

Trigger Strategies for SUSY Searches at the LHC

Antonella De Santo (for the ATLAS and the CMS collaborations)^a

Royal Holloway, University of London, Egham Hill, Egham, Surrey, TW20 0EX, UK

Abstract. Supersymmetry will be searched for in a variety of final states at the LHC. It is crucial that a robust, efficient and unbiased trigger selection for SUSY is implemented from the very early days of data taking. After a brief description of the ATLAS and the CMS trigger systems, and a more in-depth discussion of the ATLAS High-Level Trigger, a triggering strategy is outlined for early SUSY searches at the LHC.

PACS. PACS-key ATLAS – PACS-key CMS – PACS-key SUSY – PACS-key High-Level Trigger

1 Introduction

With the LHC start up next year, the largely unexplored domain of multi-TeV scale physics will finally become accessible experimentally at a collider. It is widely believed that both ATLAS and CMS will observe new physics beyond the Standard Model (SM), and supersymmetry (SUSY) is certainly one of the theoretically favoured SM extensions. Appealing features of SUSY are the fact that it provides natural cancellations to the higher mass corrections to the Higgs mass, that it unifies the electroweak and the strong force at the GUT scale, and that it provides a good dark matter candidate.

The SUSY cross-section at LHC energies is dominated by gluino and squark pair production, whose decay will typically give rise to multi-jet, high-pt final states. Moreover, in R-parity conserving models, due to the escaping LSP (Lightest Supersymmetric Particle), SUSY states will be characterized by a large energy imbalance in the plane transverse to the beam direction (large “missing ET”, or MET). Often one or more isolated leptons, from the decay of intermediate particles in the decay chain, will also be present in the final state.

Rare new physics processes, including SUSY ones, will have to be discriminated against a very large background of SM events. A sophisticated online system is hence required to apply fast and reliable signature-based selection algorithms, which must in turn deliver the required efficiency without introducing significant biases to the data written “on tape”.

ATLAS[1] and CMS[2] have both developed highly complex trigger systems which, despite the significant differences in their architectures, perform rather similarly and give comparable output rates and efficiencies. In the following, the underlying design of both systems, with particular reference to the ATLAS High-Level Trigger (HLT), is discussed, and a strategy is

described to select SUSY events online. Preliminary simulation-based results for relevant trigger menus at “initial” luminosity ($L = 10^{31-32} \text{ cm}^{-2} \text{ s}^{-1}$) are also given.

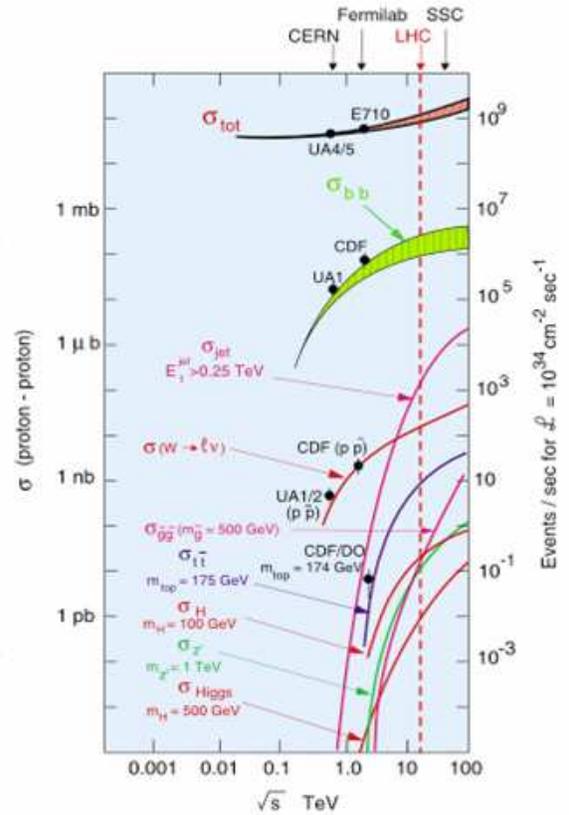


Fig. 1. Cross-sections vs. centre-of-mass energy for proton-proton interactions. Rates at $L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ are also given.

^a Email:antonella.de-santo@rhul.ac.uk

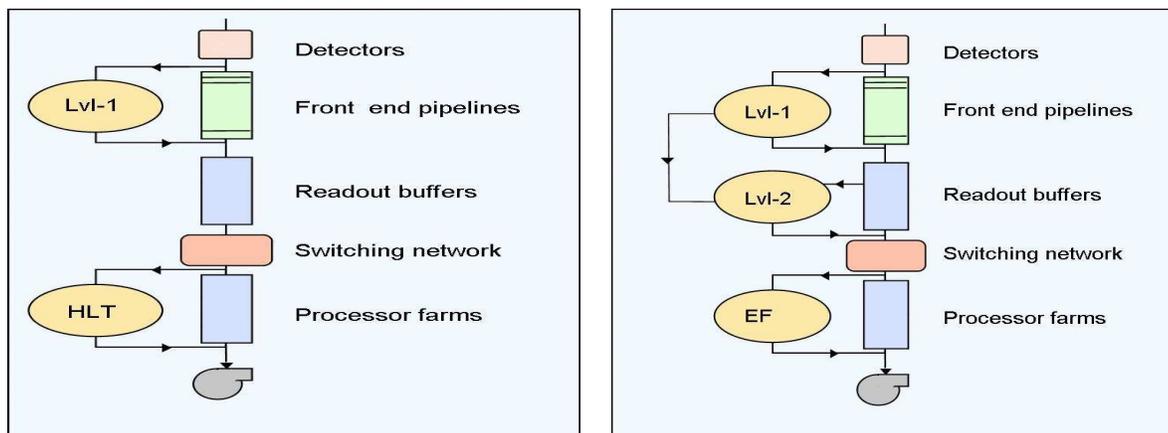


Fig. 2. Schematics of the CMS (left) and the ATLAS (right) trigger architectures.

2 The ATLAS and the CMS Trigger Systems

Typical cross-sections for different processes in proton-proton interactions, as well as the corresponding event rates at nominal “high” luminosity ($L = 10^{34} \text{cm}^{-2} \text{s}^{-1}$), are shown in Fig.1 as a function of the centre-of-mass energy. The total cross-section at 14 TeV ($O(110 \text{ mb})$) is largely dominated by soft inelastic pp interactions (“minimum bias”, or MB; $\sigma_{MB} \sim 80 \text{ mb}$), which give rise to a high-rate ($O(10^9 \text{ Hz})$ at high L) of events with low- p_T particles in the final state. At high luminosity, on average 23 MB events will be superimposed to any interesting high- p_T interaction, such as for example leptonic decays of the Z or the W bosons. However, while it will be relatively easy to separate between MB events and generic hard scatters, enriching the high- p_T sample online with rare processes such as gluino pair production, or even leptonic decays of the Higgs, will not be as straightforward. To achieve that, both ATLAS and CMS will rely on their trigger system’s capability to apply fast algorithms to signals from their calorimeters and muon detectors, and to select events with leptons, jets and large MET in the final state.

The LHC 25 ns bunch crossing determines the trigger input rate of 40 MHz, which has to be reduced to a more manageable $\sim 100 \text{ Hz}$ of interesting physics events to be kept on permanent storage. With an average event size of 1-2 Mbytes, this corresponds to about 1-2 PByte worth of data to be recorded each year.

In both experiments the required selection capabilities of the trigger are achieved via consecutive decision stages. A schematic representation of the trigger architectures for the two experiments is given in Fig.2. Both ATLAS and CMS have a hardware-based “Level-1” (Lvl-1) trigger, while further selections are performed at software level in the successive stage of the so-called High-Level Trigger (HLT). In the case of CMS, this consists of just one extra trigger level, while in the case of ATLAS the HLT is further subdivided into “Level-2” (Lvl-2) and “Event Filter” (EF).

In the hardware-based Lvl-1 trigger of both ATLAS and CMS, high-speed pipelined front-end elec-

tronics, custom-made for the experiments, gets access to coarse granularity information from the calorimeters and the muon system, and then runs simple selection algorithms to make decisions about the events. This is done synchronously with the machine bunch crossing, with a latency time of $2.5 \mu\text{s}$ and $3.2 \mu\text{s}$ for ATLAS and CMS respectively. The reduction factor that the Lvl-1 must achieve within this time is of ~ 400 for both experiments. This brings the input rate for the second stage of the trigger down to $\sim 100 \text{ kHz}$.

The HLT, which in both cases is implemented using farms of fast commercial processors running sophisticated reconstruction algorithms, has a very different architecture for ATLAS and CMS. While in CMS the full event is available at the HLT input, the ATLAS trigger is so designed that on average the Lvl-2 only needs to access a fraction ($< 10\%$) of the total event. This greatly reduces the requirements on the available bandwidth for ATLAS at that stage of the selection. A description of the ATLAS HLT is given below, while details of the CMS HLT are discussed elsewhere in these conference proceedings [3].

2.1 The ATLAS High-Level Trigger

In ATLAS, the Lvl-2 and EF trigger levels are collectively known as the HLT. The overall necessary $\sim 10^3$ reduction factor in the rate, from the $O(100 \text{ kHz})$ at the Lvl-2 input to the final $O(100 \text{ Hz})$ at the EF output, is achieved in two steps. A first suppression factor (~ 100) is provided by the Lvl-2, bringing the EF input rate down to $O(1 \text{ kHz})$, while the extra factor of ~ 10 comes from the EF itself. For an 8 GHz processor, the Lvl-2 and EF processing times are $\sim 10 \text{ ms}$ and $\sim 1 \text{ s}$ respectively.

The way ATLAS can achieve the required trigger performance by using a smaller bandwidth than CMS is by implementing the concept of the so-called “Regions-of-Interest” (RoI), which are built at Lvl-1 and then passed on to Lvl-2 for further analysis, if the event survives the Lvl-1 selection. If the event also passes the Lvl-2 selection, the full event is then built and transferred to the EF for processing.

The basic idea is to use a “seeded” and “step-wise” selection strategy, which makes it possible to accomplish early rejection of uninteresting events with minimal amount of processing. In practice, based on coarse detector granularity, the Lvl-1 processor constructs objects in the calorimeters and in the muon system which are then analysed under a specific trigger hypothesis. For example, the properties of a cluster in the electromagnetic calorimeter would be tested to verify whether or not they are compatible with those of an electromagnetic shower. If they are, the coarsely reconstructed cluster will “seed” the building of an RoI, which is then passed on to the following trigger level. At Lvl-2, full detector granularity as well as tracking information are accessible within the RoI. This, in the example above, would allow the Lvl-2 algorithms to check whether an inner detector track could be matched to the seed cluster found at Lvl-1. As a consequence, discrimination between electrons and photons becomes possible at Lvl-2. Events surviving the Lvl-2 selection criteria are then passed on to the EF, which also has access to tracking information and to full detector granularity, now for the full event. As the EF can use significantly more time than the Lvl-2 to analyze each event, it can also use slower but more refined reconstruction algorithms. Therefore, while dedicated fast “online” algorithms are run at Lvl-2, the EF uses a reconstruction that is close to that used for “offline” analysis. Based on the outcome of the EF selection, a final decision is made as to whether to transfer the current event on to permanent storage, or whether to discard it irreversibly instead.

From the above it is clear that the ATLAS HLT is a highly flexible system, where it is relatively straightforward to combine single trigger hypotheses into more complex trigger menus needed for physics analysis. This feature is particularly useful in the case of SUSY triggers, for which it will be possible to rely on a very rich phenomenology to devise a redundant and efficient selection strategy.

3 SUSY Triggers in ATLAS and CMS

Because it is not possible to anticipate which specific supersymmetric model is actually realised in Nature, if any, the overall strategy for SUSY searches at the LHC will have to be as generic as technically feasible, encompassing the maximum number of experimentally observable signatures. This is even more true for the trigger than it is for the offline analysis, as events lost at trigger level are lost forever. No later improvements in the selection techniques or in the reconstruction can help recover them, if they have not been permanently saved to storage at the online stage.

A variety of studies have been developed in both ATLAS and CMS to understand the triggering issues of more “exotic” SUSY signatures, such as non-pointing photons in GMSB models, or highly ionizing muon-like signals from R-hadrons. Some of these aspects have been discussed elsewhere in these conference proceedings [4], [5]. In this paper, however, the focus will be

on the more typical SUSY signatures from mSUGRA motivated R-parity conserving models: high- p_T multi-jets, large MET, and possibly one or more leptons in the final state.

It is very important to realize that, among the classic SUSY signatures mentioned above, some will be more robust than others. For the very early stages of data taking, particular care will have to be paid not to rely too heavily on quantities that may take significant time to be correctly understood, and may therefore initially introduce significant biases in the data. For example, experience from past and current experiments at hadron colliders suggests that the reconstruction of the MET variable takes significantly more time than others to become established. Several instrumental effects can contribute to overestimate the high-end tail of the MET distribution, which is where a SUSY signal would typically be expected to be observed. Moreover, as MET is a very good variable to discriminate between SUSY events and SM backgrounds, it is crucial that unbiased samples are collected, where MET can be used in the offline analysis to define the boundaries between control and signal regions. All of the above strongly suggests the need to de-emphasize the use of MET triggers in the early days of data taking, when the low luminosity will allow low-threshold jet triggers with affordable rates. For the same reasons, also at $L = 10^{33} \text{cm}^{-2} \text{s}^{-1}$ it will be important to keep the MET threshold as low as possible. Similarly, and again for the sake of systematic studies at the analysis phase, too tight criteria for the selection of leptons should also be avoided at trigger level.

The LHC will not reach its design luminosity for quite some time after the start up, and even “low” values of L (in the range of $10^{33} \text{cm}^{-2} \text{s}^{-1}$) will not be accessible in the early stages of the data taking. For this reason both ATLAS and CMS are developing lists of trigger menus especially conceived for “early data” scenarios, assuming “initial” benchmark luminosities of $10^{31-32} \text{cm}^{-2} \text{s}^{-1}$. Although the list of available triggers is likely to change over time, to adapt to the changing experimental conditions, and potentially to cope with higher-than-expected trigger rates, it is very important that well defined triggering strategies are in place ahead of the start of the data-taking. This will ensure that interesting events can be selected efficiently without exceeding the total rate budget available at each trigger level.

As an example, a list of trigger rates is given in Tab.1 [6] for a choice of HLT trigger paths from the CMS experiment, for an assumed initial luminosity of $10^{32} \text{cm}^{-2} \text{s}^{-1}$. All trigger signatures in the table are relevant for SUSY searches. As it is apparent from these rate figures, provided that sufficiently high thresholds are used to apply cuts on particle p_T values and on global event variables such as MET, acceptably low rates (O(10 Hz) or less) can be achieved for each trigger menu.

ATLAS uses a very similar trigger strategy for early physics running. Trigger menus are in place for a luminosity of $10^{31} \text{cm}^{-2} \text{s}^{-1}$ and new ones are being devel-

Table 1. CMS HLT rates at $L = 10^{32} \text{cm}^{-2} \text{s}^{-1}$ for some of the trigger menus relevant for SUSY searches [6]. The numbers in the second column give the p_T thresholds for the corresponding object in the trigger menu. The total CMS HLT expected output at this luminosity is ~ 150 Hz.

HLT path	p_T and MET threshold(s) (GeV)	Rate (Hz)
1-jet	200	9.3 ± 0.1
2-jets	150	10.6 ± 0.0
3-jets	85	7.5 ± 0.1
4-jets	60	3.9 ± 0.1
MET	65	4.9 ± 0.7
1-jet+MET	(180, 60)	2.2 ± 0.1
2-jets+MET	(125, 60)	1.0 ± 0.0
3-jets+MET	(60, 60)	0.6 ± 0.0
4-jets+MET	(35, 60)	1.2 ± 0.1
e +jet	(12, 40)	11.6 ± 1.2
μ +jet	(7, 40)	6.3 ± 0.7

oped for $10^{32} \text{cm}^{-2} \text{s}^{-1}$. In the current ATLAS framework, initial trigger selections of SUSY events are mostly based on Lvl-1 menus. These achieve adequately low trigger rates, provided that appropriate p_T and energy thresholds are chosen for the selection. For example, at $10^{31} \text{cm}^{-2} \text{s}^{-1}$, using the same notation as in Tab.1, single trigger menus like “1-jet” or “ e +MET” both have rates of ~ 10 Hz, for p_T and (p_T, MET) thresholds of 100 GeV and (20, 15) GeV respectively.

In ATLAS, to evaluate the trigger performance on SUSY events, the trigger efficiency has been calculated at each step for a number of offline SUSY analyses, and in particular those for the inclusive channels. The trigger efficiency has been normalized at each stage to the number of events surviving the SUSY selection at that level. Typically, for the $10^{31} \text{cm}^{-2} \text{s}^{-1}$ menus, standard jet triggers achieve efficiencies very close to 95 – 100% in a large fraction of the cosmologically relevant part of the mSUGRA parameter space, with the efficiency being higher for high-jet multiplicities and at higher-mass SUSY points. The effect of jet trigger rate uncertainties has also been studied in ATLAS. If the jet rates were significantly higher than expected, the jet p_T thresholds would have to be increased considerably to keep the rates at an acceptable level. Preliminary studies show that, should that be the case, SUSY events would still be selected with high efficiency.

4 Conclusions

Supersymmetry is one of the most appealing models of new physics to be searched for at the LHC. If SUSY exists, and it is accessible at LHC energies, the richness of its phenomenology can be used to devise redundant trigger menus that can be used to extract a significant supersymmetric signal from the dominant SM background. The performance of the trigger will be a

crucial element of the analysis flow, and it is essential that the system is capable to select SUSY events in a manner that is both efficient and bias-free. ATLAS and CMS both have very sophisticated trigger systems, which have been shown to perform adequately for the stated purpose.

References

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