Novel silicon sensors for high-precision 5D calorimetry

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Snowmass 2021 Letter of Interest, Instrumentation Frontier

1 Introduction

Particle flow calorimetry is a promising concept for future high energy colliders. Particle flow concept primarily aims precise jet energy measurements using highly granular detection layers both in transverse and longitudinal directions to separate calorimetric clusters from individual particles inside jets, which also gives precise images of development of showers (as "imaging calorimetry"). Each hit in a sensor sell gives energy deposit and position with a resolution of the size of the cell. Recently possible further improvements of spatial and timing resolution in each cell are being considered, aiming for additional functionality such as particle identification by Time-of-Flight method and particle direction measurement. Those additional information can also help improving pattern recognition possibly by deep learning to utilize all 5-dimensional information of sensor hits.

An electromagnetic calorimeter system based on silicon-pad sensors (SiW-ECAL)[1] have long been developed for a particle flow detector in CALICE collaboration with a focus to the application to the International Linear Collider (ILC)[2]. Two possibilities are being investigated for 5D calorimetry with silicon sensors: Position-sensitive Silicon Detectors (PSDs) and Low Gain Avalanche Detectors (LGADs).

PSDs are silicon sensors which have multiple electrodes in each cell to share charges which are resistively split to obtain hit position. We are thinking of PSDs to replace innermost layers of ECAL to improve pointing resolution of photons. Small prototype PSDs have been produced to check basic performance such as position resolution and reproducibility. They are designed to be nearly compatible with the current SiW-ECAL pads, which requires minimal modification to the readout electronics and assembly procedure for replacement.

LGADs are silicon sensors with multiplication layer inside. They have been developed for applications of LHC detectors to separate pileup particles by time information. Timing resolution to a few tens of picoseconds is reported[3]. This can help particle identification of hadrons (π, K, p etc.) which are especially difficult with other methods. Timing resolution, gain variation, stability and position dependence of them are important characteristics of the LGAD sensors. We are investigating them with prototype sensors, with a support by U.S.-Japan Science and Technology Cooperation Program in High Energy Physics.

2 PSD: Ongoing studies and plans

Our prototype PSD sensors have 4×4 cells with 4 electrodes each, for 64 readout channels. Each cell has 5.5×5.5 mm^2 area, which is the same as SiW-ECAL specification. To suppress the increase of readout channels, sharing readout pads with neighboring cells is considered. Basic function of charge sharing is already demonstrated[4], and detailed study with position resolution, distortion, reproducibility etc. is being prepared with a beam test in early 2021. Electronics developed for

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SiW-ECAL are used for the readout. Optimization of surface resistance and structure of the surface is also being done.

Performance of position reconstruction with the improved position resolution should be done with realistic simulation. We are preparing the reconstruction algorithm and performance study in a framework of detector simulation for the International Large Detector (ILD)[5]. This should be concluded well before the detailed design of the ILD is fixed. Effect of the direction measurement on the jet reconstruction and physics studies should be also investigated.

3 LGAD: Ongoing studies and plans

We are considering to replace several SiW-ECAL layers with LGAD layers to improve timing resolution of the clusters in the calorimeter. Cell size similar to SiW-ECAL with good stability and flat response over the surface are desired in addition to the timing resolution. Currently we are using packaged APDs from Hamamatsu to demonstrate essential functions of the LGAD. Previous test beam indicates that the hit-by-hit gain variation is rather big especially with inverse LGAD, which has multiplication region at back side, to obtain better flatness of the gain[6]. More measurements are prepared for another test beam early 2021. Realistic design for the application of SiW-ECAL will follow after the measurements.

Effect of the timing resolution of the hits to particle ID should be investigated in detail. The full replacement of all ECAL cells to LGAD is not realistic because of the cost of the sensors, power consumption at electronics, stability etc. Optimization of the layers to replace ECAL to LGAD should be investigated with detector simulation studies to obtain dependence on particle ID and jet reconstruction. Purely electonic upgrade to obtain medium timing resolution on all layers of ECAL without replacing sensors should also be investigated and compared with the performance with partial LGAD replacement.

References

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