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Use of ECAL time in physics analysis at CMS

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Summary. — The CMS ECAL is a high-resolution electromagnetic calorimeter made of $PbWO_4$ crystals, which relies upon precision calibration in order to achieve and maintain its design performance. The fast decay time of scintillation light from the $PbWO_4$ crystals, the electronic pulse shaping and the sampling rate allows for an excellent time resolution to be obtained with ECAL. For particles with an energy above 10 GeV the time of arrival can be measured with a resolution better than 1 ns. Good time resolution may provide discrimination between photons and jets by exploiting differences between the time profile measured in adjacent ECAL crystals. Constraints on the position of the primary vertex may also be obtained by exploiting the time measurement of two high momentum photons. The precise time measurement makes it possible to identify particles predicted by different theories beyond the Standard Model, for example long-lived neutralinos decaying into photons.

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1. – Time reconstruction with the CMS electromagnetic calorimeter

When a photon or an electron hits a $PbWO_4$ crystal, it loses energy, which is converted into scintillation light. This is collected and converted into electrical signals by photodetectors. The signals are then amplified and shaped by the front-end electronics. The pulse is digitized at 40 MHz by a 12-bit voltage-sampling analog-to-digital converter, providing a discrete set of ten amplitude measurements, with 25 ns spacing [1]. The signal arrival time is measured from the relative phase of the signal samples to the expected shape of an in-time signal, with an algorithm using ratios of consecutive samples [2].

2. – Study of time development of electromagnetic showers

The time development of a shower is not the same between real photons and fake photons from mis-identified jets.

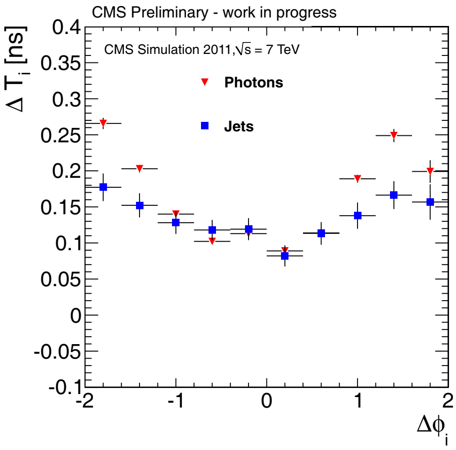

Fig. 1. – Time propagation of a shower for real photons (triangles) and fake photons from mis-identified jets (squares).

For a real photon or electron, a time difference is expected between the signal measured in the seed crystal (from the impact point on the ECAL) and the neighbouring crystals, due to the time taken for the lateral spread of the shower. On the other hand, a fake photon from a mis-identified jet will tend to have a flatter time profile across the crystals, due to multiple particles in the hadronic shower arriving at the crystals at similar times from the collision vertex.

This is represented in fig. 1, which shows the difference in time, ΔT_i, between the signal at a distance $\Delta\phi_i$ from the seed crystal and the seed itself (ϕ is the azimuthal angle of the crystal and i stands for the i-th crystal inside the cluster). This difference is normalized to the crystal width. The profile distribution of ΔT_i *vs.* $\Delta\phi_i$ is shown for both real photons and mis-identified photons from jets.

The different trend of ΔT_i, flatter for a fake photon than for a real one, may offer some separation power to reject fake photons.

3. – Vertex reconstruction using ECAL time information

The implementation of alternative methods for vertex reconstruction, which do not make use of the tracker information, can improve the performance in low track multiplicity activity cases, like $H \to \gamma\gamma$.

In order to reconstruct the primary vertex position (v_z) exploiting the ECAL time information, the following relationship is exploited: $T_{meas}(v_z) = T_{flight}(v_z) + T_{interaction}$. The measured time in ECAL, T_{meas}, is the sum of two contributions. The first one, T_{flight}, depends geometrically upon the unknown position of v_z while $T_{interaction}$ represents the time of interaction between two protons, that can happen at any point within the time of the LHC bunch crossing ($\sim 200\,\text{ps}$). Using the time measured for two photons in the same event, it may be possible to solve the two-unknowns problem and extract the position of the primary vertex. The performance of the vertex reconstruction, obtained by comparing it with the vertex reconstructed with the tracker system, currently gives a resolution of 5 cm on simulated events (fig. 2). The method presented here is just a preliminary study but the hope is that in the future analyses like $H \to \gamma\gamma$ will benefit from this approach.

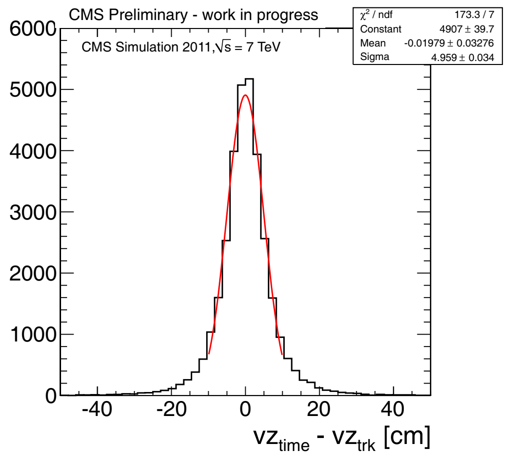

Fig. 2. – Resolution on the identification of primary vertex position using ECAL time measurement. vz_{time}, the vertex obtained from the timing information, vz_{trk}, the vertex obtained from associated tracks.

4. – Search for long-lived particles using ECAL Time

A recent application of the use of the time measured by ECAL can be found in a search for long-lived particles performed at the CMS experiment [3]. These particles travel through the detector and eventually decay at some distance from the interaction point. A photon produced from the decay of a long-lived particle, for example a long-lived neutralino, is typically out-of-time with respect to a photon from a prompt decay. The excellent time resolution of the electromagnetic calorimeter therefore allows for the identification of off-time photons from long-lived particles. For this reason, the measured time of the photon represents a key ingredient to identify delayed energy deposits in

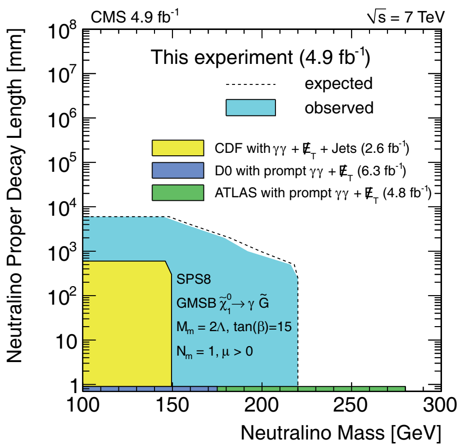

Fig. 3. – Exclusion limits in the plane neutralino proper decay length *versus* neutralino mass (from [3]).

the electromagnetic calorimeter and thus is used in order to discriminate signal from background in this kind of analysis. Since no excess has been observed over the Standard Model background expectation [3], using ECAL timing information, it has been possible to place exclusion limits for neutralinos with masses up to 220 GeV for proper decay lengths ranging from 1 mm to 6000 mm as shown in fig. 3. These results significantly improve our knowledge of the long-lived neutralino beyond those of the D0 [4], CDF [5], and ATLAS Collaborations [6].

5. – Conclusion

The excellent performance achieved in ECAL time measurement represents a possible handle in the discrimination between real photons and fake photons from mis-identified jets.

Searches for new physics with striking signatures like displaced vertex and off-time photons will also significantly benefit from this performance. Preliminary studies have been carried out to investigate the use of ECAL time in vertex reconstruction for $H \to \gamma\gamma$ events. A first analysis has been published in April 2013 that exploits the time measured by the CMS ECAL in the identification of off-time photons, that provides important limits on the properties of long-lived neutralinos [3].

REFERENCES

[1] CMS Collaboration, *JINST*, **3** (2008) S08004.
[2] CMS Collaboration, *JINST*, **5** (2010) T03011.
[3] CMS Collaboration, *Phys. Lett. B*, **722** (2013) 273.
[4] D0 Collaboration, *Phys. Rev. Lett.*, **105** (2010) 221802.
[5] CDF Collaboration, *Phys. Rev. Lett.*, **104** (2010) 011801.
[6] ATLAS Collaboration, *Phys. Lett. B*, **710** (2012) 519.