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A Time-Multiplexed Track-Trigger for the CMS HL-LHC upgrade

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A new CMS Tracker is under development for operation at the High Luminosity LHC from 2025. It includes an outer tracker based on "PT-modules" of two different types which will construct track stubs using spatially coincident clusters in two closely spaced sensor layers, to reject low transverse momentum track hits and reduce the data volume before data transmission to the Level-1 trigger. The tracker data will be used to reconstruct track segments in dedicated processors before onward transmission to other trigger processors which will combine tracker information with data originating from the calorimeter and muon detectors, to make the final L1 trigger decision. The architecture for processing the tracker data outside the detector is under study, using several alternative approaches. One attractive possibility is to exploit a Time Multiplexed design similar to the one which is currently being implemented in the CMS calorimeter trigger as part of the Phase I trigger upgrade. The current status of some of the crucial component developments needed to construct modules for the new tracker is described, including recent prototype results. The novel Time Multiplexed Trigger concept is explained, the potential benefits for processing future tracker data are described and a feasible design based on currently existing hardware is presented.

Collaboration

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Summary

A major upgrade of the CMS experiment at the CERN Large Hadron Collider is being planned so that the accelerator can deliver an integrated luminosity of 3000 fb^{-1} over a period of about a decade of operation for a physics programme which will include precision measurements of the newly discovered Higgs boson, further searches for new physics extended to higher masses, and for possible discrepancies with the standard model.

The High Luminosity LHC will require a new tracker after 2023 because of gradual deterioration of the present detector due to accumulated radiation damage. Its replacement must satisfy several demanding requirements, including a lower material budget and increased granularity compared to the present detector, and enhanced radiation tolerance combined with tolerable power consumption and affordable cost.

For the first time, data must be provided to the L1 trigger to constrain the trigger rate to 0.5-1 MHz with a latency of up to $\sim$10 μs. The baseline outer tracker design has a barrel-endcap layout with two types of modules, denoted 2S" andPS", which allow selection of hits consistent with a transverse momentum above a chosen threshold $\sim$2 GeV/c to reduce significantly the volume of data to be transmitted out of the tracker to be used for the L1 trigger decision. The basic concept, proposed some years ago \cite{Jones2005, Pesaresi2010} is to compare the binary pattern of hit strips on upper and lower sensors of a two-layer module to reject patterns that are consistent with a low transverse momentum track. Hit combinations in the two layers consistent with a high-p$_T$ track segment are known as "stubs".

In the 2S-module \cite{ Hall2010, Braga_WIT2014}, which is the most advanced, two silicon microstrip sensors are separated by a few mm, with the spacing determined by a compromise between transverse momentum precision and the fake stub rate resulting from combinatorial background caused by hits from nearby tracks, secondary interactions and photon conversions, for example. In the cylindrical barrel region, high p_T tracks can be identified if hit clusters lie within a search window in R-ϕ (rows) in the second layer. The sensor separation and search window determine the p_T cut, where the objective is simply rejection of a sufficiently large fraction of low p_T candidates in the detector so that trigger primitives can be transmitted within the available bandwidth. In the barrel region, the sensor segmentation in z (along the beam axis) determines the vertex measurement precision; the outermost tracker region uses 5 cm strips, so dedicated pixel-strip module layers are planned for added precision on the longitudinal
vertex reconstruction. The same method can be deployed in the end-cap detectors, with modifications to the module geometry.

In total, $\sim$15000 modules, each with a dedicated fibre-optic link, will send p_T-stubs to off-detector processors at a 40 MHz rate. After a L1-accept signal the full tracker data from the modules will be read out. Outside the Tracker the arriving stub data must be used to reconstruct tracks sufficiently precisely within a few μs for the L1 trigger to then associate them with other trigger primitives from the calorimeter and muon detectors.

A prototype 2S-module has been assembled using the CBC front-end readout ASICs \cite{Raymond2011, Hall2014} which have been developed for this purpose in a 130 nm CMOS technology and studied in a DESY test beam in December 2013, with performance consistent with simulations. A Time-Multiplexed Calorimeter Trigger has been demonstrated in prototypes \cite{CMS_TMT} and is currently being installed in CMS for operation during the 2016 run. The hardware, based on the MP7 \cite{MP7} processing board, which has a Xilinx Virtex-7 FPGA and Avago MiniPOD optics in a μTCA format, is designed to implement Layer 2 of the CMS L1 Calorimeter Trigger. Each MP7 has a total optical bandwidth of 0.9 Tbps, provided by 72 links operating at up to 12.5 Gbps for both input and output, and is therefore well matched to a high throughput processing application such as track finding at HL-LHC. A series of MP7 boards have been thoroughly tested during a development and prototyping phase and manufactured for use in CMS, and can serve as a prototype system for a time multiplexed track-trigger. Firmware for the track-finding algorithm is under development and a system will be in operation by summer 2015. Simulation studies which support the concept are well advanced.

The status and performance of the system elements will be described, and the application to a future track-trigger and its advantages, will be explained.

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