Letter of Interest to Snowmass 2021

# Homogeneous Hadron Calorimetry for Future Higgs Factory Experiment


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Total absorption electromagnetic calorimeters (ECAL) made of inorganic crystals provide the best energy resolution and detection efficiency for photon and electron measurements, so are the choice for those HEP experiments where high resolution is required. Recent HEP applications are CMS PWO [1], g-2 $PbF_2$ [2], Mu2e CsI [3] and CMS LYSO [4]. The experimental situation will be different at a future generation of experiments when an $e^+e^-$ Higgs Factory will be elevated to the top priority for the field. On one hand the low multiplicity and low event rate eliminate most of the environmental and technical challenges to the detector design. On the other hand, the ultimate energy resolution for hadronic decays of Z, W and Higgs bosons will be of critical importance for the full exploitation of the physics potential offered by the experiments. An extensive R&D program indicates that the calorimeters with the energy resolution of the order of 1-1.5% for ~100 GeV electrons and jets can be constructed [5]. An incomplete list of factors limiting the attainable energy resolution includes:

- Leakage fluctuations due the final size of practical detectors as well as the finite integration time.
- Fluctuations of the energy lost in nuclear processes (binding energy).
- Response differences for different particles (especially low energy protons in sampling calorimeters).
- Response and calibration differences between different detector parts (EM and hadron calorimeters or active and passive components).
- Sampling fluctuations.

The best energy resolution for precision electroweak mass and missing-energy measurements can be attained with a homogeneous calorimeter featuring total absorption for electrons, photons and jets. Its totally active medium allows even-by-event correction for the binding energy losses. Such a calorimeter collects signals produced over very large volume while preserving some spatial information. An inorganic scintillator-based calorimeter is the only practical solution feasible at present with several possible techniques available for compensation of the binding energy losses by either dual readout and/or dual gate [6]. Recent advances in inorganic scintillating crystals and glasses, and compact silicon-based photodetectors enable a conceptual design of a realistic calorimeter. We propose three-pronged R&D efforts to develop a homogeneous calorimeter system, including both ECAL and HCAL with fine segmentation and no boundary between them, for a future $e^+e^-$ Higgs Factory at the ILC or FCC-ee:

1. Consolidation and optimization of the detector simulation tool. A huge body of the existing simulations will be systematically organized and augmented where necessary, to provide a library of space and time development the electromagnetic and hadronic/jets showers in various materials. Total absorption and typical sampling geometries will be included. A GEANT-based detector simulation tool allowing for flexible detector designs will be developed on the base of the existing artg4tk [7] and CaTS products. GPU-based optics simulation will allow large statistical samples of the events to be produced. The simulation tools will allow for the optimization of the complete detector geometry and the full reconstruction of physical events.

2. Development of novel inorganic scintillators. Because of the huge detector volume novel inorganic scintillators with a mass production cost of less than $1/cc is required for this detector concept. Such a scintillator should also have short nuclear interaction length and be UV transparent to allow readout of both scintillation and Cherenkov light. Based on previous investigations our plan is to investigate titanium doped sapphire crystals (Sapphire:Ti) [8], Alkali-free Ce-doped and co-doped fluorophosphate glasses [9], and recently developed glasses [10]. $CsPbX_3$ (with X = Cl, Br, I, mixed Cl/Br and mixed Br/I) quantum dots (QD) featured with very bright and tunable emission over visible wavelength region [11] will also be investigated.

3. Photosensors for Cherenkov and Scintillation light detection. Many photosensors are available for detection of normally very bright scintillation light from inorganic scintillators, but few options can detect UV range Cherenkov light starting at a wavelength of ~200 nm. Furthermore, detecting enough Cherenkov light will require sensor areas similar to the total area of the crystal faces in addition to UV wavelength sensitivity. We will investigate novel materials that have the potential to detect wavelengths in the near to deep UV range [12, 13, 14], and our aim is to develop a UV wavelength photosensor that is very thin and that can cover multiple faces of a crystal calorimeter cell for the purpose of Cherenkov light detection.

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