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Triggering on forward physics

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Abstract

The feasibility is investigated of a dedicated trigger stream in the CMS trigger menu, with an output rate of $\mathcal{O}(1)$ kHz on the First Level Trigger and $\mathcal{O}(1)$ Hz on the High Level Trigger. By combining jet trigger information from the CMS calorimeter with information from the TOTEM Roman Pot detectors at 220 m distance from the interaction point, the default dijet trigger thresholds foreseen in the CMS trigger tables can be lowered substantially while respecting the CMS trigger bandwidth limits. The efficacy of the dedicated diffractive trigger stream is demonstrated for hard single-diffractive and double-Pomeron exchange events.

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1 Introduction

The pseudorapidity coverage of the CMS and TOTEM experiments will be unprecedented at a hadron collider, opening up the possibility to study a variety of physics subjects in diffractive interactions – from QCD and the low-x structure of the proton to Higgs Boson production.

Diffractive events are characterised by the fact that the incoming proton(s) emerge from the interaction intact, or excited into a low mass state, with only a small energy loss. Diffractive processes, for proton energy losses up to a few per cent, are mediated by the exchange of an object with the vacuum quantum numbers, the so-called Pomeron, now understood in terms of partons from the proton. For larger energy losses, mesonic exchanges – Reggeons and pions – become important. The topology of diffractive events is characterised by a gap in the rapidity distribution of final-state hadrons, caused by the lack of colour of the exchanged object. For a recent overview, see [1].

One key element in a diffractive physics program at the LHC is the trigger, notably at high luminosity, when the number of pile-up collisions overlaid to the interesting hard event becomes high. This is particularly challenging since pile-up events are themselves largely diffractive.

This paper discusses the feasibility of a forward detectors trigger stream, with Level-1 (L1) output target rate of $\mathcal{O}(1)$ kHz, as well as the potential of the already foreseen CMS L1 trigger streams for retaining events with hard diffractive processes. High Level Trigger (HLT) strategies that lead to an output rate of less than 1 Hz are also presented.

The trigger rate and its selection efficiency for several hard diffractive processes are presented. A particularly interesting and challenging channel is the central exclusive production in the Standard Model (SM) or in the Minimal Supersymmetric Model (MSSM) of a Higgs Boson, $pp \to pHp$, with mass close to the current exclusion limit.

2 Experimental apparatus

The CMS apparatus is described in detail elsewhere [2]. The main distinguishing features of CMS are a high-field solenoid inside which a full silicon-based inner tracking system is installed, along with a fully active scintillating crystals-based electromagnetic calorimeter and a brass-scintillator hadronic calorimeter. The return field is large enough to saturate 1.5 m of iron, in which 4 muon measuring stations are integrated to ensure robustness and full geometric coverage.

The CMS trigger system is designed to reduce the input rate of 10^9 interactions per second at the nominal LHC luminosity of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ to an output rate of not more than 100 Hz. This reduction of 10^7 is achieved in two steps, by the CMS L1 trigger, with output rate 100 kHz, and the CMS HLT, with output rate 100 Hz.

The L1 trigger carries out its data selection algorithms with the help of three principal components: the Calorimeter Trigger, the Muon Trigger and the Global Trigger. The Calorimeter Trigger utilizes the transverse energy, E_T, information of the CMS calorimeters (pseudorapidity coverage $|\eta| < 5$). A L1 jet consists of 3×3 regions, each with 4×4 trigger towers, where the E_T in the central region is larger than the E_T in any of the outer regions. A typical L1 jet has dimensions $\Delta\eta \times \Delta\phi = 1 \times 1$, where ϕ is the azimuthal angle. The E_T reconstructed by the L1 trigger for a given jet corresponds on the average only to 60% of its true E_T. All studies in this article use calibrated jet E_T values, obtained from the reconstructed value by means of an η and E_T dependent correction [11].

Upon receipt of a L1 trigger, after a fixed time interval of about 3.2μs, the data from the L1 pipelines are transferred to front-end readout buffers. After further signal processing, zero-suppression and/or data-compression, the data are placed in dual-port memories for access by the DAQ system. Each event, with a size of about 1.5 MB (pp interactions), is contained in several hundred front-end readout buffers. Through the event building “switch,” data from a given event are transferred to a processor. Each processor runs the same HLT software code to reduce the L1 trigger output rate of 100 kHz to 100 Hz for mass storage.

The TOTEM experiment [3, 4] will have two identical arms, one at each side of the CMS interaction point (IP). Each arm will comprise two forward tracker telescopes, T1 (Cathode Strip Chambers) and T2 (Gas Electron Multipliers), as well as Silicon detectors housed in Roman Pot (RP) stations along the LHC beam-line. The TOTEM detectors will provide input data to the Global Trigger of the CMS L1 trigger. Track finding in T1 and T2 (combined coverage $3.2 < |\eta| < 6.6$) for triggering purposes is optimized with respect to differentiating between beam-beam events that point back to the IP and beam-gas and beam-halo events that do not. The TOTEM RP stations will be placed at a distance of ± 147 m and ± 220 m from the CMS IP. Each station will consist of two units, 2.5 m and 4 m apart, each with one horizontally and two vertically movable pots that are equipped with

Silicon strip detectors.

The distribution of the fractional momentum loss, ξ, for diffractively scattered protons peaks at $\xi = 0$ ("diffractive peak"). The RP detectors at 220 m from the IP will permit to measure protons in the region $0.02 < \xi < 0.2$. The possibility of implementing a cut on ξ in the L1 trigger is currently under investigation. Detectors at a distance of 420 m from the IP, currently being studied, would provide a coverage of $0.002 < \xi < 0.02$ [5], complementary to that of the TOTEM detectors. The detectors at 420 m cannot be included in the L1 trigger without an increase in the L1 latency of 3.2 μs, though a special, long latency running mode might be feasible at lower luminosities.

The studies discussed in the following assume that the RP detectors are 100% efficient in detecting all particles that emerge at a distance of at least $10\sigma_{beam} + 0.5$ mm from the beam axis ($\sim$ 1.3 mm at 220 m and $\sim$ 4 mm at 420 m). Their acceptance was calculated by way of a simulation program that tracks particles through the accelerator lattice [6]. This has been done for the nominal LHC optics, the so-called low-β^* optics, version V6.5. Further details can be found in [7, 8]. The studies presented in the following assume LHC bunches with 25 ns spacing.

The results presented below do not depend on the specific hardware implementation of the T1 and T2 or the RP detectors; they hold for any tracker system with the T1, T2 η coverage in conjunction with RP detectors at 220 m from the IP.

3 Level-1 Trigger Rates for Forward Detectors Trigger Stream

3.1 2-Jet Conditions

The dominant decay of a SM Higgs Boson of mass $\sim$120 GeV/c ^{2} is into two b-quarks and generates two jets with at most 60 GeV/c transverse momentum, p_T, each. The L1 trigger tables of CMS are optimized for events with high p_T; the necessity of keeping the overall L1 rate at acceptable levels requires thresholds in dijet events above p_T =100 GeV/c per jet. Conversely, triggering is not a problem when Higgs decay final states with high p_T muons are utilized.

It should be noted that, from the L1 trigger point of view, central exclusive production of a low-mass Higgs is exemplary of any process that deposits relatively low E_T in the central detector. This includes central exclusive dijet production via double Pomeron exchange (DPE), $pp \rightarrow pjjp$, which gives access to the generalised (or "skewed") parton distributions (GPDs) of the proton. They quantify correlations between parton momenta in the proton; their t-dependence is sensitive to the distribution of partons in the transverse plane. It is also exemplary of inclusive dijet production via DPE, $pp \rightarrow pjjXp$, which is sensitive to the diffractive Parton Distribution Functions (dPDFs) of the proton – the conditional probabilities to find a parton in the proton when the final state of the process contains a fast proton of given four-momentum.

Detailed studies of the L1 rates and efficiencies for central exclusive Higgs production are presented in [9, 10, 11]. The main results are summarised here.

As mentioned above, the jets in events with central exclusive production of a low-mass (120 GeV/c ^{2}) Higgs Boson deposit transverse energies of at most 60 GeV in the CMS calorimeters. In order to retain as large a signal fraction as possible, as low an E_T threshold as possible is desirable. In practice, the threshold value cannot be chosen much lower than 40 GeV per jet. The L1 trigger applies cuts on the calibrated E_T value of the jet. Thus, a threshold of 40 GeV corresponds to 20-25 GeV in reconstructed E_T, i.e. to values where noise starts becoming sizable.

For luminosities of $10^{32}\text{cm}^{-2}\text{s}^{-1}$ and above, the rate from standard QCD processes for events with at least 2 central jets ($|\eta| < 2.5$) with $E_T > 40$ GeV exceeds by far the target output rate of $\mathcal{O}(1)$ kHz. Thus additional conditions need to be employed in the L1 trigger to reduce the rate from QCD processes. The efficacy of several conditions was investigated and, in the following, the corresponding rate reduction factors are always quoted with respect to the rate of QCD events that contain at least 2 central jets with $E_T > 40$ GeV per jet. These conditions are:

- Condition based on central detector quantities available to the Calorimeter Trigger (in addition to the jet requirement).
- Condition based on T1 and T2 as vetoes.
- Condition based on the RP detectors at $\pm$220 m. For completeness, conditions based on the RP detectors at $\pm$420 m distance from the CMS IP are included as well. Their coverage in ξ is complementary to that one

of the detectors at 220 m, and hence the reduction factors obtained with them are of interest both in the L1 trigger for special long-latency runs and, in normal running conditions, for the HLT.

QCD background events were generated with the Pythia Monte Carlo generator. The sample used contains 1 M events with $\hat{p_T}$, i.e. the p_T of the hard scatter, between 10 GeV/c and 1,000 GeV/c. To increase statistical significance for higher $\hat{p_T}$ values, the sample was generated in bins of $\hat{p_T}$, with roughly equal number of events per bin.

In order to assess the effect when the signal is overlaid with pile-up, a sample of 500,000 pile-up events was generated with Pythia. This sample includes inelastic as well as elastic events and events with single- and double-diffractive dissociation. Pythia underestimates the number of final state protons in this sample. The correction to the Pythia leading proton spectrum described in [12] was used to obtain the results discussed in the following.

Table 1 summarizes the situation for luminosities between $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Given a target rate for events with 2 central L1 jets of $\mathcal{O}(1)$ kHz, a total rate reduction between a factor 20 at $1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and 200 at $1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is necessary.

Table 1: Reduction of the rate from standard QCD processes for events with at least 2 central L1 jets with $E_T >$ 40 GeV, achievable with requirements on the tracks seen in the RP detectors. Additional rate reductions can be achieved with the H_T condition and with a topological condition (see text). Each of them yields, for all luminosities listed, an additional reduction by about a factor 2.

Luminosity $[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	# Pile-up events per bunch crossing	L1 2-jet rate [kHz] for $E_T > 40$GeV per jet	Total reduction needed	Reduction when requiring track in RPs: at 220 m	at 220 m, $\xi < 0.1$	at 420 m	at 220 & 420 m (asymmetric)	at 220 & 420 m (asymmetric), $\xi < 0.1$	at 420 & 420 m
1×10^{32}	0	2.6	2	370					
1×10^{33}	3.5	26	20	7	15	27	160	380	500
2×10^{33}	7	52	40	4	10	14	80	190	150
5×10^{33}	17.5	130	100	3	5	6	32	75	30
1×10^{34}	35	260	200	2	3	4	17	39	10

Condition based on central CMS detector quantities

In addition to the E_T values of individual L1 jets, the CMS Calorimeter Trigger has at its disposal the scalar sum, H_T, of the E_T values of all jets. Requiring that essentially all the E_T be concentrated in the two central L1 jets with highest E_T, i.e. $[E_T^1 + E_T^2]/H_T > 0.9$ (H_T condition), corresponds to imposing a rapidity gap of at least 2.5 units with respect to the beam direction. This condition reduces the rate of QCD events by approximately a factor 2, independent of the presence of pile-up and with only a small effect on the signal efficiency.

The requirement that the two central L1 jets are back-to-back does not yield any significant further reduction of the rate.

Condition based on TOTEM detectors T1 and T2

Using T1 and T2 as vetoes in events with 2 central L1 jets imposes the presence of a rapidity gap of at least 4 units. This condition suppresses QCD background events by several orders of magnitude. At luminosities low enough so that not more than one interaction takes place per bunch crossing, the signal efficiency is very high ($> 90\%$). In the presence of pile-up, the signal efficiency falls rapidly. The non-diffractive component in pile-up events tends quickly to fill in the rapidity gap in the Higgs production process. Only about 20 (5) % of signal events survive in the presence of 1 (2) pile-up event(s) [13].

Condition based on Roman Pot detectors

Demanding that a proton be seen in the RP detectors at 220 m results in excellent suppression of QCD background events in the absence of pile-up [10]. This is demonstrated in Fig. 1 for a luminosity of $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. There, the rate of QCD background events with at least 2 central L1 jets with E_T above a threshold is shown as function of the threshold value. The two curves reflect the rate without and with the requirement that a proton be seen in the RP detectors at 220 m. The rate of QCD background events that contain at least 2 central L1 jets with $E_T > 40$ GeV each is reduced by a factor ~ 370. At $2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, where on the average 7 pile-up events overlay the signal event, the diffractive component in the pile-up causes the reduction to decrease to a factor ~ 4, and at $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ to a factor ~ 2, as can be seen from Table 1. Table 1 summarizes the reduction factors achieved with different conditions for tracks in the RP detectors: a track in the RP detectors at 220 m distance on one side of the IP (single-arm 220 m), without and with a cut on ξ; a track in the RP detectors at 420 m distance on one side of the IP (single-arm 420 m); a track in the RP detectors at 220 m and 420 m distance (asymmetric); a track in the 420 m detectors at both sides of the IP (double-arm 420 m). Because the detectors at 220 m and 420 m have complementary coverage in ξ, the asymmetric condition in effect selects events with two tracks of very different ξ value, in which one track is seen at 220 m distance on one side of the IP and a second track is seen on the other side at 420 m. If not by the L1 trigger, these asymmetric events can be selected by the HLT and are thus of highest interest.

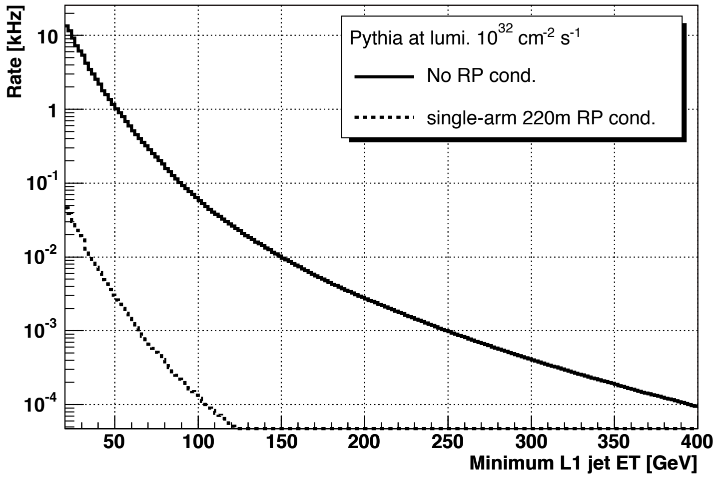

Figure 1: L1 rate for the QCD background at a luminosity of $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ as function of the L1 threshold value when at least 2 central L1 jets with E_T above threshold are required.

The reduction factors in Table 1 in the presence of pile-up were obtained by determining separately the probability per pile-up event to satisfy the relevant RP condition, which was then scaled by the average number of pile-up events at the luminosity in question. Details of this method can be found in [10]. A collimator located in front of the LHC magnet Q5, planned to be operative at higher luminosities, will have an effect on the acceptance of the RP detectors resembling that of a ξ cut. This effect has not been taken into account in Table 1.

TOTEM pursues the possibility of a ξ cut in the L1 trigger. The technical implementation and the resulting ξ resolution are being determined at the time of writing.

A further reduction of the QCD rate could be achieved with the help of a topological condition. The 2-jet system has to balance the total momentum component of the two protons along the beam axis. In signal events with asymmetric ξ values, the proton seen on one side in the RP detectors at 220 m distance is the one with the larger ξ and thus has lost more of its initial momentum component along the beam axis. Hence the jets tend to be located in the same η-hemisphere as the RP detectors that detect this proton. A trigger condition requiring that $[\eta^{jet1} + \eta^{jet2}] \times \mathrm{sign}(\eta^{220m\ RP}) > 0$ would reduce the QCD background by a factor 2, independent of pile-up, and with no loss in signal efficiency.

A reduction of the QCD rate to levels compatible with a L1 output target rate of $\mathcal{O}(1)$ kHz by including RP detectors at a distance of 220 m from the CMS IP thus appears feasible for luminosities up to $2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, as long as a ξ cut can be administered in the L1 trigger such that the accepted events can be restricted to the low ξ region. Higher luminosities would necessitate inclusion of the RP detectors at 420 m distance in the L1 trigger.

3.2 Other conditions

The effect of combining already foreseen L1 trigger conditions with conditions on the RP detectors is illustrated in Table 2. Single- and double-arm RP detector conditions are indicated with ‘s’ and ‘d’ endings, respectively. Entries marked with a ‘(c)’ indicate thresholds applicable if a cut on $\xi < 0.1$ is implemented for the RP detectors at 220 m. The jet E_T conditions consider all L1 jets with $\mid \eta \mid < 5$.

A further rate reduction by approximately a factor 2 can be obtained at luminosities for which pile-up is negligible

Table 2: Estimated E_T thresholds that result in a L1 output rate of ~ 1 kHz, for various conditions on central CMS detector quantities and on tracks seen in the RP detectors at 220 m and 420 m (see text).

L1 condition	L1 E_T [GeV] or p_T [GeV/c] threshold at $\mathcal{O}(1)$ kHz L1 output rate for luminosity [cm^{-2} s^{-1}]			
	1×10^{33}	2×10^{33}	5×10^{33}	1×10^{34}
1 Jet	115	135	160	190
2 Jet	90	105	130	150
1 Jet+220s	90	115	155	190
2 Jet+220s	65	90	125	150
1 Jet+220d	55	85	130	175
2 Jet+220d	30	60	100	140
1 Jet+220s(c)	70	90	150	185
2 Jet+220s(c)	60	70	115	145
1 Jet+220d(c)	30	65	110	155
2 Jet+220d(c)	20	45	85	125
1 Jet+420s	65	90	125	165
2 Jet+420s	45	70	100	130
1 Jet+420d	20	40	80	115
2 Jet+420d	< 10	30	60	90
1 μ+220s	12	16	23	> 100
1 μ+220d	4	9	17	80
1 μ+220s(c)	–	11	22	100
1 μ+220d(c)	–	6	13	30
1 μ+420s	7	11	14	37
1 μ+420d	< 2	4	7	14

by imposing a rough large rapidity gap cut in the L1 trigger. This was implemented by requiring that there be no forward jets, i.e. jets in the CMS HF, in either hemisphere in the event.

4 Level-1 Signal Efficiencies

Of the L1 conditions discussed so far, only those based on the RP detectors have a significant impact on the signal efficiency. Of further interest is the question how many signal events are being retained by the already foreseen CMS trigger streams, notably the muon trigger.

4.1 Central Exclusive Higgs Production ($H(120\text{GeV/c}^2) \rightarrow b\bar{b}$)

In order to study the effect of the L1 trigger selection on the Higgs signal, signal samples of 100,000 events with central exclusive production of a Higgs Boson were generated with the Monte Carlo programs EDDE [14] (version 1.1) and Exhume [15] (version 1.0).

Condition based on Roman Pot detectors

Figure 2 shows the L1 selection efficiency as a function of the E_T threshold values when at least 2 central L1 jets with E_T above threshold are required [10]. No pile-up is assumed since its effect on the efficiency curves is small. The plot on the left-hand side compares the efficiency curves obtained for EDDE and Exhume. For a threshold of 40 GeV per jet, Exhume and EDDE both yield an efficiency of about 20%. The plot on the right-hand side overlays the efficiency curves obtained with Exhume when either of four different RP detector conditions are combined with the L1 2-jet trigger: single-arm 220 m, single-arm 420 m, double-arm 420 m and the asymmetric 220 & 420 m condition. At an E_T threshold of 40 GeV per jet, the single-arm 220 m (420 m) condition results in an efficiency of the order 12% (15%), the double-arm 420 m condition in one of 8% and the asymmetric condition in one of 6%. This also means that, even without the possibility of including the RP detectors at 420 m from the CMS IP in the L1 trigger, 6% of the signal events can be triggered on with the single-arm 220 m condition, but will have a track also in the 420 m detectors that can be used in the HLT.

Condition based on Muons

An alternative trigger strategy is to exploit the relatively muon-rich final state from B-decays: about 20% of the

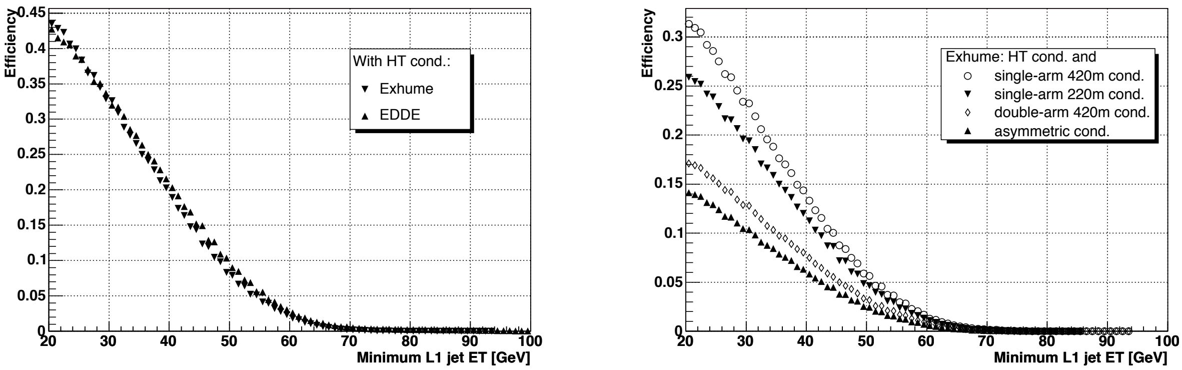

Figure 2: L1 selection efficiency for $pp \rightarrow pHp$ and $H(120\text{GeV/c}^2) \rightarrow b\bar{b}$ as function of the E_T threshold value when at least 2 central L1 jets with E_T above threshold are required. All plots are for the non-pile-up case and the H_T condition (see text) has been applied. Left: Comparison between the EDDE and Exhume Monte Carlo generators, without applying any additional RP conditions. Right: Comparison of the effect of different RP conditions on the efficiency in the Exhume Monte Carlo sample.

events have at least a muon in the final state. A number of conditions have been studied [11]. All rates are quoted at a luminosity of 10^{33} cm^{-2} s^{-1}:

- At least 1 muon. This was studied as a function of the L1 threshold on the muon p_T. A p_T threshold of 14 GeV/c corresponds to an efficiency of 6% at a rate of approximately 2 kHz.
- At least 2 muons. This was studied as a function of the L1 threshold applied on the lower p_T muon. A p_T threshold of 3 GeV/c, as in the CMS DAQ-TDR [19], gives an efficiency of 2% and a rate of approximately 1.5 kHz.
- At least 1 muon and 1 jet, the latter with $E_T > 40$ GeV. This condition is not yet forseen in the CMS trigger tables. For a muon p_T threshold of 3 GeV/c, the rate is slightly less than 3 kHz, with a signal efficiency of 9%.

In summary, about 20% of the $H \rightarrow b\bar{b}$ events have a muon in the final state. Of these, about half can be triggered on by implementing a 1 muon + 1 jet trigger with thresholds of 3 GeV/c on the muon p_T and 40 GeV on the jet E_T. The rate would then be approximately 3 kHz at a luminosity of 10^{33} cm^{-2} s^{-1}; no condition on the forward detectors is assumed. Other conditions have been looked at: 3 muons, 2 muons + jets, 1 muon +2 or 3 jets, but they do not contribute significant extra signal efficiency.

4.2 Central Exclusive Higgs Production ($H(140\text{GeV/c}^2) \rightarrow WW$)

Here we limit ourselves to a few remarks on the L1 selection efficiency. For SM Higgs masses above 120 GeV/c^2, the $H \rightarrow WW$ branching ratio becomes sizable; in this case the final state contains high-p_T leptons that can be used for triggering.

Efficiencies are in general high [11]. About 23% of the events have at least one muon in the final state. Approximately 70% of these (i.e. 16%) are retained by requiring at least one muon with a p_T threshold of 14 GeV/c. An extra $\approx 10\%$ (i.e. 2%) would be retained by implementing the muon/jet slot discussed above with thresholds of 3 GeV/c on the muon p_T and 40 GeV on the jet E_T.

4.3 Single-diffractive Processes

We have focussed so far on DPE processes; they constitute only a small part of the diffractive cross section that can be explored by CMS and TOTEM. Hard single-diffractive (SD) processes, $pp \rightarrow pX$, where only one proton remains intact and the other is diffractively excited into a state X that contains a vector boson, high-E_T jets or heavy quarks give access to the low-x structure of the proton in terms of the dPDFs introduced earlier. In combination with the DPE events, hard SD events also give information on the hard diffractive factorisation breaking at the LHC – i.e. to the rapidity gap survival probability, in turn related to multiple scattering effects.

In order to study the efficiency of the CMS trigger for hard SD events, samples of 100,000 events each of SD production of dijets ($p_T > 10$ GeV/c) and of Z and W bosons that decay into anything or that decay into final states with muons were generated with the Pomwig Monte Carlo generator [16]. No gap suppression factor was applied.

Figures 3, 4 and 7 show the efficiency for SD production of W and Z bosons and of dijets as a function of the L1 threshold value when at least one (left) or two (right) L1 jets with E_T above threshold are required [10]. All L1 jets with $|\eta| < 5$ were considered. The values of the efficiency for L1 threshold $\rightarrow 0$ reflect the W and Z branching ratios to jets for events where for the diffractively scattered proton $0.001 < \xi < 0.2$ holds.

Figures 5 and 6 show the efficiency for decays with a muon in the final state as a function of the L1 threshold value when at least one L1 muon with p_T above threshold is required. The efficiency is normalized to the number of events with final states that contain at least a muon and where for the diffractively scattered proton $0.001 < \xi < 0.2$ holds.

Efficiencies are given for three different trigger conditions: trigger on central detector quantities alone (i), trigger on central detector quantities in conjunction (ii) with the single-arm 220 m condition, and (iii) with the single-arm 420 m condition. Also shown are the number of events expected to pass the L1 selection per pb $^{-1}$ of LHC running. In all cases, the efficiencies are shown separately for the Pomeron-only and Reggeon-only contributions. The former dominates for values of ξ lower than about 3%. The Reggeon component is cut out by the requirement of a track in the 420 m detectors. Conversely, a significant fraction of both Pomeron and Reggeon events is retained if a track is required in the 220 m RP detectors.

In all cases, even for rather hard cuts, the yield for SD W, Z and dijet production is very large.

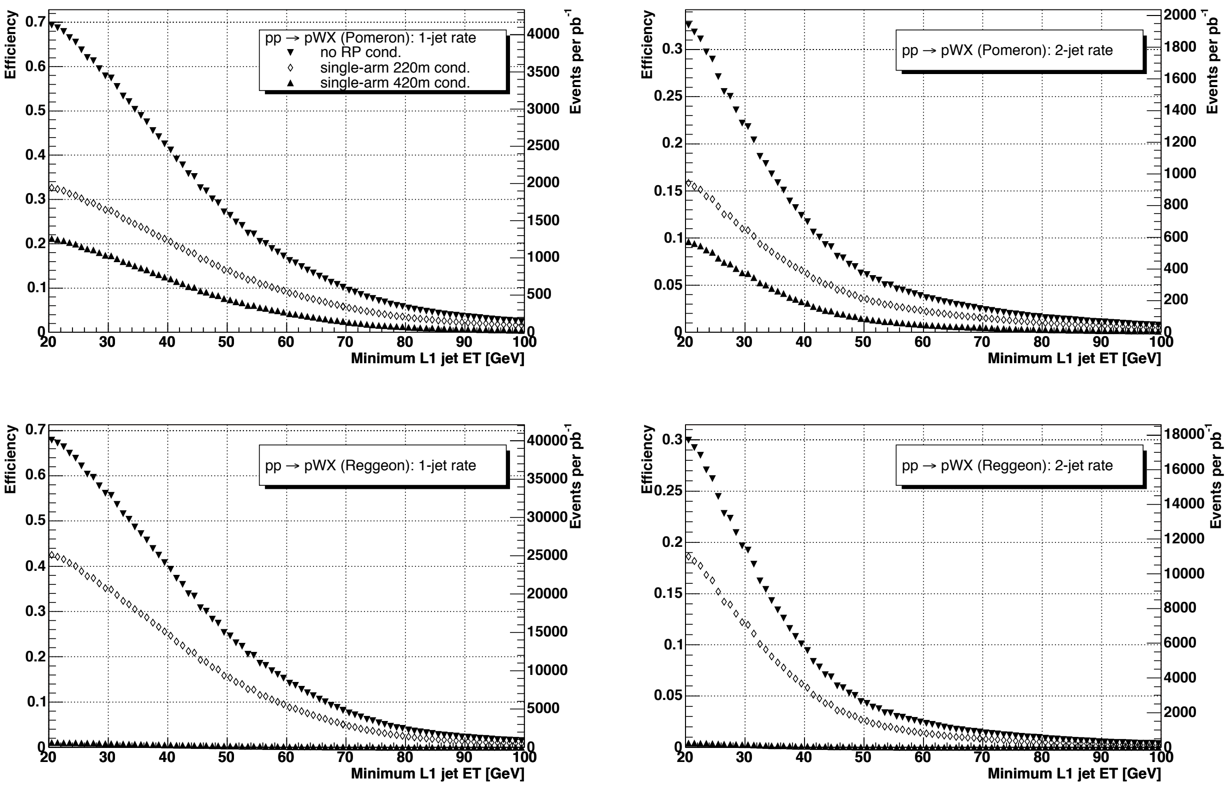

Figure 3: L1 selection efficiency for $pp \rightarrow pWX$ as function of the E_T threshold value when at least 1 (left) or 2 (right) L1 jets with E_T above threshold are required, in conjunction with RP detector conditions. All plots are for the non-pile-up case. The upper (lower) 2 plots pertain to W production mediated by single Pomeron (Reggeon) exchange.

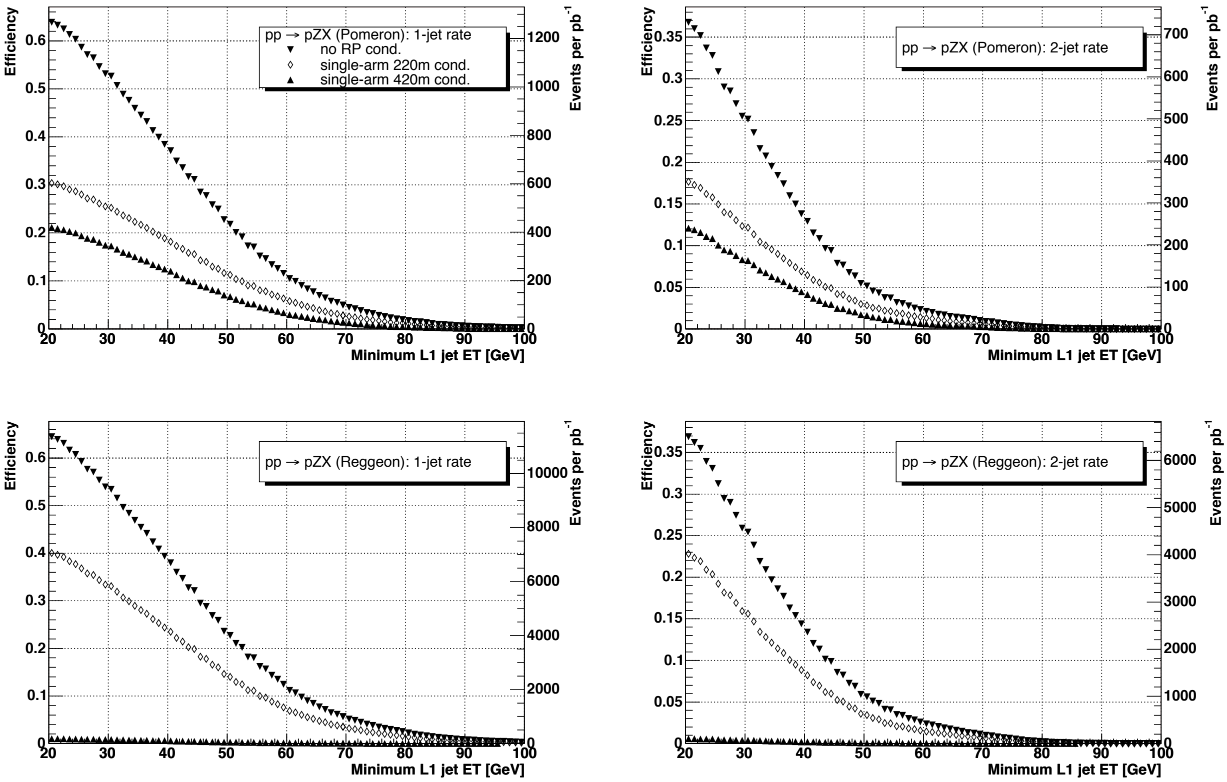

Figure 4: L1 selection efficiency for $pp \to pZX$ as function of the E_T threshold value when at least 1 (left) or 2 (right) L1 jets with E_T above threshold are required, in conjunction with RP detector conditions. All plots are for the non-pile-up case. The upper (lower) 2 plots pertain to Z production mediated by single Pomeron (Reggeon) exchange.

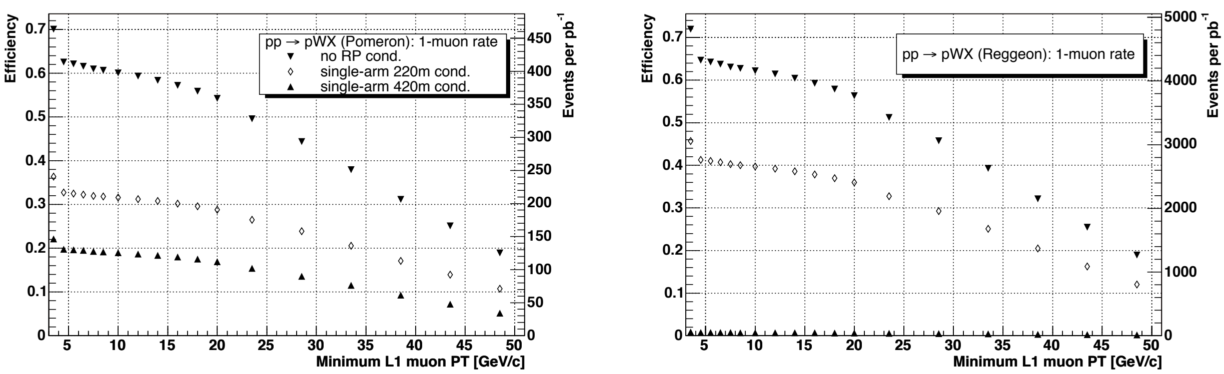

Figure 5: L1 selection efficiency for $pp \to pWX$, where the W decays with a muon in the final state, as function of the p_T threshold value when at least 1 L1 muon with p_T above threshold is required, in conjunction with RP detector conditions. All plots are for the non-pile-up case. The left (right) plot pertains to W production mediated by single Pomeron (Reggeon) exchange.

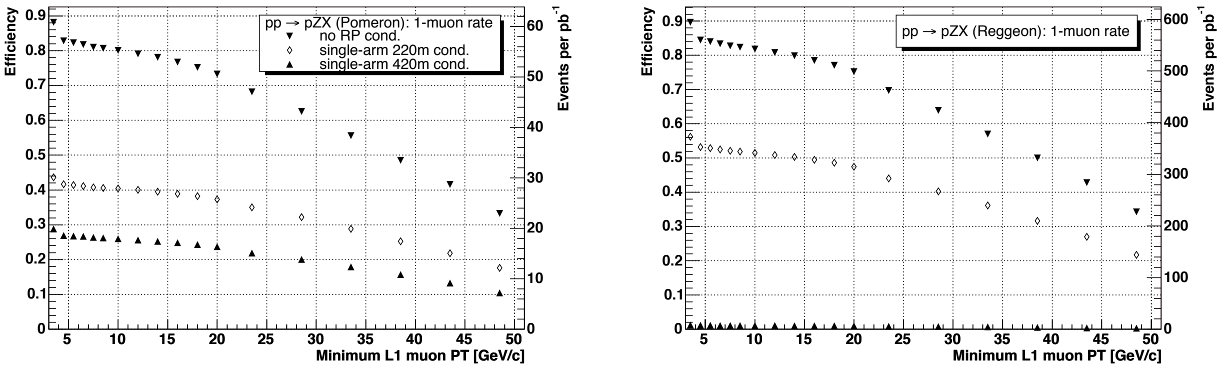

Figure 6: L1 selection efficiency for $pp \to pZX$, where the Z decays into muons, as function of the p_T threshold value when at least 1 L1 muon with p_T above threshold is required, in conjunction with RP detector conditions. All plots are for the non-pile-up case. The left (right) plot pertains to Z production mediated by single Pomeron (Reggeon) exchange.

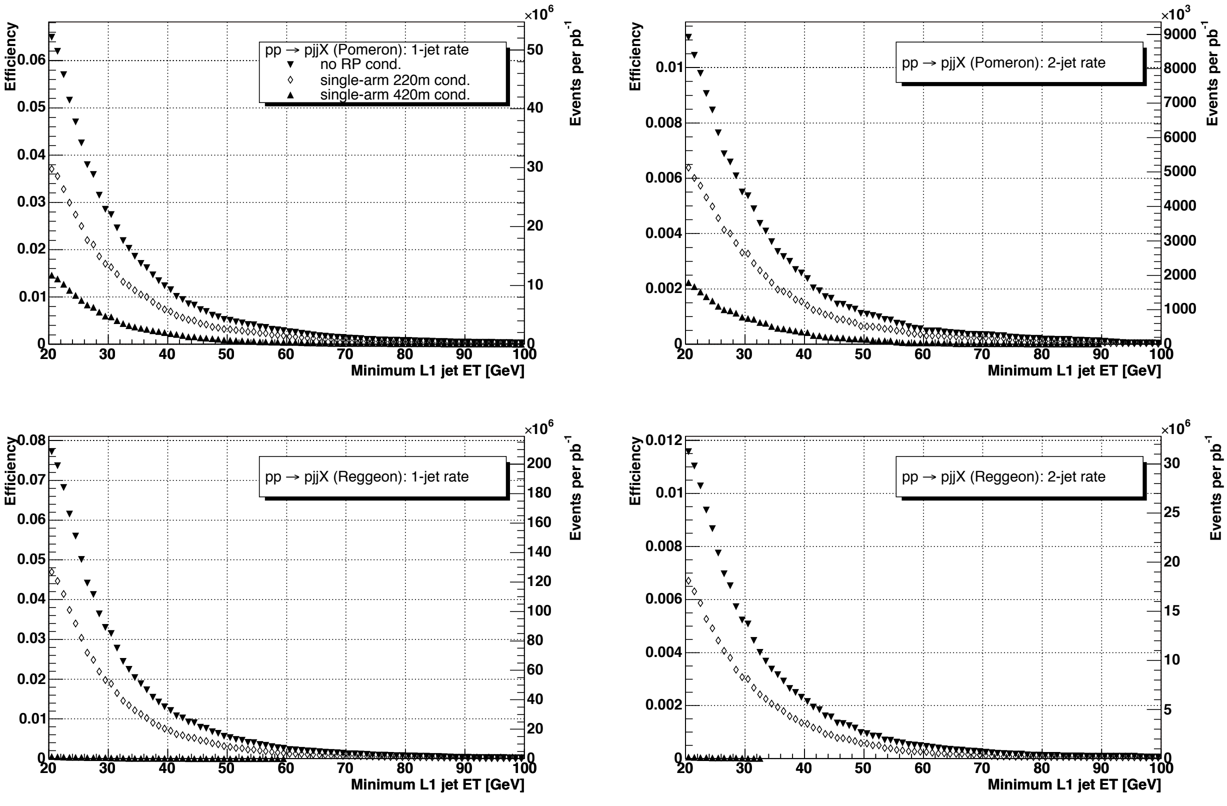

Figure 7: L1 selection efficiency for $pp \to pjjX$ as function of the E_T threshold value when at least 1 (left) or 2 (right) L1 jets with E_T above threshold are required, in conjunction with RP detector conditions. All plots are for the non-pile-up case. The upper (lower) 2 plots pertain to dijet production mediated by single Pomeron (Reggeon) exchange.

5 Effect of pile-up, beam-halo and beam-gas backgrounds

Pile-up effects are included in all rate and efficiency studies presented. In the 220 m stations, 0.055 protons/pile-up event are expected on average, in the 420 m stations, 0.012 protons/pile-up event. At a luminosity of 10^{34} cm^{-2} s^{-1}, there are 35 pile-up events on average; this entails, on average, 2 extra tracks in the 220 m stations and less than one in the 420 m stations.

The effect from beam-halo and beam-gas events on the L1 rate is not yet included in the studies discussed here. Preliminary estimates [17] suggest that they are chiefly a concern for any trigger condition based solely on the forward detectors. For any trigger condition that includes a requirement on central CMS detector quantities the size of their contribution is such that they do not lead to a significant increase of the L1 output rate.

6 HLT strategies

Jets are reconstructed at the HLT with an iterative cone ($R < 0.5$) algorithm. The L1 selection cuts are repeated with HLT quantities. The following conditions are imposed [10]:

A The event pass the single-arm 220 m L1 condition with $\xi < 0.1$ cut. As demonstrated in Table 1, this condition reduces the L1 output rate to below $\mathcal{O}(1)$ kHz. Additional rate reduction factors of ~ 300 (~ 1000) at $1(2) \times 10^{33}$ cm^{-2} s^{-1} are needed to reach the HLT target output rate of $\mathcal{O}(1)$ Hz.

B The two jets are back-to-back in the azimuthal angle ϕ ($2.8 < \Delta\phi < 3.48$ rad), and have $(E_T^1 - E_T^2)/(E_T^1 + E_T^2) < 0.4$, and $E_T > 40$ GeV for each jet.

C The proton fractional momentum loss ξ is evaluated with the help of calorimeter quantities [20]:

$$\xi_{+-} = (1/\sqrt{s})\Sigma_i E_{Ti} \exp{(\mp\eta_i)}, \tag{1}$$

where the sum runs over the two jets and the $+, -$ signs denote the two hemispheres. The result is compared with the ξ value measured by the RP detectors. At present, no simulation of the RP reconstruction is available. As estimate of the ξ resolution, 15% (10%) is assumed at 220 m (420 m) [18]. Events are rejected if the difference between the two values of ξ is larger than 2 σ.

D At least one of the two jets is b-tagged.

E A proton is seen at 420 m.

The case without pile-up presents no difficulty: essentially no QCD background events survive the selection. If conditions A+B+C are applied, the signal efficiency for $pp \to pHp$ with $H(120\text{GeV/c}^2) \to b\bar{b}$ is at 11% essentially unchanged with respect to the L1 selection, but the HLT output rate exceeds the target output rate, see Table 3. If b-tagging is required but no ξ matching (conditions A+B+D), the efficiency drops to 7%, without any improvement in the rate reduction. The combination of conditions A+B+C+E finally leads to the targeted HLT output rate of $\mathcal{O}(1)$ Hz, without any loss in signal efficiency compared to L1.

Table 3: Results of HLT selection.

HLT selection condition	A+B+C	A+B+D	A+B+C+E
HLT rate at 1×10^{33} cm^{-2} s^{-1}	15 Hz	20 Hz	< 1 Hz
HLT rate at 2×10^{33} cm^{-2} s^{-1}	60 Hz	80 Hz	1 Hz
Signal eff. $H(120)$GeV/c^2) $\to bb$	11%	7%	6 %

7 Summary

We showed the potential for diffractive physics of combining trigger conditions based on the CMS central detector with information from detectors further downstream of the IP, notably from the detectors planned for TOTEM at distances up to 220 m, and from possible additional detectors at 420 m distance.

The default CMS dijet trigger thresholds can be lowered substantially, to $E_T > 40$ GeV for each jet, when in addition a proton candidate is required in the RP detectors at 220 m. At the HLT, conditions can be used that are based on the match between the invariant mass produced in the interaction as calculated from the jets in the central CMS detector and as calculated from the fractional momentum loss, ξ, of the detected proton candidates in the Roman Pot detectors.

A dedicated diffractive trigger stream hence is found feasible, with output rates of $\mathcal{O}(1)$ kHz on L1 and $\mathcal{O}(1)$ Hz on the HLT.

We showed the efficacy of this dedicated diffractive trigger stream for selecting central exclusive production, a potential discovery channel for a Higgs Boson with mass close to the current exclusion limit. In addition, we discussed the efficacy of the foreseen CMS-only trigger conditions for hard single-diffractive processes.

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