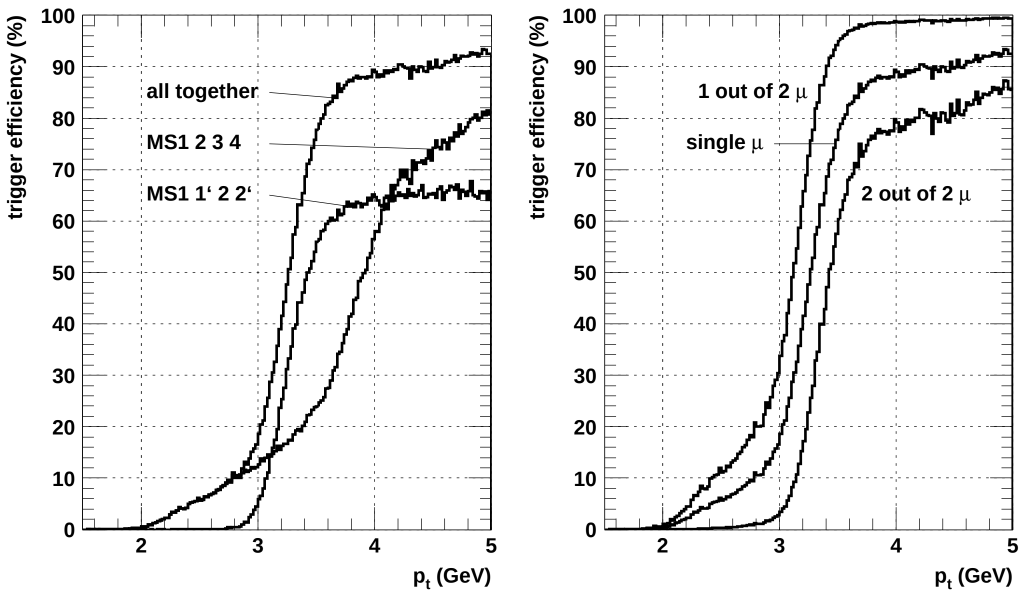

Fig. 6. a) Trigger efficiency for |η| < 1.5 for low and high p_t algorithms.
b) Trigger efficiency in the case of 1- and 2-muon events (|η| < 1.5).

In the case of heavy ion physics we are interested in two-muon events. Requirement of 2 muons at the first level trigger squares the single muon trigger efficiency. The result is shown as the lower curve in Fig. 6b. In such a case the trigger is rather inefficient, especially at low p_t, so crucial for heavy ion physics. If one can, however, trigger on **anyone of the two muons** then the inefficiency gets squared, and the trigger performance becomes very good, as seen from the upper curve in Fig. 6b.

A single muon trigger is however subject to various backgrounds. Among them are prompt muons form c- and b-quark decays, muons from π and K decays, punchthrough of hadronic showers. The crucial question is then whether the first level trigger rate due to background is tolerable in view of higher levels. We are going to address this question in the following sections.

3 Calculation of muon trigger rates

The question of the trigger rate due to background should be addressed through rather detailed simulation. One cannot, however, simulate full events, because getting reasonable statistics would require enormous amount of CPU time. Therefore it is importatant to identify various contributions to the trigger rate and find an optimal simulation strategy for each of them. A muon trigger can be caused by:

- prompt muons from c- and b-quark decays
  (in the case of heavy ion collisions, havier particles can be neglected),
- muons from hadron decays (mainly π and K),
- charged particles (electrons, hadrons, muons) emerging from hadronic showers
  (this component is often called *punchthrough*),
- hadrons non-interacting in the calorimeters,
- beam halo muons,
- uncorrelated hits due to electrons produced by photons following a thermal neutron capture,
- detector noise.

The first three sources clearly dominate over the others and only those are considered in this paper. In order to achieve reasonable statistics we simulate single hadrons and muons. Hadrons are allowed to develop showers and decay into muons. All charged particles can produce hits in RPC detectors and thus cause a trigger. Obtained trigger rates should be weighted by the expected p_t spectra. In order to do that one needs to know the shape of the hadron and muon p_t spectra.

4 Hadron and muon p_t spectra

Typically the p_t spectrum of hadrons in proton-proton (pp) or heavy ion (AA) collisions is parameterised in the following way

$$\frac{dR}{dp_t}\left[\frac{\text{Hz}}{\text{GeV} \cdot \eta\text{-unit}}\right] = A \cdot \exp-\frac{\sqrt{m_\pi^2 + p_t^2}}{T} \qquad for \qquad p_t \leq p_t^{lim}$$

$$= \frac{B}{(1 + p_t / p_t^0)^n} \qquad for \qquad p_t > p_t^{lim}$$

where

$$A = B \cdot (1 + p_t^{lim} / p_t^0)^n \cdot \exp-\frac{\sqrt{m_\pi^2 + p_t^{lim2}}}{T}$$

Recent experimental data, closest to the LHC conditions, are from the CDF experiment [2]. Parameters of the above formula fitted to these data are listed in Tab. 1. Pb-Pb collisions at $\sqrt{s}$ =5.5 TeV have been simulated by the ALICE collaboration [3] using PYHIA and HIJING Monte Carlos. Results of fits to obtained hadron p_t distributions are also given in Tab. 1. The parameter B in the table is normalised to give an expected number of charged particles per rapidity unit. In the case of minimum bias Pb-Pb collision at $\sqrt{s}$ =5.5 TeV a conservative estimate is ~2500 particles per η-unit.

Tab. 1. Parameters of fits to measured and simulated hadron p_t spectra.

	CDF pp	**PYTHIA**	**HIJING**
T	0.16 GeV	0.16 GeV	0.16 GeV
p_t^0	1.30 GeV	0.74 GeV	0.16 GeV
n	8.28	7.2	5.1
p_t^{lim}	0.5 GeV	0.5 GeV	1.1 GeV
B	$8.120 \cdot 10^8$	$8.804 \cdot 10^8$	$9.355 \cdot 10^8$

An interesting question is how much different could be the hadron p_t spectra in Pb-Pb collisions at $\sqrt{s}$ =5.5 TeV and in pp collisions at $\sqrt{s}$ =14 TeV. The former one was simulated with PYTHIA and parameterised by the following formula [4]

$$\frac{dR}{dp_t}\left[\frac{\text{Hz}}{\text{GeV} \cdot \eta\text{-unit}}\right] = f(p_t) = C \cdot 1.1429\times10^{10} \cdot (p_t^{1.306} + 0.8251)^{-3.781}$$

The ormalisation factor was chosen such that the parameter C is equal to 1 for pp collisions at $\sqrt{s}$ =14 TeV and $L=10^{34}cm^{-2}s^{-1}$. In order to apply this spectrum to heavy ion collisions we used a simple scaling law

$$\sigma_{AA}^{hard} = A^{2 \cdot 0.95} \cdot \sigma_{pp}^{hard}$$

The cross sections in the above formula are marked “hard”, because this scaling law can be applied for relatively hard object only. This is our case because we are interested in hadrons with $p_t > 1$ GeV. Softer hadrons cannot penetrate calorimeters and therefore they cannot contribute to the muon trigger background.

The parameter C one can calculate as a ratio of particle rates in AA and pp cases. Values obtained are given in Tab. 2.

$$C = \frac{R_{AA}(p_t)}{R_{pp}(p_t)} = \frac{\sigma_{AA}^{hard} \cdot L_{AA}}{\sigma_{pp}^{hard} \cdot L_{pp}} = A^{2 \cdot 0.95} \cdot \frac{L_{AA}}{L_{pp}}$$

Tab. 2. Parameter C for various ion species

	pp	**O O**	**Ca Ca**	**Nb Nb**	**Pb Pb**
A	1	16	40	93	207
luminosity [$cm^{-2}s^{-1}$]	10^{34}	$3.2 \cdot 10^{31}$	$2.5 \cdot 10^{30}$	$9 \cdot 10^{28}$	10^{27}
C	1	0.621	0.277	0.0495	0.00251

All parameterisations discussed above are plotted in Fig. 7. The HIJING spectrum is the hardest, but the overall rate is the smallest. It can be seen however that these distributions do not differ significantly in the region of 3-6 GeV which gives the main contribution to the background (as it will be shown in Sec. 5, Fig. 13). The rescaled LHC-pp spectrum is a rather conservative estimate and therefore it is used hereafter in this paper. Consequently we applied the same scaling law also to the p_t spectrum of prompt muons (from c- and b-quark decays). We used the parameterisation proposed in [4]. The result is shown in Fig. 8.

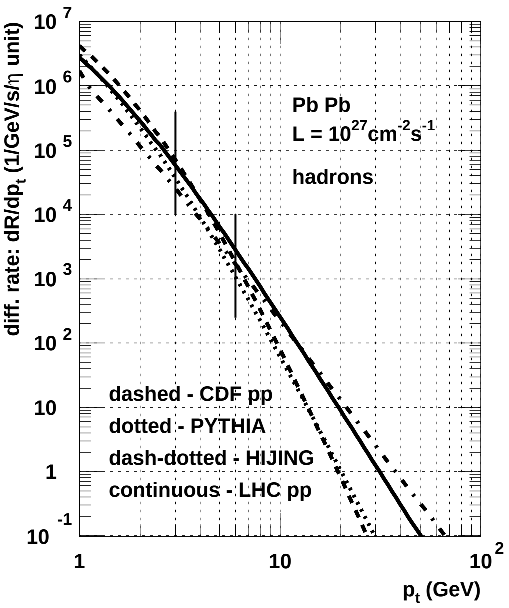

Fig. 7. Expected hadron rate in LHC minimum bias Pb-Pb events at L=10^{27}cm^{-2}s^{-1}, compared to present CDF data and rescaled expectation for pp collisions at LHC.

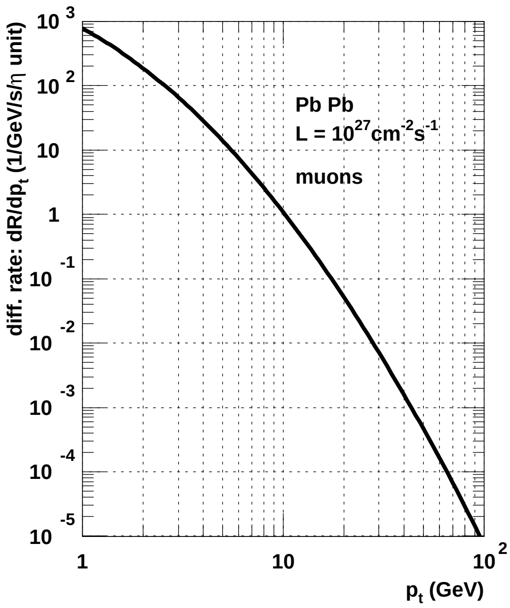

Fig. 8. Expected muon rate in LHC minimum bias Pb-Pb events at L=10^{27}cm^{-2}s^{-1}, obtained by rescaling expectation for pp collisions.

5 Simulation of hadrons

In order to simulate particle passage and detection in CMS we used CMSIM/GEANT/FLUKA software. FLUKA was chosen to simulate hadronic showers because it was shown [5] that it reproduces the RD5 data on punch-through significantly better than GHEISHA. The CMS detector was described by the CMSIM 101 package. The RPC trigger was simulated in detail using the MRPC software [6]. Since it is crucial to optimize the energy cut-offs in such a simulation we list all the used cuts in Tab. 3. The approximate time needed to simulate one particle or one event in given in Tab. 4.

Tab. 3. GEANT cuts used in the simulation

particle or process	GEANT name	far from the muon chambers	close to the muon chambers	inside the muon chambers
γ	CUTGAM	100 MeV	10 MeV	10 keV
e	CUTELE	100 MeV	10 MeV	10 keV
n	CUTNEU	1 MeV	1 MeV	1 MeV
hadrons	CUTHAD	1 MeV	1 MeV	100 keV
μ	CUTMUO	10 MeV	10 MeV	100 keV
e $\rightarrow$ bremsstrahlung	BCUTE	10 MeV	10 MeV	10 MeV
μ $\rightarrow$ bremsstrahlung	BCUTM	10 MeV	10 MeV	10 MeV
e $\rightarrow$ δ-rays	DCUTE	off	off	10 keV
μ $\rightarrow$ δ-rays	DCUTM	off	off	10 keV
μ $\rightarrow$ pair production	PPCUTM	10 MeV	10 MeV	10 MeV

Tab. 4. Simulation time at SHIFTCMS

μ	$<\pi> \in$ 1-100 GeV	π = 100 GeV	π = 1 TeV	min. bias event
0.04 s	2.2 s	1 min.	5 min.	1 min.

Trying to simulate hadrons according to this spectrum one would immediately have the same problems with CPU time as in the case of full minimum bias events. Therefore we have generated hadrons of $p_t \in$ 1-100 GeV with a flat distribution of $\log_{10}(p_t)$. One event took on average ~2.2 s, which allowed us to simulate 215 000 hadrons using “only” 5.5 CPU days. 803 among the simulated hadrons caused a trigger (see Tab. 5). The hadrons were generated with $\phi \in (0, 2\pi)$ and $\eta \in (-0.25, 0.25)$. The following mixture was generated: 31.62% of π^+, π^-, 5.32% of K^+, K^-, K^0_L, K^0_S, 3.87% of p, $\bar{p}$, n, $\bar{n}$. The sample contains also those events where the hadron decayed into μ before the calorimeter.

Tab. 5. Statistics of simulated hadrons

simulation time	events simulated	triggered	fraction
5.5 CPU days	215 000	803	0.37%

Momentum (p_t^{hadron}) distributions of hadrons causing a muon trigger (for whatever reson) and distribution of momentum given by the trigger ($p_t^{trigger}$) are shown in Fig. 9 and Fig. 10 respectively. As expected, higher p_t hadrons have a higher probability to produce punchthrough. However the trigger response $p_t^{trigger}$ distribution is rather flat, with a peak at 5 GeV. This is because the trigger algorithm is based on 4 muon stations for $p_t > 5$ GeV whereas only the first two stations are used below this threshold. Thus any punchthrough event which has no hits in station 3 or 4 cannot have $p_t > 5$ GeV assigned by the trigger. Since most of the punchthrough events cannot reach station 3 (which is too deep) they are “suppressed” below 5 GeV. This is well illustrated by Fig. 11.

The probability that a hadron of a given p_t causes a trigger can be calculated normalising the distribution from Fig. 9 to the number of generated hadron. The result is shown in Fig. 12.

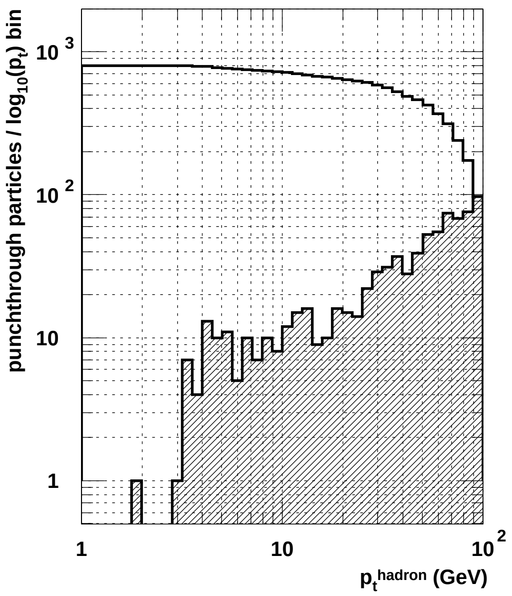

Fig. 9. Differential (hatched histogram) and integral (solid line) p_t spectra of hadrons causing a trigger.

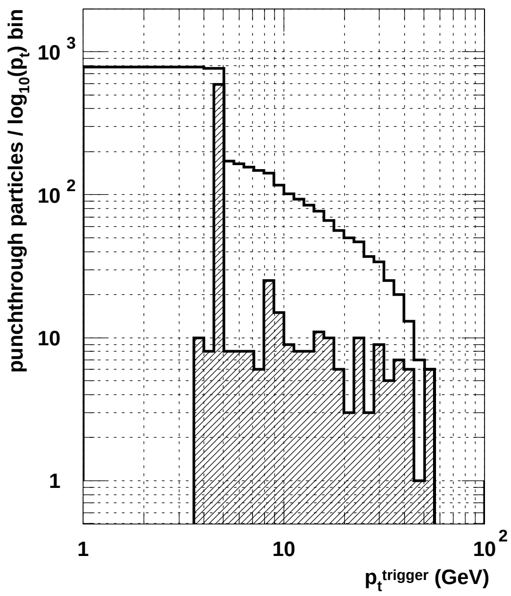

Fig. 10. Differential (hatched histogram) and integral (solid line) spectra of trigger responses $p_t^{trigger}$.

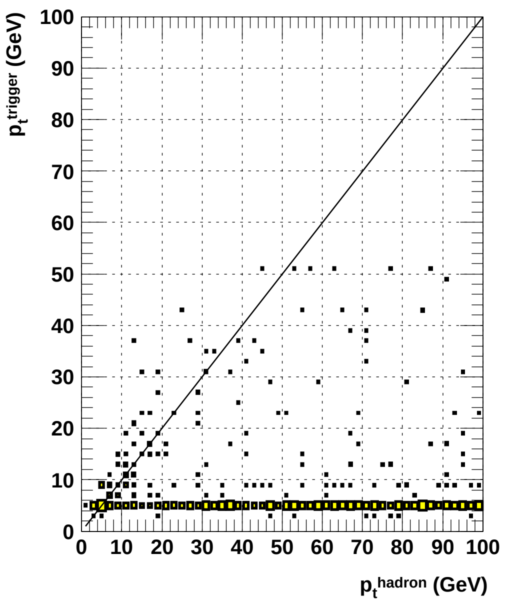

Fig. 11. Correlation between hadron momentum p_t^{hadron} and trigger response $p_t^{trigger}$.

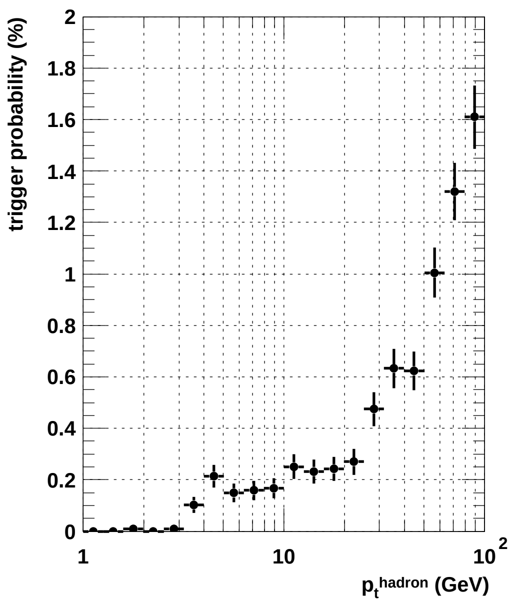

Fig. 12. Trigger probability as a function of hadron momentum p_t^{hadron}.

Let us denote the expected p_t spectrum of hadrons by

$$\frac{dR_{expected}}{dp_t}\left[\frac{\text{Hz}}{\text{GeV}\cdot\eta\text{-unit}}\right] = f(p_t)$$

We have simulated a flat distribution in $\log_{10}(p_t)$:

$$\frac{dN}{d\log_{10}(p_t)} = \frac{N}{\Delta_l} = \text{const}$$

where N is the total number of generated hadrons and $\Delta_l = \log_{10}(100\text{ GeV}) - \log_{10}(1\text{ GeV}) = 2$.

This can be transformed into

$$\frac{dN}{dp_t} = \frac{dN}{d\log_{10}(p_t)} \cdot \frac{d\log_{10}(p_t)}{dp_t} = \frac{N}{\Delta_l} \cdot \frac{1}{p_t \cdot \log_e 10}$$

The number of particles can be converted into a rate by a weight function $w(p_t)$:

$$\frac{dR}{dp_t} = w(p_t) \cdot \frac{dN}{dp_t}$$

In the case of the generated hadron distribution this reads:

$$f(p_t) = w(p_t) \cdot \frac{N}{\Delta_l \cdot p_t \cdot \log_e 10}$$

From here we can calculate the weight function $w(p_t)$:

$$w(p_t) = f(p_t) \cdot \frac{\Delta_l}{N} \cdot p_t \cdot \log_e 10$$

This weight function has been applied to the distributions from Fig. 9 and Fig. 10. The results are shown in Fig. 13 and Fig. 14 respectively. It is seen that the contribution from low p_t (3-6 GeV) hadrons dominates. The punchthrough probability is higher for high hadron momenta, but the rate of low p_t hadrons is high enough to overcompensate this effect.

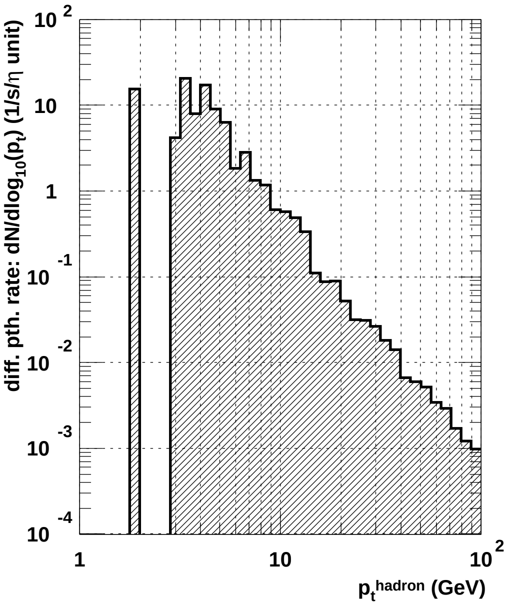

Fig. 13. Weighted spectrum of hadrons causing a trigger (in the barrel).

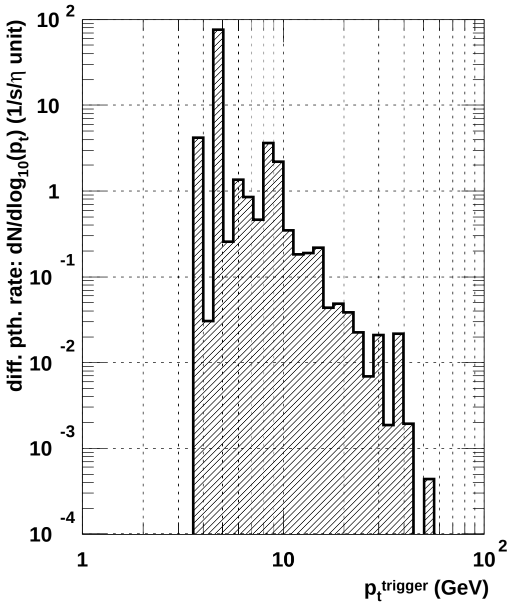

Fig. 14. Weighted distribution of trigger responses (in the barrel).

In order to obtain the trigger rate as a function of the p_t^{cut} threshold, the distribution from Fig. 13 has been integrated. The result is shown in Fig. 15. The rate due to prompt muons (those from c- and b-quark decays) is shown for comparison. The two rates contribute almost equally to the total trigger rate at the lowest p_t, appropriate for heavy ion physics. They are summed up and normalised to $|\eta|<1.5$ in Fig. 16. It can be seen that the total single muon trigger for this η range at the lowest accessible p_t^{cut} is about 500 Hz.

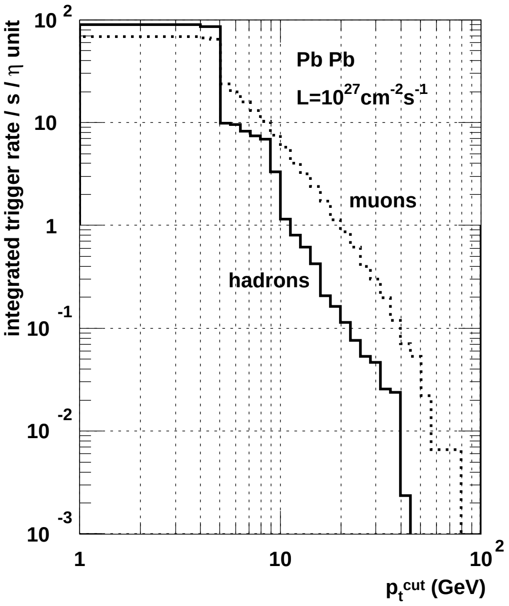

Fig. 15. Single muon trigger rate due to prompt muons and punchthrough (including π and K decays) in the barrel.

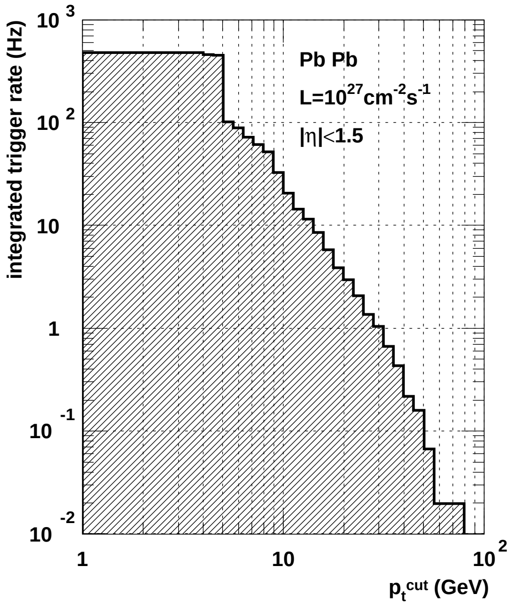

Fig. 16. Total single muon trigger rate.

6 Luminosity considerations

The rate obtained for Pb-Pb collisions can be rescaled to other ion species assuming luminosities given in the ALICE Technical Proposal [3]. The results are shown in Tab. 6. The luminosities given in the table are initial ones, assuming 125 ns bunch spacing and only one experiment running at a time. There are several factors influencing the nominal luminosity:

- after ~10 hours of a run the luminosity is about 2 times lower;
- reducing bunch spacing to 25 ns can increase the luminosity by factor 4-5 (this option is impossible for Pb-Pb collisions);
- running 2 experiments at the same time reduces the luminosity by a factor 3-4;
- running 3 experiments at the same time reduces the luminosity by a factor 6-9.

Trigger rates for the last two cases are given in Tab. 7. The two-muon trigger rates according to Ref. [7] are also given.

Tab. 6. Single muon trigger rates for |η|<1.5

	pp	**O O**	**Ca Ca**	**Nb Nb**	**Pb Pb**
luminosity [$cm^{-2}s^{-1}$]	10^{34}	$3.2 \cdot 10^{31}$	$2.5 \cdot 10^{30}$	$9 \cdot 10^{28}$	10^{27}
average collision rate [kHz]	550 000	32 000	5200	400	7.6
trigger rate [kHz]	190	120	53	10	0.5

Tab. 7. Muon trigger rates for |η|<1.5

Pb Pb: experiments	**1**	**2**	**3**
luminosity [$cm^{-2}s^{-1}$]	10^{27}	$3.3 \cdot 10^{26}$	$1.7 \cdot 10^{26}$
average collision rate [Hz]	7600	2500	1300
1μ trigger rate [Hz]	500	165	85
2μ trigger rate [Hz]	60	20	10

Luminosities and trigger rates given above should be taken with care when used to estimate available statistics. They show possibilities of the LHC machine, but it is not obvious that the experiments can stand them. For example luminosity of $3.2 \cdot 10^{31}$ $cm^{-2}s^{-1}$ quoted for O-O collisions with the cross section of 1 barn gives an average collision rate of 30 MHz. This is to be compared with the bunch crossing frequency of 8 MHz corresponding to a bunch spacing of 125 ns. In such a case one should expect on average 4 O-O collisions per bunch crossing which makes absolutely impossible most of the study planned for heavy ion collisions!

7 Trigger strategy for Pb-Pb collisions

Let us assume the following:

- $L=10^{27} cm^{-2}s^{-1}$ (1 experiment running at a time) for Pb-Pb
- mass storage capacity: 60 events/s (see [8]), equally divided between dimuon and “calorimetric” physics
- equal rates for muon and calorimeter triggers
- pseudorapidity range of interest for dimuon physics: |η|<1.5

For these conditions we propose the following trigger strategy:

- require single muon trigger in |η|<1.5 at the first level ⇒ ≈ 500 Hz
- search for a second muon in muon chambers in |η|<1.5 at the second level ⇒ < 60 Hz

Since one can write to tape ≈30 dimuon events/s we are already in the right ball park. In fact the estimate of 60 Hz for the two-muon trigger was based on a very soft requirement on the second muon — a least one hit in any muon station. Slightly more restrictive requirement may easily reduce the rate. Presumably a factor two can be gained by rejecting same sign muon pairs.

In any case, if there is a mismatch between the 2-nd level trigger rate and the mass storage capacity there are several possibilities to solve it:

- have a bigger mass storage
- reduce the luminosity
- reconstruct $\Upsilon \rightarrow \mu\mu$ at the virtual third level and cut on a μμ mass range

The first two possibilities are trivial, so let us consider the third one. Assume a farm of 500 processors, divided equally for 2nd and 3rd level, and for muon and calorimeter events. Hence available processing time per event is 500 / 2 / 2 / 60 Hz = 2 s. Is it feasible? It is difficult to conclude today. At least it does not look impossible. In fact this solution will probably not be needed for Pb-Pb collisions, but might be very useful for lighter ions where we expect higher luminosities and thus higher rates.

The strategy described above works well for Pb-Pb collisions and it may work (with some modifications) in the Nb-Nb case. For lighter ions, however one has to require two muons already at the first level. This is necessary in order to maintain an acceptable trigger rate. The price for this is an efficiency for low p_t muon pairs of 80% or even lower. Fortunately this is not a problem, because in the case of light ions we expect much higher luminosities which ensure to collect high enough statistics in spite of low efficiency.

8 Conclusions

The expected p_t spectra above 1 GeV in AA collisions at $\sqrt{s}$ = 5-7 TeV are not much different from those in pp collisions at $\sqrt{s}$ = 14 TeV. A simple scaling by $A^{2 \cdot 0.95}$ works well. This has a big practical importance, as a lot of study was done in CMS for the pp case and this can be easily extrapolated to heavy ion collisions. For example, one gets Pb-Pb rates at $L=10^{27}cm^{-2}s^{-1}$ multiplying pp rates at $L=10^{34}cm^{-2}s^{-1}$ by 0.0025.

For Pb-Pb collisions at $L=10^{27}cm^{-2}s^{-1}$ one can expect a single muon trigger rate of ≈500 Hz in $|\eta|<1.5$ with almost equal contributions from prompt muons (c- and b-quark decays) and from hadronic punchthrough + decays (mainly π and K). This allows us to run requesting a single muon at the first level trigger, which ensure high efficiency for $\Upsilon \rightarrow \mu^+\mu^-$. The muon trigger threshold is determined by the energy loss in calorimeters and it is equal to ≈3.2 GeV in the barrel region. This allows to explore central Υ, Υ', $\Upsilon'' \rightarrow \mu^+\mu^-$ production with good statistics at all $p_t(\Upsilon)$, down to $p_t(\Upsilon)=0$, with nuclei from pp to Pb-Pb. The exploitation of the forward region of $1.5<|\eta|<2.4$, either for still lower $p_t(\mu)$ detection of Υ, Υ', $\Upsilon'' \rightarrow \mu^+\mu^-$, or for observation of ψ, $\psi' \rightarrow \mu^+\mu^-$ requires a separate study.

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