Development of Highly Granular Scintillator Strip Electromagnetic Calorimeter

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Abstract

Highly granular electromagnetic calorimeter based on scintillator strip with SiPM readout (Sc-ECAL) is under development in the framework of the CALICE collaboration for future electron-positron colliders such as ILC and CEPC. After the validation of the concept with the physics prototype, a technological prototype with full layers is being constructed to demonstrate the performance of Sc-ECAL with more realistic technical implementation. The status and prospects of the R&D of Sc-ECAL are briefly described.

1 Introduction

The physics program at future electron-positron colliders requires a jet energy resolution of 3–4% over a wide energy range. The particle flow calorimetry with highly granular calorimeters is proposed to achieve this unprecedented jet energy resolution. International R&D efforts on the highly granular calorimeters based on different technology options for both electromagnetic and hadronic calorimeters are in progress being coordinated by the CALICE collaboration.

The electromagnetic calorimeter based on scintillator strip with SiPM readout (Sc-ECAL) is one of the promising technology options. The detection layers with scintillator strips ($45\,\mathrm{mm} \times 5\,\mathrm{mm} \times^{\mathrm{t}} 2\,\mathrm{mm}$ each) coupled to SiPMs are stacked alternately in an orthogonal orientation to achieve an effective transverse segmentation of $5 \times 5\,\mathrm{mm}^2$, allowing to significantly reduce the number of readout channels. The same performance as the real segmentation of $5 \times 5\,\mathrm{mm}^2$ is achievable with an appropriate reconstruction algorithm. The detection layers are interleaved by tungsten absorber layers totalling more than $20\,X_0$. The Sc-ECAL with the compact and cost-effective design is proposed for ILC-ILD[1] and CEPC-ECAL[2].

2 R&D Status

The concept of Sc-ECAL was already validated using a physics prototype [3]. The R&D efforts now focus on demonstrating the performance of Sc-ECAL with a technological prototype with fully integrated detection layers, which is now under construction.

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Important progresses have recently been made on the SiPMs for Sc-ECAL. MPPCs [1] with a smaller pixel pitch of 10 or 15 μm have been developed by Hamamatsu Photonics K.K[4], which can provide a larger dynamic range required for Sc-ECAL. Further improvements have been made for the most recent small-pixel MPPCs, including reduced optical cross-talk by a trench structure between pixels, lower dark noise and higher photon detection efficiency, which have been confirmed by lab tests.

In the previous studies, the SiPM was attached to the side edge of the strip. New designs of the SiPM readout at the bottom side of the strip are being developed for more uniform response and a better compatibility with future large-scale production. Especially a recently developed design based on a strip with a dimple directly coupled to a surface-mounted SiPM on the PCB, which is similar to the SiPM-on-tile technology of AHCAL, shows a promising performance. Another design of the scintillator strip with double SiPM readout is also being studied. There are possible advantages over the standard design with single SiPM readout such as a noise reduction by taking coincidence and a possible capability of hit position reconstruction, although twice longer strips (90 mm) have to be used to retain the total number of the readout channels.

Low cost and high light yield plastic scintillator materials are also being developed for Sc-ECAL. The development focuses on the polystyrene-based scintillator produced by the injection moulding method, which is suitable for a large-scale production. A reasonably high light yield, which is 65–70% of that of the commercial PVT-based scintillator, has been achieved by optimizing the production parameters.

The fully integrated technological prototype with 32 layers (30 standard layers with single SiPM and 2 layers with double SiPM) is under construction by a joint effort of the R&D groups for the ILC-ILD and the CEPC-ECAL, for which most of the recent developments are implemented, to demonstrate the performance of the Sc-ECAL technology and its scalability to the full-size detector. An important advancement of the technological prototype compared to the physics prototype is the front-end readout electronics fully integrated into the detection layers. Each readout board with six ASICs (SPIROC2e from OMEGA group[5]), called ECAL base unit (EBU), is equipped with 210 scintillator strips. The assembly of the prototype has been completed and the commissioning is in progress.

The remaining challenges include the development of the detector assembly system for the large scale production, testing the power pulsing operation of the integrated electronics for the ILC Sc-ECAL and optimizing the cooling system for the integrated electronics for the CEPC Sc-ECAL where a continuous operation is required unlike the ILC Sc-ECAL.

3 Prospects

The technological prototype is supposed to be tested in beam at the DESY test beam facility at the beginning of year 2021. It will hopefully be followed by combined test beam experiments together with other CALICE calorimeter prototypes such as AHCAL.

References

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[2] CEPC Conceptual Design Report: Volume 2 - Physics & Detector, arXiv:1811.10545v1.

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[1] MPPC is the product name of the SiPM of the Hamamatsu Photonics K.K.