RADiCAL: Ultra-compact, Radiation Hard, Fast-timing EM Calorimetry

Salim Cerci, Deniz Sunar Cerci[1]
Adiyaman University, Adiyaman, Turkiye
[1]also at Yildiz Technical University, Istanbul, Turkiye

Liyuan Zhang, Renyuan Zhu
California Institute of Technology, Pasadena, CA USA

Ugur Akgun[2], James Wetzel[2]
Coe College, Cedar Rapids, IA USA
[2]also at University of Iowa, Iowa City, IA

Carlos Perez Lara[3]
Hofstra University, Hempstead, NY USA
[3]also at University of Virginia, Charlottesville, VA USA

Dylan Blend, Paul Debbins, Ohannes Kamer Koseyan,
Alexi Mestvirishvili, Yasar Onel, Aldo Penzo
University of Iowa, Iowa City, IA USA

Buse Duran, Selbi Hatipoglu, Berkan Kaynak, Onur Potok,
Suat Ozkorucuklu, Ali Tosun, Caglar Zorbilmez
Istanbul University, Istanbul, Turkiye

Ilknur Hos
Istanbul University – Cerrahpasa, Istanbul, Turkiye

Kerem Cancocak, Gizem Gul Dincer
Istanbul Technical University, Istanbul, Turkiye

Thomas Barbera, Colin Jessop, Daniel Ruggiero, Randal Ruchti,
Mark Vigneault, Mitchell Wayne, Yuyi Wan
University of Notre Dame, Notre Dame, IN USA

Thomas Anderson, Nihal Chigurupati, Bradley Cox, Max Dubnowski,
Alexander Ledovskoy
University of Virginia, Charlottesville, VA USA

Bora Isildak, Reyhan Kurt, Ayben Karasu Uysal, Taylan Yetkin
Yildiz Technical University, Istanbul, Turkiye

(Names in red are students)

Project Abstract/Summary

To address the challenges of providing high performance calorimetry and other types of instrumentation in future experiments under high luminosity and difficult radiation and pileup conditions, R&D is being conducted on promising optical-based technologies that can inform the design

of future detectors, with emphasis on ultra-compactness, excellent energy resolution and spatial resolution, fast timing capability and radiation hardness of the components. The strategy builds upon the following concepts: use of dense materials to minimize the cross sections and lengths (depths) of detector elements; maintaining Molière radii of the structures as small as possible; use of radiation-hard materials; use of optical techniques that can provide high efficiency and fast response while keeping optical paths as short as possible; and use of radiation resistant, high efficiency photosensors.

Recent studies have been conducted with a single modular structure called a RADiCAL module, a Shashlik/Kebap-like structure, consisting of 29 layers of LYSO:Ce scintillator of 1.5 mm thickness interleaved with 28 tungsten plates of 2.5mm thickness. The arrangement forms an ultracompact module of 14 x 14 mm^2 cross section and 11.4 cm length, having a depth corresponding to 25 radiation lengths and equivalently 0.9 absorption lengths. Light collection and transfer from the scintillation layers to photosensors is enabled by quartz capillary tubes which act as waveguides and into which are inserted specialized solid filamentary wavelength shifters (WLS) developed through this research program, including DSB1 organic plastic filaments and LuAG:Ce ceramic WLS filaments and quartz rods which are fused into the regions not occupied by the WLS. SiPM photosensors are positioned at both upstream and downstream ends of the capillaries. The upstream sensors detect WLS light. The downstream sensors detect WLS + Cerenkov light. The transmitted light signals are detected with HPK SiPMs, that are read out with both low-gain amplifiers for energy measurement and high-gain amplifiers for timing measurement.

In past work, the radiation hardness of the various components has been studied and qualified, and the energy resolution measured and compared with simulation. The aim of the current R&D effort is focused on four steps:

(Step 1) To measure the timing resolution and spatial precision of shower localization using a RADiCAL module in electron beam at CERN, over the energy range 25 GeV < E < 150 GeV, by making the timing and spatial measurements at the EM shower maximum, where the number of charged shower particles is very large and where the shower transverse size is scaled by the radiation length rather than the Molière radius. GEANT4 simulation indicates that a timing resolution of $\sigma_t \leq 25$ ps and spatial localization of a few millimeters might be achieved in a single module by this method. The objective here is to measure the actual timing and spatial performance using DSB1 and LuAG:Ce wave shifters and compare the results with the simulation. This step is currently underway.

(Step 2) Based on the results of step one, GEANT4 simulation will be used to design a next generation RADiCAL module that will simultaneously satisfy the timing and spatial resolution requirements and bring the energy resolution to design requirements appropriate for endcap/forward physics applications and for FCC-hh operating conditions: $\sigma_E/E = 10\%/\sqrt{E} \oplus 0.3/E \oplus 0.7\%$. This is expected to be accomplished by increasing the sampling fraction of the LYSO:Ce layers and through the use of the new WLS filaments in quartz capillaries. Based upon the simulations, a new module will be designed, built and tested in high energy electron beam at CERN to confirm the design.

(Step 3) Once the design is confirmed, a 3x3 modular array will be designed and fabricated to study shower reconstruction, timing and position and energy resolution, and transverse and longitudinal uniformity. The array would be tested in high energy electron beam at CERN.

(Step 4) The modular array is then foreseen to be used as a test bed for new scintillators, wave shifters and photosensors to further improve performance, radiation resistance and cost efficiency.

The impact of this research and development program, while directed toward future colliding-beam and fixed target/forward physics applications, is not experiment specific, is potentially broad and significant and can be expected to inform further developments in high energy physics instrumentation. The technological innovations are versatile and can be applied in particle physics, nuclear physics, materials science, basic energy sciences and extended to medical physics and related domains.