Snowmass 2021 Letter of Interest

Physics potential and prototyping of technological solutions for timing layers in highly granular calorimeters

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1 Introduction

Single-channel timing with a precision of a few 10 picoseconds is emerging as a key enabling technology for future experiments in particle physics. Dedicated timing detectors are part of the Phase 2 upgrades of ATLAS and CMS, where timing for minimum-ionizing particles will contribute significantly to the ability of the detectors to cope with high levels of pile-up and in the reconstruction of the hard scatter event. The question of timing will extend to future experiments at the energy frontier, both at lepton colliders from "Higgs Factories" to multi-TeV colliders and future hadron colliders.
For the past 15 years, the CALICE collaboration has been developing highly granular electromagnetic and hadronic calorimeters, primarily for experiments at future linear electron-positron colliders using particle flow event reconstruction. Following the successful demonstration of the principle of such detectors, which has resulted in the adoption of the concept in other concepts, for example by the CMS high granularity calorimeter for the HL-LHC, the focus of the R&D activities in CALICE have shifted to the solution of the technological challenges in full scale systems. Recently, a small-scale silicon-tungsten ECAL prototype [1], and a full-scale SiPM-on-tile based hadron calorimeter [2] have been constructed and tested in particle beams. These prototypes provide high spatial granularity and full analog amplitude information, and timing accuracy of approximately 1 ns on the single cell level for minimum-ionizing particles.
Improved timing resolution, either over the full detector volume or in dedicated timing layer(s), may further increase the physics potential of experiments using such detectors, as for example illustrated in [3].

2 Goals and General Concept

The goal of this LoI is to explore the physics motivation, to identify technological challenges, and to define an R&D program for one or several timing layers integrated into highly granular electromagnetic and hadronic calorimeters developed by CALICE.
The main goal is to develop a realistic concept of timing layers integrated into silicon- and scintillator-based electromagnetic and hadronic calorimeters for a timing resolution of 30 ps for MIP energy deposits. The benefits of these dedicated timing layers will be compared to a more moderate time resolution on the order of 100 to 200 ps for all readout cells of the detector volume.

3 Next Steps

The program is expected to proceed along two complementary avenues:

- The benefits will be explored by reviewing and extending studies of such timing layers within the calorimeter volume. This will also require an understanding of trade-offs between benefits provided by the timing elements and a possible negative impact on calorimetric performance, and the comparison to benefits provided by more moderate time resolution available throughout the full detectors.

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- The definition of the outline of an R&D program to develop detector concepts that enable timing layers as part of highly granular calorimeter systems. The systems should be integrated into silicon, scintillator / SiPM based electromagnetic and hadronic calorimeters. Possible technologies envisaged are silicon and optical readout-based timing systems. Key questions will include, among others, the performance of such systems as well as the integration challenges in the area of mechanics, thermal behavior and cooling needs, electronics and power requirements, relative to current systems and detectors with moderate improvements of timing capabilities in the full volume.

References

[1] K. Kawagoe et al., *Beam test performance of the highly granular SiW-ECAL technological prototype for the ILC*, *Nucl. Instrum. Meth. A* **950** (2020) 162969, [arXiv:1902.00110].

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[3] S. Chekanov, A. Kotwal, C.-H. Yeh and S.-S. Yu, *Physics potential of timing layers in future collider detectors*, arXiv:2005.05221.