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CMS tracker towards the HL-LHC

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Summary. — In sight of the incoming new LHC era (High Luminosity - LHC), characterized by a jump forward in the precision boundary and in the event rate, all the CMS sub-detector are developing and studying innovative strategies of trigger, pattern recognition, event timing and so on. A crucial aspect will be the online event selection: a totally new paradigm is needed, given the huge amount of events. In this picture the most granular and innermost sub-detector, the tracker, will play a decisive role. The phase-2 tracker will be involved in the L1 Trigger and, taking advantage of both the Associative Memories and the FPGA, it can ensure a trigger decision in proper time and with satisfactory performances.

1. – Introduction

The recent discovery of a new boson, with a mass around 125 GeV, at LHC, launched an exciting era for the particle physics. The challenge will be the characterization of this new particle and the measure of its decay modes and branching ratios, specially in the leptonic channels: $t-\bar{t}$, $b-\bar{b}$ and $\tau-\tau$.

Every deviation from the Standard Model predictions, eventually observed, could represent a New Physics signal. Albeit the change from 8 TeV to 13 TeV, as energy in the centre of mass, in 2015, does not admit a direct New Physics candidates observation, the High Luminosity reached in phase 2 (HL-LHC) will increase the statistics and refine the precision to have indirect indications.

In order to not loose interesting events and to not overcome the acquisition bandwidth, given the huge statistics collected, a totally innovative event selection paradigm has to be realized [1]. Already at online trigger level (L1), all the sub-detectors have to work in synergy and the most granular one, the tracker, has to play a decisive role [2, 3]: the charged tracks reconstruction will be introduced at L1 trigger.

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2. – Motivations for the upgrade

The choice to move forward the precision boundary in the LHC machine involves the four main issues explained below for the CMS detector [4].

- Higher rate: this is direct consequence of the instantaneous luminosity growth and means a greater effort for the trigger system for respecting the bandwidth limit, without missing efficiency in interesting events; that would happen, for example, raising the p_T thresholds. It is useful, instead, to insert the tracker information at L1, in order to gain a rate reduction factor, and to diminish the L1 latency time.

- Pile up: during the Phase 2 the number of proton-proton collisions will attest at around 140, three time what the experiment was designed for. The track finding and the reconstruction of the event pattern will have to be performed in a high-density tracks and vertices enviroment. A low p_T track cleaning, a wider forward detection, a tracker higher granularity and resolution and a timing capability of calorimeters (20–30 ps resolution) can decisively help.

- Radiation damage: collecting totally $3000\,\text{fb}^{-1}$ corresponds to 6 times the design radiation level. This damage reduces the charge collection in the Pixel Detector and increases the leakage current in the Outer Tracker. Both the effects are responsible for a worse vertex resolution, a tracking efficiency reduction and an higher fake rate, as the simulations show. Tracker and Endcap Calorimeter will need to be replaced, new materials and smaller pixel and strips are required.

- Object identification: it can take advantage of the Particle Flow algorithms improvements, but requires also the detectors to have high granularity and resolution, lower tracker material budget and low noise in calorimeters.

3. – New tracker layout

The new Tracker has only two components: the Pixel Detector and the Outer Tracker, their boundary is at $R = 20\,\text{cm}$.

- Pixel Detector: here the requirement of radiation tollerance is very demanding, so the pixel sensors are smaller and thinner and the design leaves open the possibility to replace all modules. The increase of the endcap disks, from 3 to 10, extends the forward coverage.

- Outer Tracker: provides the data for L1 trigger. It contains modules capable to filter low p_T tracks: the CMS magnetic field is so intensive that the spatial correlation between two hits in consecutive layers depends on the track p_T. After a first hit is registered, a selection window is open, whose amplitude determines the p_T threshold. If the second hit is within the window, a stub (pair of hits) is collected. There are 6 barrel layers and 5 endcap disks. PS (Pixels + Strips) module are employed in the half of the detector nearest to the beam, while SS (Strips + Strips) sensors cover the rest.

4. – Track finding: pattern recognition and fitting

The "trick" to improve the quality in the events selection and gain a reduction factor is to anticipate at L1 the reconstruction process that now is performed only in the High Level Trigger. At each bunch crossing, the stubs data are processed to form L1 tracks that are the tracker primitives to combine to the other sub-detectors' information to perform L1 trigger.

The track finding process has to be very fast and can benefit from the employment both of the Associative Memories (AM), a custom chip already used in the CDF experiment, and of the programmable device FPGA. The junction of these two tecnologies provides a faster pattern recognition function, thanks to the parallelism of the AM chips, and an extraction of high quality tracks, implementing the track fitting algorithm in the FPGA device.

The information collected by the tracker at this initial step of trigger can be exploited to discriminate the primary vertices, to stem the PU contamination, to discriminate electrons from photons, matching the electromagnetic showers with tracks, and to reduce the rate, mantaining intact the efficiency, thanks also to isolation criterions. Simulations of specific final states or object oriented (like b-jets or τ) are under construction and are addressed to evaluate online recostrucion efficiencies and latencies.

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