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L1 Muon Trigger at the HL-LHC: the INFN community view of the Atlas and CMS perspectives

Nicola Pozzobon*
Università degli Studi di Padova and INFN – Sezione di Padova
E-mail: nicola.pozzobon@pd.infn.it

Ignazio Lazzizzera
Università degli Studi di Trento
and TIFPA – Trento Institute for Fundamental Physics and Applications
E-mail: ignazio.lazzizzera@unitn.it

Fabio Montecassiano
INFN – Sezione di Padova
E-mail: fabio.montecassiano@pd.infn.it

Sandro Ventura
INFN – Sezione di Padova
E-mail: sandro.ventura@pd.infn.it

Riccardo Vari
INFN – Sezione di Roma 1
E-mail: riccardo.vari@pd.infn.it

Pierluigi Zotto
Università degli Studi di Padova and INFN – Sezione di Padova
E-mail: pierluigi.zotto@pd.infn.it

In this document the perspectives of the Italian LHC community on early muon triggers are reviewed, as of spring 2014. In particular, the Italian effort is aimed at the Atlas L1 RPC trigger and the CMS L1 DT trigger.

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*Speaker.

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1. Introduction

The current perspectives of frontier particle phyisics with high-energy colliders are still an open issue, despite the observation of a new boson of mass $m \approx 126\,\text{GeV}$ at the CERN Large Hadron Collider with data collected from proton-proton collisions at $\sqrt{s} = 7$ and 8 TeV by the Atlas and CMS collaborations [1, 2]. While measurements are still ongoing in order to determine if such boson is the Higgs boson of the Standard Model, the analysis of the forthcoming collisions at 13 and 14 TeV is awaited in order to clarify future subjects of study and shape the tools needed to carry them on. With such a blurry picture of what is coming next from questioning Nature, we are aware that any upgrade of the LHC experiments must maintain the acceptance on electroweak processes that can lead to a detailed study of the properties of the candidate Higgs boson, as understanding its nature is of paramount importance. The acceptance of the key leptonic, photonic and hadronic trigger objects should be kept such that the overall physics acceptance, in particular for low-mass scale processes, can be the same as the one the experiments featured in 2012 [3, 4].

The design of the LHC experiments dates back to the Nineties. The goals for the instrumentation, the environment they must work in, and the available technologies have really changed, and will certainly change also in the next decade, before any HL-LHC upgrade becomes operational. In particular, the detectors and the trigger are requested to be functional and efficient while facing higher and higher radiation damage, disentangling hundreds of superimposed events from extremely high luminosity, and undergoing aging and wear. The systems in use, as they are designed and built in their current shape, will be severely limiting the trigger performance at high rates, therefore an upgrade is necessary. Upgrading the Atlas and CMS trigger systems will involve refurbishing some parts of the detector, redesigning and replacing other elements, and adding new functions to some specific sub-detectors [5, 6, 7].

In such a scenario, a new approach to early trigger implementation is needed. In the last two decades consumer electronics and telecommunications have taken over the scientific community about microelectronics design and production and data transmission technologies. In the past, the triggers of particle physics experiments were mainly designed around custom and expensive ASICs. Nowadays it is more convenient to survey the market for the right product in order to get extreme performance at contained cost. As current requests foresee *intelligent* and flexible readouts, the typical early trigger for the HL-LHC can be represented by a farm of large-area FPGAs. In such a configuration, the *intelligent* part of the readout will be put off-detector, most likely into service caverns, enhancing the flexibility and re-programmability of the whole system. Moreover, with a flexible and powerful early trigger, multiple and more refined algorithms could be implemented, so that a larger number of trigger objects can be handled than ever done so far.

One of the major steps to be taken it the so-called "track trigger" (or "tracking trigger"), i.e. the exploitation of high-granularity tracking sub-detectors, such as the CMS Silicon Tracker and the Atlas Inner Detector, in taking the early trigger decision. Their inclusion into the trigger chain can be crucial in providing confirmation of triggers in other subsystems, improving the resolution of the on-line momentum measurement, finding primary vertices at early trigger level, and building complex trigger from all of these. Higher granularity will turn into a benefit for resolution and isolation, while lower threshold and complex triggers will be made affordable by higher trigger rates and latencies for decision taking [8, 9].

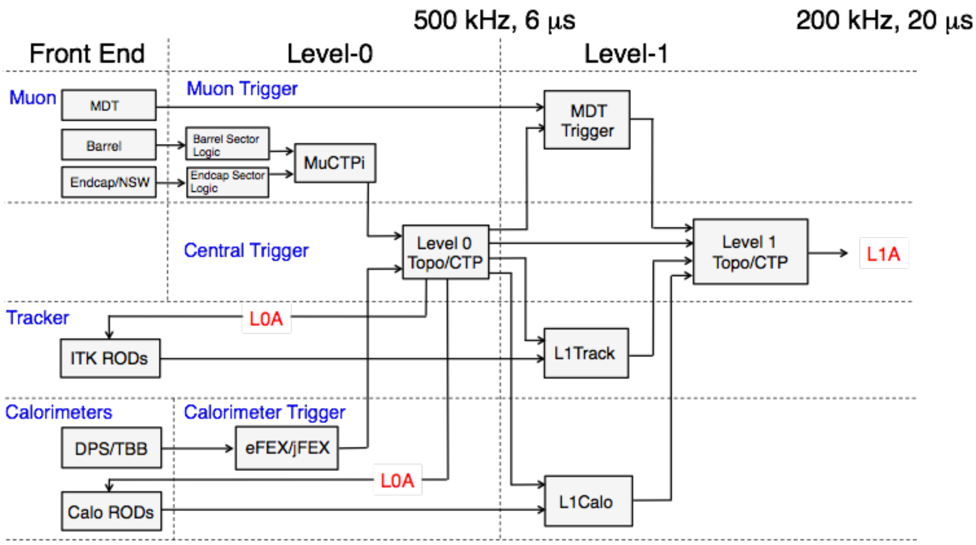

Figure 1: Block diagram of a possible implementation of Atlas early trigger. Muon trigger can be combined with a Region-of-Interest-based track trigger after L0 accept.

This contribution is focussed on the INFN interests about L1 muon trigger, in particular the Atlas RPC trigger and the CMS DT trigger.

2. Current perspectives for the Atlas early RPC trigger

The Atlas community is planning to introduce a new layer in the early trigger. The current L1 layer is becoming a L0 layer, and will be followed by an additional layer including a Region-of-Interest-based (RoI-based) track trigger to confirm muon candidates from the L0 RPC triggers, as shown in figure 1 [10]. The possibility of using also MDT for muon trigger at L1 is currently under evaluation. Both the RoI-based track trigger and the MDT trigger, if any, need higher latencies than the current ones. L0 is expected to provide an output rate of 500 kHz with a 6 μs latency, while the L1 is expected to provide an output rate of 200 kHz after additional 14 μs.

In particular, the RPC front-end cabling will not be replaced, while the data coming from it will be collected by a new Data Collector Transmitter box (DCT). The new DCT box will embed some simple logic, providing timing information with an expected resolution of 3 ns, a time-over-threshold to improve spatial resolution and sharpen the trigger turn-on, one radiation hard optical link [15] for both trigger and readout (hence the main limit being the bandwidth of optical fibre), as well as masking of noisy channels and recovery from SEU.

The RoI-based muon trigger algorithm will be mostly implemented in off-detector Sector logic. It will increase the coverage through different algorithms and, maybe, exploiting a new layer of RPC's, being designed to add also muon charge information and feature at least 6 different flexible and fully-programmable thresholds.

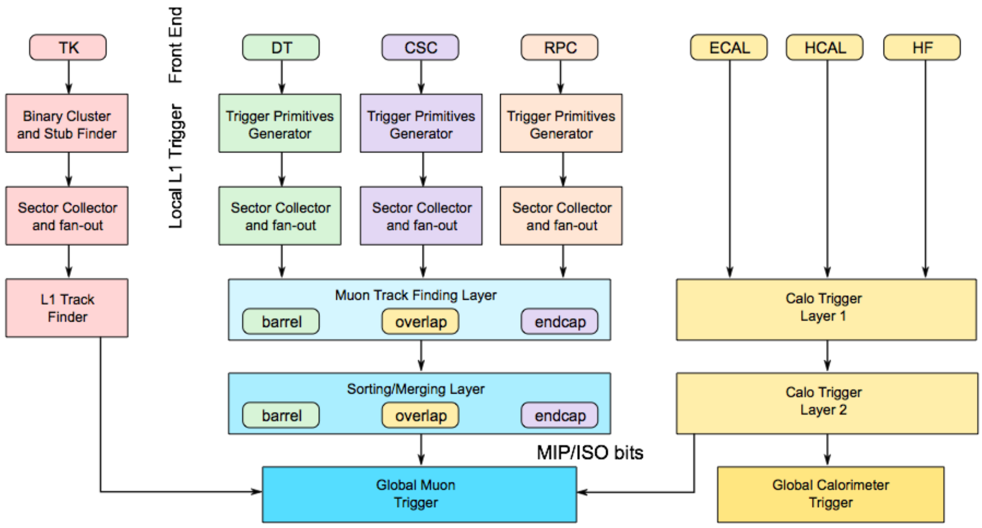

Figure 2: Block diagram of a possible implementation of CMS early trigger. Muon trigger can be combined with a track trigger that runs in parallel as an independent sub-system contributing to the final L1 decision with information on a global scale.

3. Current perspectives for the CMS L1 DT trigger

The CMS muon trigger is undergoing a wider upgrade, starting from the readout and local trigger. A new track finding layer is being designed to be shared among all muon subsystems. Track trigger will be embedded in the L1 as an independent trigger that is combined with standalone muon triggers in a dedicated layer in order to improve the resolution of L1 muon candidates [8, 11].

Mini-crate replacement

Re-locating the DT readout and trigger electronics, currently hosted in on-detector mini-crates, should be done without compromising the quality of the output information. One can roughly evaluate if is is possible to move the functions of a whole mini-crate into a single FPGA-based board by counting the number of gates needed to implement the current local trigger in ASICs. This number can be compared with the specifications of state-of-the-art FPGAs, which are likely to be widely available, consolidated and affordable technology at the start of the HL-LHC.

One mini-crate hosts many kind of electronic boards for the trigger, the read out and the slow control of the Drift tube chamber. Among them up to 7 boards are Trigger boards, each of whom includes 32 BTIs, 4 TRACOs and one Trigger Server [12, 13, 14]. These can be summed up to about 20 millions of gates, including a 20% safety margin. Better estimates will need an implementation of the mini-crate in a real target FPGA. This estimate does not take into account that new DT readout will provide the L1 with all DT data, so that a larger number of bits needs to be handled. Also, higher combinatorics due to pile-up and implementation of the track finding layer are not taken into account in this estimate. Nevertheless, one can take as an example the products offered by Xilinx, which claims 20 millions of gates vor the Virtex 7 family in 208 nm (7V200T) and up to 50 millions for the Virtex UltraScale family in 20 nm (VU440 3D IC) [16, 17]. Assuming that the number of gates in one state-of-the-art FPGA in 2020 will scale by a factor 4, 1 FPGA will likely be capable of including the equivalent of 4 mini-crates as of 2012, which correspond to one sector. As the CMS DT system is composed by 5 wheels, each divided into 12 sectors, a number of 60 FPGA boards is expected for the whole system, that can be hosted in less 5 μTCA crates [18].

4. Silicon tracker for the L1 muon trigger: a case for CMS

A test algorithm has been studied at CMS to improve muon candidates with track trigger using current DT trigger primitives as seeds to be matched with tracks found at L1. This algorithm is based on a full parameterisation of track extrapolation including low-quality muon p_T and dependence on ϕ and θ [19]. Some of the outcomes can be taken as independent on the specific case:

- the muon p_T assignment is better when using the tracker, as muon detectors overestimate it, although low-p_T misassignment is still possible from badly built seeds in the DT;
- combined candidates feature sharper turn-on curves and less contamination from muons below threshold because of the better p_T resolution;
- a rate reduction of at least a factor 5 at 20 GeV threshold is expected in comparison to the current DT Track Finder;
- as the momentum resolution measured with the tracker is much better than the one measured with DTs, full data from muon detectors in future triggers (i.e. TDC for CMS DT) shall be used to improve the association of muon candidates to tracks found at L1.

The expected efficiencies and rates of a combined muon-tracker trigger have already been shown at the 2014 ECFA HL-LHC Experiments Workshop, as in figure 3.

5. Concluding remarks

The two communities are working on future muon triggers under common assumptions: higher trigger rate and decision latency. Although the the INFN community involvement is different with the two experiments Atlas (RPC L0 trigger) and CMS (DT L1 trigger), there is a chance to share expertise in qualification of the components and data transmission: both the experiments are going to use fast radiation hard optical links based on the CERN GBT technology. On the other side, the trigger strategies cannot be decoupled from the detectors themselves. The two experiments will require different specifications for the use of such general devices: different trade-off figures must be understood. The implementation of early trigger stages in the service cavern, off-detector, is a goal that can be met with current state-of-the-art commercially available FPGAs. The use of track trigger will require the muon triggers to be precise in matching with tracks, rather than measuring muon p_T. Nevertheless, the path towards the HL-LHC is still long, and there is plenty of room for new algorithms and clever ideas.

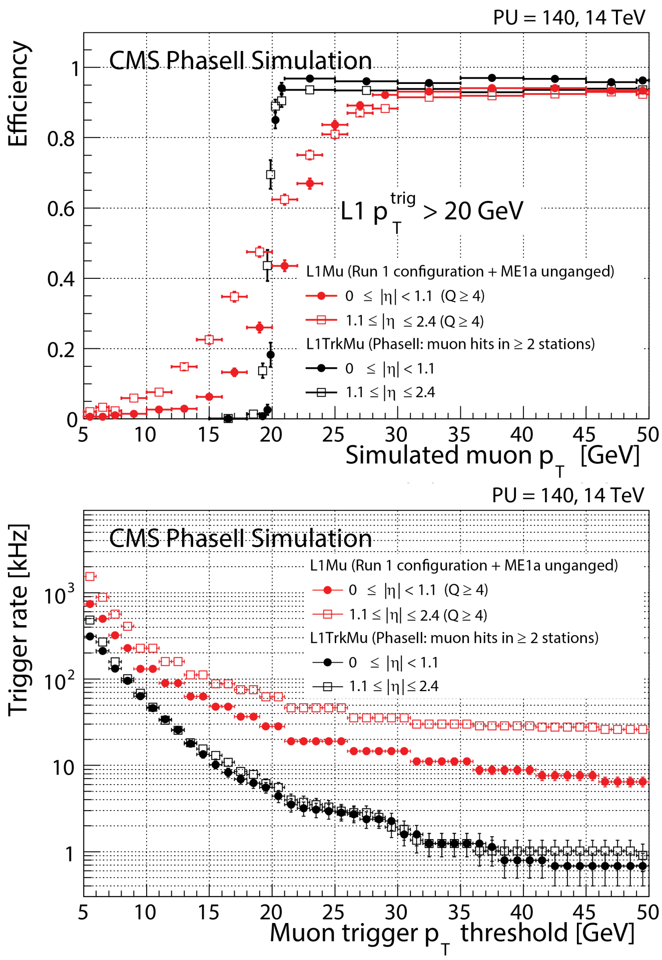

Figure 3: Top: Efficiencies for a single muon trigger with 20 GeV threshold as a function of the generated transverse momentum of the muon, for stand-alone L1 muons (red symbols) and for muons that are matched to L1 tracks (black symbols). Bottom: Rates of single muon triggers as a function of the p_T threshold.

References

[1] THE ATLAS COLLABORATION, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys. Lett. B **716** (2012) 1.

[2] THE CMS COLLABORATION, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Phys. Lett. B **716** (2012) 30.

[3] THE CMS COLLABORATION, *CMS Technical Design Report for the Level-1 Trigger Upgrade*, CERN-LHCC-2013-011, CMS-TDR-12 (2013).

[4] THE ATLAS COLLABORATION, *Physics at a High-Luminosity LHC with ATLAS*, ATL-PHYS-PUB-2012-004 (2012).

[5] THE ATLAS COLLABORATION, *Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment*, CERN-LHCC-2012-022, LHCC-I-023 (2012).

[6] THE CMS COLLABORATION, *CMS Expression of Interest in the SLHC*, CERN-LHCC-2007-014, LHCC-G-131 (2007).

[7] THE CMS COLLABORATION, *Technical proposal for the upgrade of the CMS detector through 2020*, CERN-LHCC-2011-006, CMS-UG-TP-1, LHCC-P-004 (2011).

[8] THE CMS COLLABORATION, *Technical proposal for the Phase-II upgrade of the Compact Muon Solenoid*, *in preparation*.

[9] B.T. Huffman, *Plans for the Phase II upgrade to the ATLAS detector*, *JINST* **9** (2014) C02033.

[10] E. Lipeles, *L1 track triggers for ATLAS in the HL-LHC*, *JINST* **7** (2012) C01087.

[11] S. Mersi and N. Pozzobon, *The CMS Tracker Upgrade for the HL-LHC: Tracking at Early Trigger Level*, in proceedings of 14th International Conference on Advanced Technology and Particle Physics, Como, Italy, 23 âĂŞ 27 September 2013, S. Giani, C. Leroy, L .Price, P.G. Rancoita and R. Ruchti editors, Volume 8 of Astroparticle, Particle, Space Physics and Detectors for Physics Applications Series, World Scientific.

[12] THE CMS COLLABORATION, *CMS The TriDAS Project Technical Design Report, Volume 1: The Trigger Systems*, CERN-LHCC-2000-038, CMS-TDR-6-1.

[13] THE CMS COLLABORATION, *The CMS experiment at the CERN LHC*, *JINST* **3** (2008) S08004.

[14] P. Arce et al., *Bunched beam test of the CMS drift tubes local muon trigger*, *Nucl. Instr. Meth. A* **534** (2004) 441.

[15] P. Moreira, et. al., *The GBT, a Proposed Architecture for Multi-Gbps Data Transmission in High Energy Physics*, in proceedings of TWEPP-07, Prague, 2007.

[16] Xilinx Virtex-7 family data sheets http://www.xilinx.com/products/silicon-devices/fpga/virtex-7.html.

[17] Xilinx Virtex UltraScale family data sheets http://www.xilinx.com/products/silicon-devices/fpga/virtex-ultrascale.html.

[18] PICMG MicroTCA description http://www.picmg.org/openstandards/microtca/.

[19] M. d'Alfonso et al., *Use of tracking in the CMS L1 trigger for the phase-2 upgrade*, CMS DN-2014/002 (2014).