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Precision Timing Calorimetry for High Energy Physics

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The High Luminosity upgrade of the Large Hadron Collider (HL-LHC) and potential future Hadron Colliders operating at even higher energies will deliver unprecedented instantaneous luminosities. The detectors have to cope with a very high rate of simultaneous collisions, referred to as pile up (PU). A powerful mitigation technique uses detectors with excellent time resolution which allows association of particles to primary interactions utilizing the time-of-flight information. In this context we present studies of scintillator based calorimeter technology with the aim to achieve particle detection with a time resolution of a few 10 ps for high energy electrons. We present results from a prototype of a 1.4x1.4x11.4 cm3 sampling calorimeter cell consisting of tungsten absorber plates and Cerium-doped Lutetium Yttrium Orthosilicate (LYSO) scintillator plates. The LYSO plates are read out with wave lengths shifting fibers which are optically coupled to photo detectors on both ends. The timing performance of several photo detectors was characterized. The photo detectors tested were conventional photomultiplier tubes (PMTs), silicon photomultipliers (SiPMs), and microchannel plate PMTs (MCP-PMTs). The measurements were performed at the Fermilab Test Beam Facility, the CERN test beam and at Caltech. As a benchmark setup we use MCP-PMTs to further characterize the timing properties of the high energy showers and other experimental effects. We also present measurements with a fast laser to characterize the response of the prototype and the photo sensors. These measurements are part of an R&D program towards a large scale electromagnetic calorimeter with a time resolution on the order of 10 picoseconds, to be used in high energy physics experiments.

Summary

The High Luminosity upgrade of the Large Hadron Collider
(HL-LHC) and potential future Hadron Colliders operating at even higher energies will deliver unprecedented instantaneous luminosities.
At HL-LHC, the rate of simultaenous interactions per bunch crossing (pileup) is projected to reach an average of 140 to 200. The large amount of pileup increases the likelihood of confusion in the reconstruction of events of interest, due to the contamination from particles produced in different pileup interactions. The ability to discriminate between
jets produced in the events of interests–especially those associated with the vector boson fusion processes, and jets produced by pileup interactions, will be degraded, the missing transverse energy resolution will deteriorate, and several other physics objects performance metrics will suffer.

One way to mitigate pileup confusion effects, complementary to
precision tracking methods, is to perform a time of arrival
measurement associated with a particular layer of the calorimeter, allowing for a time assignment for both charged particles and photons. Such a measurement with a precision of about 20 to 30 ps, when unambiguously associated to the corresponding energy measurement, will significantly reduce the inclusion of pileup particles in the reconstruction of the event of interest given that the spread in collision time of pileup interactions is about 200 ps. The association
of the time measurement to the energy measurement is crucial, leading to a prototype design that calls for the time and energy measurements to be performed in the same active detector element.

In this context we present studies of scintillator based calorimeter technology with the aim to achieve particle detection with a time resolution in the range of a few 10 ps for electrons at energies of a few 10 GeV and above. We present results from a prototype of a 1.4x1.4x11.4 cm3 sampling calorimeter cell consisting of tungsten absorber plates and Cerium-doped Lutetium Yttrium Orthosilicate (LYSO) crystal scintillator plates. The LYSO plates are read out with wave lengths shifting fibers which are optically coupled to fast photodetectors on both ends of the fibers. The performance of several fast photodetectors on the time resolution was characterized. The photodetectors tested were conventional photomultiplier tubes (PMTs), silicon photomultipliers (SiPMs), and microchannel plate PMTs (MCP-PMTs). The measurements were performed at the Fermilab Test Beam Facility (FTBF) and the CERN SPS test beam and at Caltech. As a benchmark setup we use MCP-PMTs, operated with a quartz radiator as well as in secondary emission mode, to further characterize the timing properties of the high energy showers and other experimental effects.
We also present measurements with a fast laser to further characterize the response of the prototype and the photo sensors.
Studies of the impact of different types of wave length shifting materials are presented as well.
These measurements are part of an R&D program whose aim is to demonstrate the feasibility of building a large scale electromagnetic calorimeter with a time resolution on the order of 10 picoseconds, to be used in high energy physics experiments.
Our research demonstrates that with our prototype all factors influencing the time resolution can be controled controlled to within 30~ps, and the goal of obtaining a few 10 ps resolution time measurements using a LYSO-based calorimeter was achieved. The next step will be to investigate any ultimate limitation in time resolution in the limit of very large light yield, and to make improvements to the light collection efficiency in these kinds of detectors.

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