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Triggers for New Physics in ATLAS and CMS

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Summary. — The large rate of inelastic collisions expected at the LHC is a challenge for the trigger systems of the ATLAS and CMS experiments. The strategies adopted to trigger on new physics signals are shown, with special focus on supersymmetric events, very high-p_T objects and heavy stable charged particles.

PACS 12.60.-i – Models beyond the standard model.
PACS 14.80.-j – Other particles (including hypothetical).

1. – The trigger challenge

The rate of inelastic collisions expected at the Large Hadron Collider (LHC) is 10^9 Hz at the design luminosity ($10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$) and energy (14 TeV), but new physics is expected to occur at a much lower rate. The trigger systems of the LHC experiments must select in an efficient way 200 Hz of the most interesting physics events out of the GHz of other interactions produced by the LHC. A good efficiency is necessary, since events lost at trigger level can never be recovered, and biasing of selected samples must be avoided.

In ATLAS [1], a three-level trigger has been designed. The Level-1 Trigger (L1) is hardware based. The information collected by the Calorimeters and the Muon Systems is used to reconstruct in a fast way trigger primitives with a coarse resolution. The L2 trigger is based on 500 CPU's which can access 10% of the event data, according to trigger candidates given by L1 to be used as seeds. The L3(HLT) trigger is based on 2000 CPU's (Event Filter), running off-line quality algorithms with a time budget of 4 seconds. The selected events are finally stored for off-line analysis.

The CMS [2] trigger system is organized in two levels only: a hardware-based L1 Trigger, based on coarse resolution objects reconstructed using the Calorimeter and the Muon System information, and a High Level Trigger (HLT). The HLT is based on 2000 CPU's which have access to the whole event information passed on by the L1.

The first runs of the LHC machine will be devoted to the commissioning of the accelerator and of the detectors, and to early physics studies on Standard Model processes.

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TABLE I. – *ATLAS HLT triggers and expected rates for* $1 \times 10^{31}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ *luminosity.*

Trigger item	e12	2e5	g20	tau60	tau25i_XE30	MU10
Rate (Hz)	19	7	7	10	3.5	18
Trigger Item	2MU4	e10_MU6	J120	4J23	2b23	
Rate (Hz)	2.3	0.5	9	7	3	

The initial luminosity will be very low, of the order of $8 \times 10^{29}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, and will be gradually increased when the performance of the machine is proved to be stable. The trigger tables designed by the experiments for the start-up phase are very simple, based essentially on single objects, with very low thresholds applied on their p_T. Table I [3] shows an example of a trigger table for $1 \times 10^{31}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ luminosity for the ATLAS experiment. In this table, e12 means single electron trigger with a threshold of 12 GeV/c, 2e5 means double electron trigger with a threshold of 5 GeV/c, tau25i_XE30 means a cross trigger with an isolated tau of 25 GeV/c threshold plus missing transverse energy (MET) with a threshold of 30 GeV. The other triggers are g20 for a photon with a threshold of 20 GeV/c, MU for muons, J for jets, b for b-jets.

When the luminosity increases, new conditions must be applied to the trigger definitions to keep the rates at acceptable levels. Prescales can be applied to the triggers with the lowest thresholds. Searches for new physics cannot rely on prescaled triggers, but soft events useful for monitoring or calibration can be collected. Higher threshold triggers can be defined in order to keep the rate low without any prescale. Since they cut away an entire range of spectrum of interesting physics, the topologies of the expected signals can be exploited to lower the rate of the collected events keeping low thresholds: conditions such as b-tagging or lepton isolation can be used, or events characterized by objects of different type in the final states could be selected using cross-triggers.

2. – Triggers for supersymmetry

Supersymmetry events in collider experiments are characterized by final states containing jets, MET and possibly leptons. Triggers based on MET are largely efficient, due to the presence in supersymmetric events of the lightest supersymmetric particle escaping the detector. An ATLAS study [3] shows, for a luminosity of $1 \times 10^{31}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, an efficiency of more than 98% for a trigger requiring a single jet with $p_T > 70$ GeV/c and $MET > 70$ GeV for all the models considered and for analyses performed with jets+MET, with or without leptons.

In spite of its high efficiency, we know from past experiments that MET can be an experimental observable difficult to commission in a hadronic collider. Instead, the experiments are developing methods based on alternative to MET observables, that could be more reliable in the start-up phase. The CMS experiment defines the HT as the scalar of the vectorial sum of the jets passing a given threshold. The missing HT (MHT) is defined as the scalar sum of the p_T of all the jets in the event passing a given threshold. These objects are more robust against noise effects or pileup since the threshold of the jets can be adjusted above the level of the noise. A CMS analysis on simulated ADD monojet signals [4] shows that, if needed, it is possible to adjust the threshold of the jets up to 60 GeV with an efficiency greater than 75% for the signal, as shown in fig. 1.

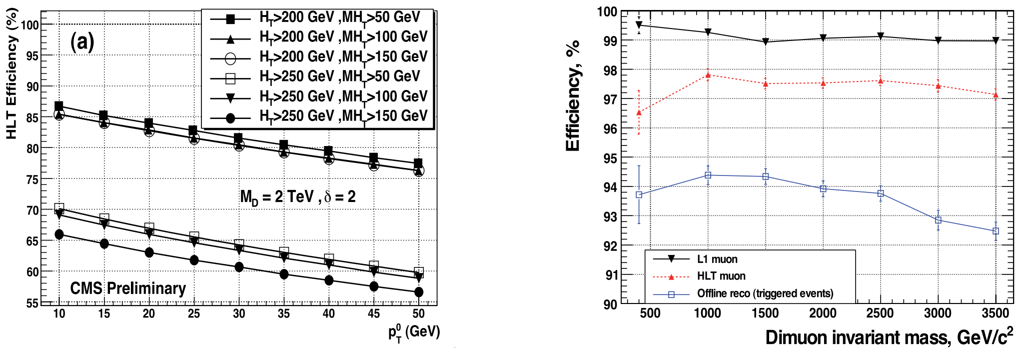

Fig. 1. – Left: HLT efficiency as a function of the jet thresholds for various cuts of HT and MHT in a ADD monojet CMS analysis. Right: L1, HLT and reconstruction efficiency as a function of the dimuon invariant mass in a RS graviton CMS analysis.

3. – Triggers for very high-p_T objects

Heavy objects decaying to very high-p_T leptons can be produced at LHC according to many New Physics models. The standard lepton triggers are usually well efficient for this kind of events.

Figure 1 shows the L1, HLT and reconstruction efficiencies as a function of the dimuon invariant mass for an RS graviton CMS analysis [5]. The trigger table refers to a luminosity of $1 \times 10^{32}\,\text{cm}^{-2}\,\text{s}^{-1}$. The HLT efficiency is larger than 96% for dimuon mass greater than $500\,\text{GeV}/c^2$, but a loss can be observed with respect to the L1 efficiency. This loss is due to high-p_T muons showering in the muon chambers, causing a failure in the track reconstructions performed by the CMS HLT algorithms. New ideas are being tested by the experiments to recover efficiency also for very high-p_T muons: a dedicated algorithm being investigated by CMS exploits the large multiplicity of hits released by the showering muons in the muon chambers in a cone pointing to the interaction vertex, without reconstructing the track.

4. – Heavy Stable Charged Particles (HSCP)

Many models predict the production at LHC of long-lived heavy particles, characterized by a high p_T, high mass and a velocity significantly lower than the speed of light. They can be hadronic or leptonic depending on the model. Leptonic ones behave like heavy muons, crossing the detector and releasing a signal in the muon chambers. Hadronic ones, in addition, can flip their charge in flight, since the quarks in the cloud surrounding the HSCP can be exchanged with the quarks in ordinary matter. Two different approaches can be followed to trigger on these particles: a muon trigger looking directly at the flying HSCP or a MET trigger looking at the rest of the event. The former is model independent, and a CMS study performed on different models showed that the trigger efficiency for leptonic HSCP's would be between 75% and 97% depending on the model [6]. For hadronic HSCP the muon trigger efficiency is much lower (11–24%), because of the charge flipping which reduces the efficiency of track reconstruction in the trigger algorithm. For both hadronic and leptonic HSCP's the efficiency of muon trigger strongly decreases for slow particles: particles with $\beta < 0.6$ would be assigned to the wrong bunch crossing because it takes more than 25 ns to reach the muon chambers. The

MET trigger does not suffer from the problem of the bunch crossing assignment, and it is more efficienct for hadronic HSCP's, but it is model dependent since it is based on the rest of the event and not on the long-lived particle itself.

The ATLAS experiment developed a dedicated trigger to solve the problems related to muon triggers used for HSCP's: a measurement of the β of the particle is performed at L2 exploiting the excellent resolution of the RPC detectors (3 ns). Applying some cuts on the β, p_T and mass of the particle measured by the L2 trigger, a rate for true muons lower than 1 Hz at a luminosity of $1 \times 10^{33}\,\text{cm}^{-2}\,\text{s}^{-1}$ can be obtained. Since no requirement is set on the matching between the L2 particle and the information in the tracker, charge-flipping hadronic particles can be recovered. An ATLAS study showed [3] that the efficiency for a stable gluino of $300\,\text{GeV}/c^2$ increases from 39% to 92% with this dedicated trigger.

In some models, the heavy stable particles can be trapped in the detector and decay some time later, with times ranging from μs to months depending on the model. The CMS Collaboration has developed a dedicated trigger for this peculiar scenario, based on a calorimeter trigger looking at particles trapped in the CMS HCAL during periods of no proton-proton collisions. Simulation studies, combined with background studies performed using data from cosmic runs, show that the potential of $5\,\sigma$ discovery can be achieved in a matter of days over many orders of magnitudes for lifetime of the trapped particles for a luminosity of $1 \times 10^{32}\,\text{cm}^{-2}\,\text{s}^{-1}$ [7].

5. – Conclusions

The ATLAS and CMS detectors have good and robust trigger systems, capable to select New Physics events. For supersymmetric events, the usage of single jet and lepton triggers, of MET triggers and of alternative definitions of MET triggers like the MHT, less dependent on detector conditions, guarantee large efficiencies at low luminosities. For exotic events containing very high-p_T objects or heavy stable charged particles the experiments are studying their normal trigger table, which appears to have a good efficiency in triggering also on peculiar events, and are in addition developing dedicated triggers exploiting the special features of the models.

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