Letter of Interest to Snowmass 2021

Development of Novel Inorganic Scintillators for Future High Energy Physics Experiments

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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 the CMS PWO ECAL [1], the g-2 PbF_2 ECAL [2], the Mu2e CsI ECAL [3] and the CMS LYSO-based barrel timing layer (BTL) detector [4]. Novel crystal detectors are continuously being discovered in academia and in industry. Continuing our on-going research, we plan to develop novel inorganic scintillators of three categories for future HEP experiments at the energy and intensity frontiers. They are (1) bright, fast, radiation hard inorganic scintillators for an ultra-compact and radiation hard ECAL at the FCC-hh, (2) ultrafast crystals for an ultrafast calorimeter and a precision time of flight (TOF) detector, and (3) cost-effective inorganic scintillators for a homogeneous hadron calorimeter at a future lepton Higgs factory collider, such as the ILC or FCC-ee.

1. RE3+ (Ce^{3+} or Pr^{3+}) activated bright, fast and radiation hard inorganic scintillators, such as LYSO, LuAG, GGAG, GYAG and GLuAG, in both crystal and ceramic form. We have measured radiation harness of LYSO crystals against ionization dose up to 300 Mrad [5], neutrons up to 9×10^{15} n_{eq}/cm^2 [6] and protons up to 8×10^{15} p/cm^2 [7]. The results of these investigations served as a foundation for the LYSO+SiPM BTL detector for the CMS upgrade for the HL-LHC [4]. We also found that radiation hardness of some novel scintillating ceramics, such as LuAG:Ce [8], is better than LYSO crystals. Such a scintillator would serve as a foundation for a fine segmented ultra-compact and radiation hard calorimeter to be operated in ultra-hostile radiation environment, such as 100 Mrad and 3×10^{16} n_{eq}/cm^2 expected by the endcap calorimeter at the FCC-hh, and even 500 Grad and 5×10^{18} n_{eq}/cm^2 expected by the forward calorimeter at the FCC-hh [9].

2. Ultrafast core-valence luminescence inorganic scintillators, such as yttrium doped barium fluoride (BaF_2:Y) crystals. BaF_2 crystals have a unique ultrafast scintillation light with 0.5 ns decay time, but also a slow scintillation component with a decay time of 600 ns, which causes pile-up for high rate environment. Our previous work

found that Yttrium doping is effective on suppressing the slow component, and keeping the amplitude of the ultrafast component unchanged [10, 11, 12]. BaF_2:Y crystals thus provides a foundation for an ultrafast total absorption ECAL for the Mu2e-II experiment to face the challenge of unprecedented event rate [13]. Since BaF_2 crystals are featured with the highest light yield in the 1^{st} ns as compared to all other inorganic scintillators they may also help to break the ten ps time barrier for a time of flight (TOF) detector [14].

3. Cost-effective inorganic scintillators with a mass production cost of less than $1/cc, such as titanium doped sapphire crystals (Sapphire:Ti) [15] and Alkali-free Ce-doped and co-doped fluorophosphate glasses [16] etc. Such a material may be used to construct a homogeneous hadron calorimeter (HHCAL), including both electronic and hadronic parts, featuring total absorption for electrons, photons and jets, and providing the best energy resolution for precision electroweak mass and missing-energy measurements for HEP experiments at a future lepton Higgs factory collides, such as the ILC or FCC-ee.

4. $CsPbX_3$ (with X = Cl, Br, I, mixed Cl/Br and mixed Br/I) quantum dots (QD) featured with very bright and tunable emission with sub-nanosecond decay time over visible wavelength region [17] will also be investigated. Such a QD-based inorganic scintillator will also find applications in future HEP experiments.

In all the above developments, we plan to use the existing facilities at Caltech, and keep a close collaboration with industry through e.g. the DOE SBIR program. Scintillator performance, including excitation/emission spectra, optical absorption, light output, decay time and radiation-induced damages and color center densities after ionization dose, neutron and proton fluences will be investigated. Irradiation facilities at Caltech and national labs, e.g. LANSCE, will be used. The inorganic scintillators developed are expected to find broad applications beyond HEP experiments, such as TOF positron emission tomography (TOF-PET) [14, 18] and GHz hard x-ray imaging [19, 20] for a future free electron laser-based research facility.

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