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Simulation studies on precise timing information during High-Luminosity LHC

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Summary. — We present prospects for the usage of precise timing information during the high-luminosity phase of the LHC (HL-LHC) at the CMS experiment. During the HL-LHC the instantaneous luminosity is estimated to be greater than $10^{34}\,\text{cm}^{-2}\text{s}^{-1}$, resulting in about 140 simultaneous proton-proton collisions (pileup) that occur every 25 ns. The time information can be exploited to improve the object reconstruction, for instance obtaining an alternative vertex determination, based on pure timing information, with a O(cm) resolution. This is particularly relevant in events with low track multiplicity (*e.g.* $H \to \gamma\gamma$), where the vertex cannot be precisely determined with tracking information. A time requirement can be also used to reduce the occupancy in the electromagnetic calorimeter (ECAL), removing the energy deposits with a time not compatible to the one expected from a particle coming from the hard collision. This may have important consequences in many aspects: reduction of event size, improvement of photon and jet energy resolution.

1. – Introduction

Between 2024 and 2026, the CMS detector will undergo a major upgrade, needed to face the subsequent data-taking that will occur at high luminosity. The increasing in luminosity will produce an average of 140 concurrent interactions per bunch crossing that will cause the signal to pileup in the detector. This will represent an issue for the trigger and the reconstruction, degrading the jet and photon energy resolution and all the physic objects isolation quantities.

The use of the tracker information is the most effective way to discriminate particles from different primary vertices, but it is limited to the PU activity coming from charged particles in the tracker acceptance. The complementary use of precise timing can be used for both charged and neutral particles, without any restriction to the tracker acceptance.

The interaction of a particle with the ECAL crystals is simulated with Geant4 [1]. Accessing the Geant4 information, it is possible to store the time and the energy deposits of every single interaction of a particle with the ECAL crystals crossed. From these

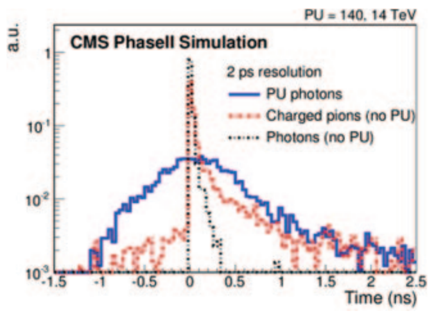

Fig. 1. – Time distribution for photons (black line) and pions (in red line) coming from the hard collision, and from photons coming from pileup interactions (blue line).

information it is possible to extract the time a particle crossed the ECAL, with a precision of few picoseconds. Such time resolution is not achievable from any realistic time detector, for this reason we will smear the time obtained from the simulation, in order to simulate more realistic time resolutions up to 50 ps.

This time information allows to associate each crystal crossed by a particle to a time measure. Since an electromagnetic shower can propagate into a cluster of several crystals, the time associated to each particle refers to the time of the most energetic crystal of the cluster.

Figure 1 shows the time distribution for photons (in black) and pions (in red) coming from the hard collision, and the time distribution for photons coming from pileup vertices (in blue). It can be seen that timing could represent a powerful discriminator to reject particles coming from pileup vertices.

2. – Timing performance

The time information can be used to compute the z-vertex position in processes where there are few or no charged particles, exploiting the dependence between the time of arrival of a particle in the ECAL and the vertex position. For this purpose $H \to \gamma\gamma$ events with 20 additional PU vertices have been generated.

The time obtained from the simulation has been smeared by using a Gaussian distribution centered on the simulated time, with a width corresponding to the time resolution to be tested.

For several $H \to \gamma\gamma$ events the vertex position has been extracted and compared to the simulated one. From the RMS of the difference between the estimated and simulated z-vertex position it has been computed the z-vertex resolution. In fig. 2, the z-vertex resolution is shown as a function of the time resolution that has been used. On the left both photons are in the barrel, on the right at least one photon is in the endcaps.

It can be seen that for a time resolution of 30 ps, we obtain a resolution on the z-vertex position of the order of the centimeter.

A time measurement can be also used to reject crystals containing an energy deposit with a time incompatible with the one of a particle coming from the hard collision.

We generated a $H \to \gamma\gamma$ sample with and without 140 additional PU interactions. The ΣE_t variable, defined as the scalar sum of all the energy deposits in the electromagnetic calorimeter, has been computed in both cases. Figure 3 shows the ΣE_t distribution

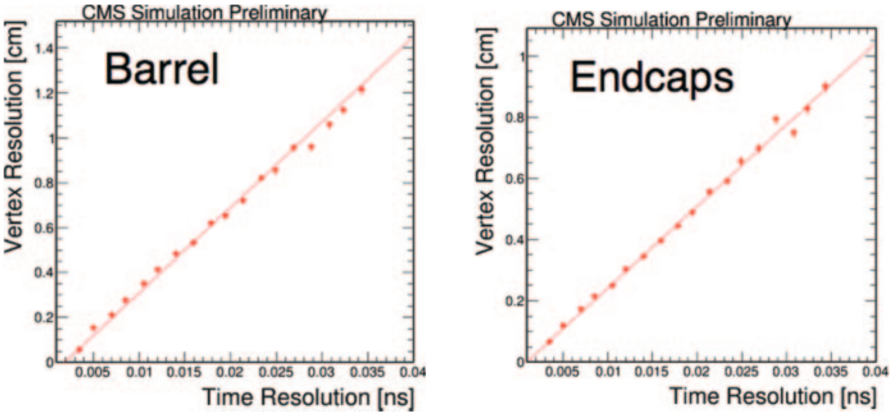

Fig. 2. – Z vertex position resolution as a function of the time resolution for events with the two photons in the barrel (left) and with at least one photon in the endcaps (right).

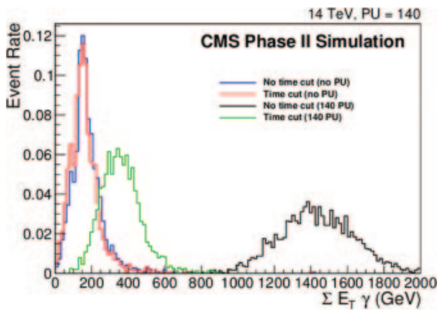

Fig. 3. – Distribution of the ΣE_t variable for the $H \rightarrow \gamma\gamma$ process. The blue distribution is for a sample without PU and without any time selection, while the red curve represents the same distribution after a time windows selection of 90 ps. The ΣE_t distribution for the signal with 140 PU is shown in black, and in green after the time selection. The time measurement has a resolution of 50 ps and no pileup from previous bunch crossing has been included.

in blue for the sample without PU and without any time selection, while the same distribution after a time selection is shown in red. The selection requires the crystal time to be included in a windows of 90 ps centered on the time expected for a particle coming from the hard collision. The two distributions are close to each other, proving that the time requirement does not affect the signal. The ΣE_t distribution for the sample with 140 PU is shown by the black distribution. A clear increase in occupancy is observed due to the activity from the pileup interactions. Applying the same time selection to the 140 PU sample, we obtain the green distribution, thus reducing the occupancy significantly. In this study the time measurement has a resolution of 50 ps, in order to simulate a realistic detector. No pileup from previous bunch crossing has been included.

3. – Conclusions

The studies presented in this chapter want to show a proof of principle of the utility of the use of timing in the object reconstruction, in presence of high PU multiplicity.

A time measurement has been extracted for the simulation, and used to test the improvement in particle reconstruction.

First of all it has been tested the performance on the vertex reconstruction as a function of the time resolution, in the case of a process with no or few tracks multiplicity, as $H \to \gamma\gamma$. It has been found that a 30 ps time resolution corresponds to a z vertex position resolution of about one centimeter.

A time selection on the ECAL energy deposits has been performed to show its effects on the ECAL occupancy. It has been shown that, by collecting the crystals into a 90 ps window around the time expected for a particle traveling from the hard collision, it is possible to strongly decrease the ECAL occupancy.

All the results have been documented in the CMS Analysis Note [2, 3].

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