CALICE
R&D for a highly granular silicon tungsten electromagnetic calorimeter, SiW-ECAL

Letter of Interest for the Snowmass Study 2021
Instrumentation Frontier - Calorimetry

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Abstract

Highly granular calorimeters play a central role in the concepts of future detectors for particle physics. They present practical as well as conceptual challenges addressed by the various prototypes of the CALICE collaboration. This note sketches the main aspects of the CALICE SiW-ECAL prototypes R&D.

1 Context of the project

The Particle Flow Approach (PFA) employed to improve the measurement of jet energies in high-energy particle collisions, relies on the combination of information from a high precision tracker and a very granular ("imaging") calorimeter. Compared to traditional, the imaging calorimetry poses additional technological challenges (compactness, embedded electronics, power limitation, high level of integration, scalable design) but opens room for innovative measurements such as track and shower separation, shower pattern recognition, improved particle-ID; all of them will be enhanced by using timing information.

The first dedicated sub-detector will be the CMS HGCAL for the LHC upgrade but some detectors fully based on this concept, such as ILD, SiD or CLIC-dp, will be built in the near future at Higgs factories (ILC, CLIC, CEPC, and FCC-ee). The CALICE collaboration studies imaging calorimeters in all aspects: design, realization, and analysis of prototypes. This note focuses on the status of the Silicon-Tungsten ECAL, where the challenges accumulate; other concepts are addressed separately.

After the realization of a physics prototype (2005–2011) as a proof of concept, CALICE has constructed a technological prototype of a highly granular silicon tungsten electromagnetic calorimeter (SiW-ECAL) [1], taking into account the many constraints of a large scale detector, using ILD as a baseline. The most critical part is the so-called Active Sensor Unit (ASU), base element of detection, including a PCB, glued Si sensors, and ASICs.

By the end of 2020, after ten years of R&D, a calorimeter stack with around 20 layers, each composed of a single ASU, of size $18 \times 18 \times 0.5\,\mathrm{cm}^3$ with a total depth of about one interaction length will be available. The ASUs are subdivided into 1024 readout cells around $5 \times 5\,\mathrm{mm}^2$. Their embedded front-end readout electronics records the energy deposit and the time at which a cell is hit, with 12-bit resolution on a large dynamic range (1–3000 MIPs) and a time precision of $\sim 1.5\,\mathrm{ns}$ for a MIP (very modest compared to the possible raw time precision of $2.5\,\mathrm{mm/c} \simeq 12\,\mathrm{ps}$).

In the coming years, we will fully characterize the prototype in beam tests in conditions compatible with the ILC (1-2 % power cycles), in terms of linearity uniformity, noise, and cross talk, for MIPs, electromagnetic and hadronic showers. Detailed characterization of the spatial shape of electromagnetic and hadron cascades in tungsten, will be complemented by the timing information.

The beam test program of CALICE foresees combined beam tests at DESY, CERN, and maybe FNAL, with already existing prototypes of hadronic calorimeters from 2021 onward.

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With an overall depth of about 6 interaction lengths, starting with the much higher segmentation of the ECAL, where 55 % of hadrons interact [2], these setups are an important validation of the PFA performances with realistic devices.

2 Aspects and objectives of future R&D

System issues: The design of an ASU must take into account its integration into long cassettes of up-to twelve chained ASUs, to be inserted in carbon-fiber-tungsten module structures. A first working reduced electronics demonstrator has already pointed at improvements [3]. At linear colliders, the layer will be powered by pulses with a frequency of 5-15 Hz for a duration of 1 ms. Careful power management using local storage based on low ESR capacitances and precise regulators on the PCB close to the readout ASICs will be tested within the coming year.

A new ASIC design, allowing for full zero-suppression, and individual ASIC reconfiguration has to be developed for the final experiment.

Large sensors: So far, the prototypes are based on diode matrices cut out from 6" wafers. Mainly for cost reasons, the trend set by the CMS-HGCAL is towards 8" wafers. Therefore, we will conduct an R&D program to yield updated 8" wafers ASUs in about two years, revamping PCB and gluing procedures. This R&D program will benefit from the CMS experience, and we are looking forward to a fruitful exchange of experience during the Snowmass process.

Thin design: So far, most prototype layers use ASICs equipped with BGA packaged ASICs yielding an overall ASU thickness of about 3 mm. An ultra-thin ASU called chip-on-board (COB), 1.2 mm thick, has also been developed, where the ASICs are mounted in recessed cavities. First tests of the COB ASUs have been successfully performed at the 2019 beam test at DESY [4], and the R&D will be pursued, especially on ancillary components.

Reliability: All components of the detector (connectors, flat capacitors, ...) have to work reliably in an experiment for more than twenty years, possibly operated in a pulsed mode in a strong magnetic field; they should be qualified in dedicated aging test benches reproducing the expected stress.

3 Conclusions

The CALICE SiW-ECAL is in the middle of a comprehensive R&D program. Ideally within 5 years, prototypes will evolve into an integrated full-scale module prototype. This requires innovative technological solutions, sustained financial support, and human resources. Many R&D aspects are shared between circular and linear Higgs factories; the most notable difference is the power management. A scrutinizing comparison of both modes of operation will be an interesting study on its own.

References

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