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Precision Timing with PbWO Crystals and Prospects for a Precision Timing Upgrade of the CMS Barrel Electromagnetic Calorimeter at HL-LHC

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The Barrel part of the CMS Electromagnetic Calorimeter is made of 61200 scintillating lead tungstate (PbWO4) crystals, read out by avalanche photo-diodes. For the high luminosity phase of the LHC, a timing measurement with a precision of approximately 10 ps can be exploited for pileup mitigation and vertex assignment. Test beam results on the timing performance of PbWO4 crystals with various photosensors and readout electronics will be shown, along with the results from simulation studies. The implications of the very precise timing requirements on the design of the new readout electronics will be discussed.

Summary

The CMS Electromagnetic Calorimeter (ECAL) is made of 75848
scintillating lead tungstate crystals (PbWO), arranged in a barrel and two endcaps. The scintillation light is read out by avalanche photo-diodes in the barrel and vacuum photo-triodes in the endcaps. In the current on-detector electronics, the signal is amplified and then sampled at 40 MHz.

The single-channel time resolution of ECAL measured at beam tests for
high energy showers is better than 100 ps. This talk will show the time resolution achieved with proton-proton collision
data of the LHC. It will also discuss the main factors contributing to
the measured performance by comparing the results to the time resolution obtained with laser-based monitoring data.

The precise time information from ECAL has been already exploited
successfully during the LHC Run1 to extend the reach of analyses
searching for physics beyond the Standard Model, such as those looking
for displaced or delayed photons in the final state.

In addition, the time information is a valuable handle to mitigate
the pile-up of energy deposits coming from different interactions, which deteriorate the calorimeter performance in term of energy measurement and particle identification, as individual particles appear as less isolated. This will be particularly important during the Phase2 of the LHC, when the instantaneous luminosity is expected to reach peaks of up to $5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, corresponding to about 140 simultaneous events per bunch crossing.

The high level of irradiation to be sustained by the on-detector
electronics and the need to cope with an increased trigger latency
to preserve the trigger efficiency will require a replacement of the
front-end and very front-end electronics of the ECAL for the LHC Phase2. This opens the possibility to explore new electronics design to target a precision in the time measurement of few 10 ps.
Such a precise time reconstruction can be exploited to help the vertex
assignment of Higgs boson particles decaying into two photons.
The x and y coordinates of the vertex, along with the time and location of the arrival of the two photons in the detector, can be used to reconstruct the location of the third spatial coordinate of the vertex. With a time

resolution of a few 10 ps, one achieve a performance similar to or better than the one achieved in the analysis of Higgs boson decay to photons with the LHC Run1 data.

Test beam campaigns have also been performed to investigate the ultimate time performance of PbWO crystals by looking at different photo-detector configurations and by studying the effect of the travel path of scintillation light.

Along with the aforementioned results on the time resolution achieved during the Phase1 of the LHC, the talk will present the prospects for the high luminosity phase of the LHC, and the results of the test beam R\&D programs to explore the possibility of achieving a precision of few 10 ps with an upgraded CMS detector.

Presenter: CIRIOLO, Vincenzo (Universita & INFN, Milano-Bicocca (IT))

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