DOE-OREGON-13575

Silicon-tungsten Electromagnetic Calorimetry Final Report, DE-SC0013575

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March 2018

Abstract

A highly granular silicon-tungsten electromagnetic calorimeter has been designed and modelled, and a partial prototype was constructed, tested and evaluated.

In order to demonstrate the feasibility of assembling a highly compact electromagnetic calorimeter without printed circuit boards and with direct bonding of chips to wafers, a first prototype stack for an ECAL was constructed, following the design constraints of the the ILC SiD experiment. A section of this SiD ECAL with KPiX readout[1] was exposed to a 12.1 GeV electron beam at the SLAC End Station (A) Test Beam Facility. A schematic of the test setup is shown in Figures 1 and 2. This aggressive design has an active gap between absorber plates of 1.25 mm, a cell size of 13 mm^2, and an effective Molière radius of 14 mm.

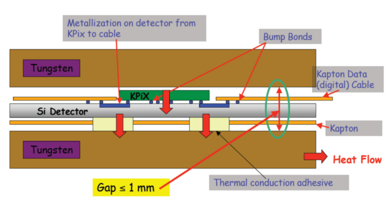

Figure 1: The 1.25 mm gap between tungsten absorber layers includes a 0.3 mm silicon sensor layer bump-bonded to the KPiX readout chip.

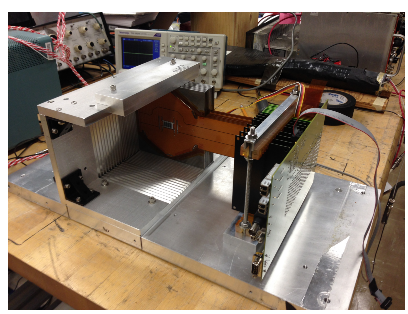

Figure 2: The ECAL prototype setup at SLAC, in a silicon-first arrangement.

In the initial test, a stack of nine silicon sensor planes and eight tungsten plates (corresponding to six radiation lengths) was exposed to beam. The full stack will ultimately consist of 30 layers as in the SiD ECAL design. Data was taken over a four-day period with a beam rate between 0.5 and 5 electrons per pulse. The beam was concentrated in a small area of the stack, with mean separation of two electron events of 15-20 mm. This data collection provides good measurements of multiple particle overlap and reconstruction of overlapping showers [2]. Figure 3 shows the measured total charge distribution for two of the exposure runs compared to a GEANT4 simulation. The distribution was best fit to the simulation assuming a Poisson distribution of beam particles with an average of 0.87. Comparison of the deposited energy distribution in each of the nine layers also agrees well with the simulations.

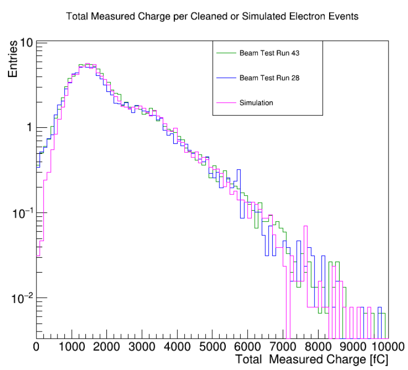

Figure 3: Prototype runs match very well with GEANT4 simulated data.

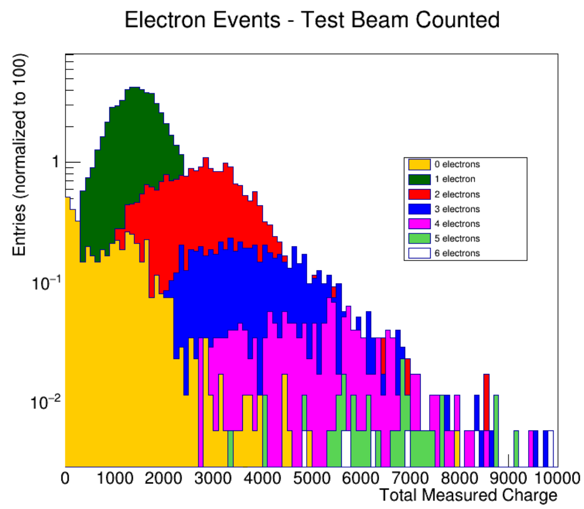

Figure 4: Distributions of the number of counted electrons.

An algorithm was developed to count the number of incident electrons in each event. The algorithm uses the energy and distribution of energy in each of the nine test beam layers. After confirming the success of the algorithm with simulated events, it was applied to the test beam data. Figure 4 shows the test beam distribution of total energy in the nine layers for each of the counted number of events.

The results of this analysis were used to assess the ability of the calorimeter to separate two showers as a function of the separation of the showers. Figure 5 presents the two shower separation efficiency versus separation distance. The separation efficiency achieves 100% for separations of > 10 mm.

The beam test also showed crosstalk from capacitive coupling among pixels. A novel improved design of the sensor was developed that only used two metal layers. As shown in Figure 6, Metal 1 is used as before to connect the diode implant to the signal traces on Metal 2. However, that connection is only a small disk over the implant, and the rest of Metal 1 is used as a shield, with

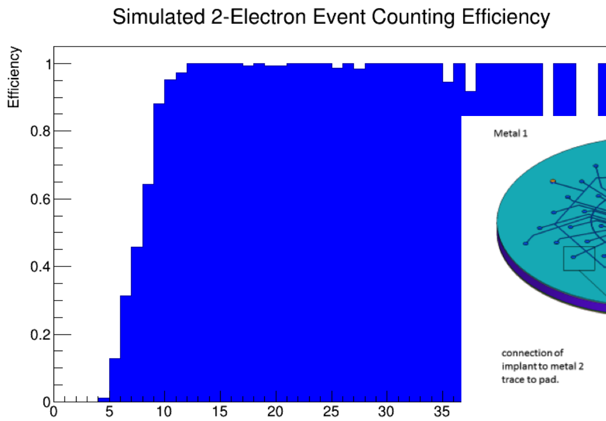

Figure 5: Efficiency of electron counting algorithm with simulated two electron events.

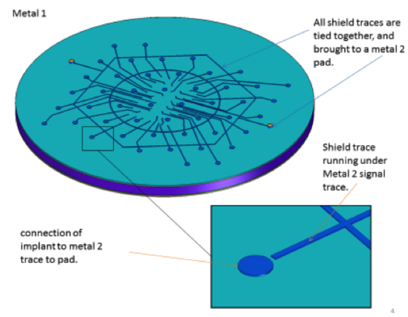

Figure 6: Schematic of the shielded sensor.

traces running under the signal traces and held at a fixed potential. A new set of prototypes was fabricated, with an additional improvement by the sensor vendor of a gold surface stack under bump metallization for KPiX bonding. It was also decided that the cable bump bonding procedure was too cumbersome, and a new cable with wire bond connections to the sensor has been developed. The new sensors and cables are about to be tested [3].

The studies reported here have also been extended to consider practical issues for the integration into the 4π detector, SiD [4]. The full SiD simulation with appropriate geometry was employed, where overlapping modules creates physically significant effects. Studies of appropriate energy and angle-dependent calibration was studied and applied. The energy and angle-dependent leakage was also investigated and reported.

The results from this work are now being applied in a DESY test beam experiment [5].

References

[1] J. Brau, M. Breidenbach *et al.*, "KPiX - A 1,024 Channel Readout ASIC for the ILC," SLAC-PUB-15285 (2013), 2012 IEEE Nuclear Science Symposium, `http://slac.stanford.edu/pubs/slacpubs/15250/slac-pub-15285.pdf`

[2] A. Steinhebel and J. Brau, "Studies of the Response of the SiD Silicon-Tungsten ECal," Proceedings of the 2016 Linear Collider Workshop (LCWS), Morioka, Japan, arXiv:1703.08605 [physics.ins-det].

[3] A. Steinhebel for M. Breidenbach *et al.*, "SiD ECal Progress," Americas Workshop on Linear Colliders, 26 June 2017, https://agenda.linearcollider.org/event/7507/contributions/39239/.

[4] A. Steinhebel and J. Brau, "SiD ECal geometry and Calibration studies," Americas Workshop on Linear Colliders, 26 June 2017, https://agenda.linearcollider.org/event/7507/contributions/39277/.

[5] A. Steinhebel, " ECal studies," Americas Workshop on Linear Colliders, 30 June 2017, https://agenda.linearcollider.org/event/7507/contributions/39392/.