Toolkit for opening the New Physics Window at LHC and possible spin off effects

The Large Hadron Collider (LHC) is the world largest and most powerful particle accelerator opening a new frontier in particle physics. It started on September 10, 2008, and remains the latest addition to CERN accelerator complex. CERN LHC experiment is one of representative big science managed and operated by international collaboration.

The ATLAS (A Toroidal LHC Apparatus) and the CMS (Compact Muon Solenoid) are particle detectors that are designed to see a wide range of elementary particles and phenomena produced in high-energy collisions in the LHC. Like a cylindrical onion, different layers of detectors measure the different particles, and use this key data to build up a picture of events at the heart of the collision.

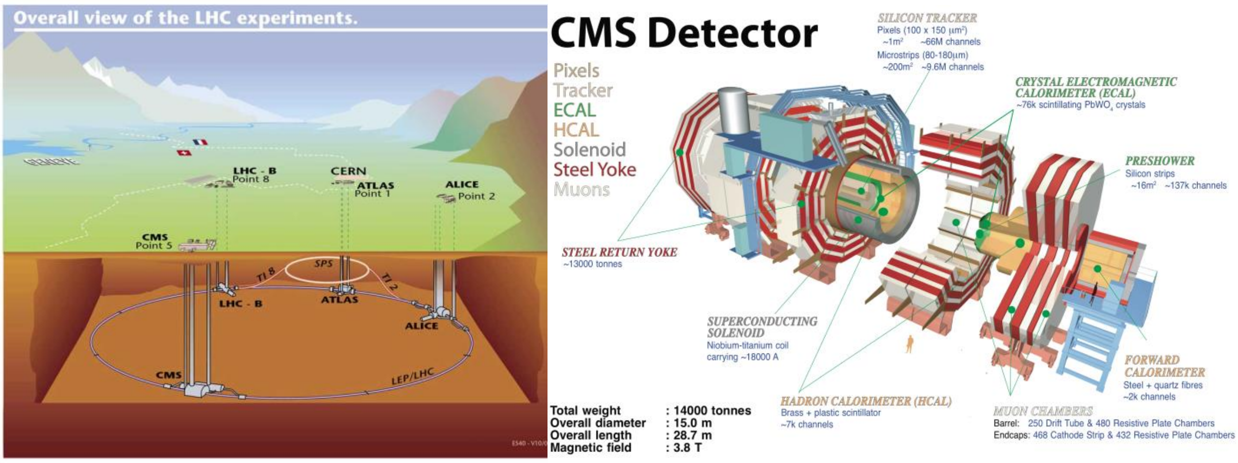

Figure 1. Overall view of the LHC experiments and overall view of CMS Detector

The LHC experiments ran successfully and provided excellent data at the central collision energy of 7 to 8 TeV. ATLAS and CMS collaborations have discovered in 2012 a new boson with a mass near 125 GeV and properties compatible so far with those predicted for the standard model Higgs boson. The discovery of the Higgs boson completes the set of predicted particles by the Standard Model (SM) of particle physics.

It will start operating at the central collision energy of 13 TeV initially and then closer to the design energy of 14 TeV as a new energy frontier. This will substantially enlarge the mass reach in the search for new particles and will also greatly extend the potential to study the properties of the Higgs boson discovered at the LHC in 2012 and allow searching for New Physics. In order to meet the experimental challenges of unprecedented proton-proton luminosity, the CMS collaboration will need to improve and upgrade the ability of the apparatus to isolate and precisely measure the products of the most interesting collisions. Therefore, a key goal of the LHC upgrade will be to maintain the overall physics acceptance under the challenging high luminosity LHC (HL-LHC) conditions. CMS must retain its capability to efficiently trigger events originating from low-mass physics processes (e.g. Higgs production at 125 GeV) and for performing precision measurements of low to medium transverse momentum (pT) physics objects among which the identification of an essential object for New Physics, i.e. the tau lepton. This program has concentrated on one of the most if not the most novel triggering e.g. the one using the pixel tracker information setting at the core of the interaction.

We have thus been working on including the Pixel information into the overall tracking trigger system for the CMS upgrade so that we can reduce the rate of events but still maintain a high efficiency for selecting interesting events. We have been playing a leading role in the R&D for a CMS level-1 Pixel

Trigger for the CMS Phase 1 and 2 upgrades. We developed the Level-1 (real-time and hardware-based) pixel tracking algorithm (PiXTRK) matching with the electromagnetic (EM) calorimeter object also extendable to the tau trigger and we have been developing the level-1 b quark tagging algorithm using pixel detector.

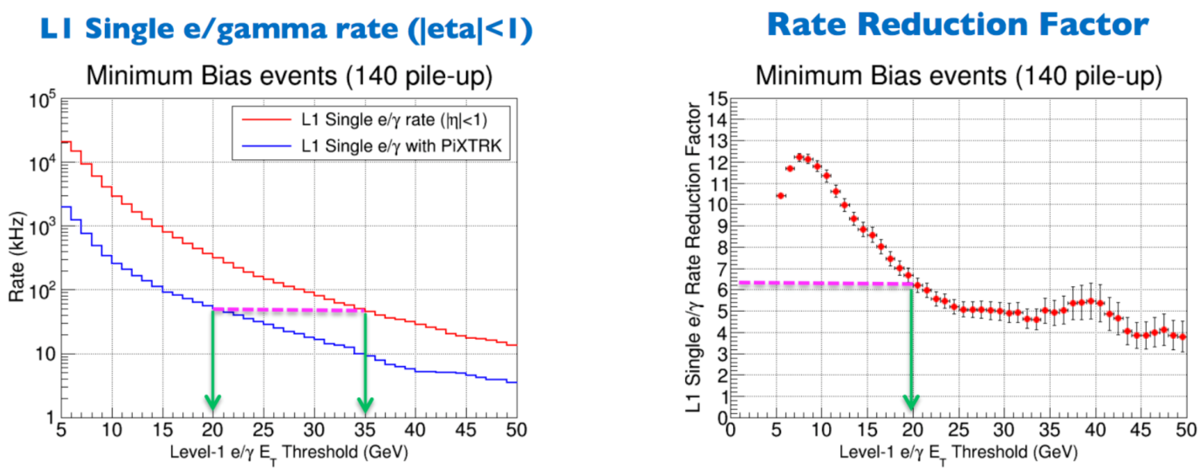

Figure 2. Level-1 single electron/photon trigger rate and the rate reduction factor using the PiXTRK algorithm.

The left plot of attached Fig 2 shows Level-1 single electron/photon trigger rate as a function of the transverse energy (ET) threshold, while the right plot shows the rate reduction factor by the PiXTRK algorithm. For a threshold of 20 GeV, the rate of a single electron trigger can be reduced by a factor of about 6 when Level-1 e/γ objects are matched to pixel based tracks. It also allows lowering ET threshold from 35 to 20 GeV while keeping 50 kHz event rate. This means not having to apply higher thresholds in the energy of the elementary physics objects in the calorimeter based trigger. This is a big technological challenge as well and our exploratory studies have shown their feasibility and interest.

Since the Level-1 latency for CMS upgrade is designed to be about 12.5 microsecond, the new Level-1 pixel track matching should be done very quickly in less than few micro seconds. In order to implement the PiXTRK algorithm, we considered to use the new generation of FPGA's (field programmable gate array) and multi process units (Intel Xeon Phi Co-processor or GPGPU) or even more novel firmware and hardware solutions, this has been started in the last part of this project.

We performed in a complementary way to this work the development of an innovative position sensitive pixelated sensor to detect and measure with high precision the coordinates of the ionizing particles. The silicon avalanche pixel sensors (APiX) is based on the vertical integration of avalanche pixels connected in pairs and operated in coincidence with embedded digital electronics on the chip. The APiX sensor addresses the need to minimize the material budget and related multiple scattering effects in tracking systems requiring a high spatial resolution in the presence of a large occupancy. The expected operation of the new sensor features low noise, low power consumption and suitable radiation tolerance. The APiX device provides on-chip digital information on the position of the impact coordinate of the impinging charged particle and can be seen as the building block of a modular system of pixelated arrays, implementing a sparsified readout. The technological challenges are the 3D the vertical integration of the device under CMOS processes and integration of electronics. The outcome of this R&D activity can be beneficial to a number of other fields, including: research instrumentation; biomedical applications (e.g.: with beta-emitters); electron microscopy; CMOS imagers; other (industrial quality controls, homeland security etc). Similarly the work on real time processing and fast algorithm is useful in many other fields of research (ex astrophysics) but also applied to Medical Imaging or several other computing areas.