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Precision Timing Detectors with Cadmium Telluride Sensors

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Precision timing detectors for high energy physics experiments with temporal resolutions of a few 10 ps are of pivotal importance to master the challenges posed by the highest energy particle accelerators. Calorimetric timing measurements have been a focus of recent research, enabled by exploiting the temporal coherence of electromagnetic showers. Scintillating crystals with high light yield as well as silicon sensors are viable sensitive materials for sampling calorimeters. Silicon sensors have very high effciency for charged particles. However, their sensitivity to photons, which comprise a large fraction of the electromagnetic shower, is limited. A large fraction of the energy in an electromagnetic shower is carried by photons. To enhance the efficiency of detecting photons, materials with higher atomic numbers than silicon are preferable. In this paper we present test beam measurements with a Cadmium-Telluride sensor as the active element of a secondary emission calorimeter with focus on the timing performance of the detector. A Schottky type Cadmium-Telluride sensor with an active area of 1 cm^2 and a thickness of 1 mm is used in an arrangement with tungsten and lead absorbers. Measurements are performed with electron beams in the energy range from 2 GeV to 200 GeV. A timing resolution of 20 ps is achieved under the best conditions.

Summary

Precision timing detectors for high energy physics experiments with temporal resolutions of a few 10 ps are of pivotal importance to master the challenges posed by the highest energy particle accelerators. Calorimetric timing measurements have been a focus of recent research, enabled by exploiting the temporal coherence of electromagnetic showers.

In this paper, we present results of studies of a calorimeter prototype using Cadmium-Telluride (CdTe) sensors as the active material. CdTe has been studied extensively in the context of thin film solar cells and has become a mature and wide-spread technology. It has also been used as a radiation detector for nuclear spectroscopy, and is known to have high quantum efficiency for photons in the x-ray range of the spectrum. This feature is of particular interest in the context of its use in calorimetery because it would be sensitive to secondary particles in the keV range, a significant component of the electromagnetic shower. Therefore, the first study of electromagnetic showers using CdTe sensors has the potential to yield new insight into the behavior of secondary particles produced within an electromagnetic shower with energies in the keV range, and has the potential to yield an improvement on the energy measurement due to the additional contribution of the higher energy x-ray photons to which previous calorimeters were not sensitive.
The recent interest on precision timing has resulted in new studies of the timing properties of silicon sensors. These studies have found a time resolution at 20 ps level, provided a suffciently large signal size in a variety of applications ranging from calorimetery to charged particle detectors. The signal formation process in CdTe sensors are very similar to the process in silicon and has similar potential to yield precise timestamps. In this article, we study the signal response of the CdTe sensor to electromagnetic showers of varying energies and at different shower depths. We also study the timing performance of the CdTe sensors for electromagnetic showers.

The semi-conducting properties of Cadmium-Telluride has been studied since many decades, in particular in the the context of using the material in photovoltaic applications. Cadmium-telluride sensor are widely used in X-ray detectors. They have also been investigated for synchrotron radaition detectors in accelerator technology. In our previous studies we have demonstrated that increasing the primary sensor signal is crucial to achieve good timing resolutions. Cadmium-telluride features a significantly larger effciency for detecting photons in the 10 to 100 keV energy range compared to silicon sensors. The higher atomic number of Cadmium and Tellurium, averaging to about 48 for the compound bulk material, results in a higher interaction cross section for photons in this energy range. Photons with such energies are abundant in electromagnetic showers. Furthermore, CdTe sensor are available with thicknesses of 1 mm and more. The path-length of the charged shower particles in the sensor material scales accordingly, resulting in a larger primary signal. Our measurements were conducted with a CdTe Schottky type diode purchased from Acrorad. It is 1 cm^2 in transverse size and 1 mm thick. It was operated at a bias voltage of 700 V and the dark current was between 3 nA and 6 nA depending on the environmental conditions in the test beam experimental zones. The sensor

was placed in a box made of 0.3 mm copper sheets sealed with copper tape to shield against environmental noise.
A broadband amplifier with a bandwidth of 1.5 GHz was used to amplify the signals from the sensor.
We performed the measurements at the H2 beamline of the CERN North-Area testbeam facility and the T9 beamline of the CERN East-Area testbeam facility. They provide secondary electron beams from the Proton Synchrotron (PS) and Super Proton Synchrotron (SPS) of energies ranging from 2 GeV to 200 GeV. The DAQ system uses a CAEN V1742 switched capacitor digitizer based on the DRS4 chip. Wire chambers are used to measure the position of each incident beam particle in the plane transverse to the beamline. A micro-channel plate photomultiplier (MCP-PMT) detector is used to provide a very precise reference timestamp. The precision of the time measurement for both types of MCP-PMT' s is less than 10 ps.

Our initial results are encouraging and motivate future work on more detailed comparisons with simulation and more detailed
measurements of transverse and longitudinal shower profiles. We have measured the rise time for signals in the Schottky type CdTe sensor diode to be about 1.3 ns which makes them suitable as devices for precision timing applications.
The large ionization signal yield we achieve with a 1 mm thick sensor is equally favorable for precision timing applications. We observe dependencies of the measured time on the geometric position of the beam particle impact point on the sensor, which may indicate differences in the charge collection dynamics. More detailed studies of this aspect are needed and a more optimal design of the
connection of the sensor readout is envisioned. Correcting for these dependencies yield time resolutions of 25 ps for a single layer CdTe sensor of transverse area 1 cm$\times$ 1cm,
uniformly sampled by the electromagnetic shower of electrons with energy above 100 GeV
after 6 radiation lengths of tungsten and lead absorber. In the most favorable region of the sensor we observe time resolutions as low as 20 ps. These initial results are encouraging and motivate
further in-depth studies in the future.

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