High-Granularity Crystal Calorimetry Letter of Intent

Future lepton colliders provide a unique opportunity to probe the Standard Model and potentially uncover new physics beyond the Standard Model with Higgs, W, and Z bosons richly produced in the exceptionally clean environment. The recently released European Strategy Updates on the Particle Physics [1] elaborates this consensus that an electron-positron Higgs factory is the highest-priority next collider, including implementations such as the Circular Electron Positron Collider (CEPC) [2, 3], the Future Circular Collider (FCC-ee) [4], and International Linear Collider [5]. The precision physic programs set a stringent requirement on the jet energy resolution to separate and measure hadrons and jets. Detectors based on the Particle-Flow Approach (PFA) [6] provide an essential and feasible option to meet this goal and achieve an unprecedented jet energy resolution of around $30\%/\sqrt{E(\mathrm{GeV})}$), which further requires calorimetry to be finely segmented in 3 dimensions. Within the CALICE Collaboration [7], as proof-of-principles, various high-granularity calorimetry options have been extensively studied with prototyping and beam tests.

A highly granular crystal electromagnetic calorimeter (ECAL) is newly proposed in the context of the PFA-oriented detector design for future lepton colliders, with an aim to achieve an optimal intrinsic energy resolution (around $3\%/\sqrt{E} \oplus 1\%$) using the homogeneous design with scintillation crystals while maintaining the PFA capability for precision measurements of jets with finely segmented crystal cells. The electron momentum resolution can be improved with Bremsstrahlung corrections to refine Higgs recoil mass measurements. With the capability to trigger on single photons, crystal calorimetry can also play an essential role in the rich flavor physics programs as well as searches for new physics. Dedicated readout schemes to determine Cherenkov and scintillation photons in crystals with the information of the wavelengths or timing can potentially improve the precision to measure hadronic showers.

Questions

The electromagnetic energy resolution of the crystal calorimeter aims at around 3% for the stochastic term and 1% for the constant term. To strengthen the joint efforts, software developments and design optimizations are indispensable. Small-scale hardware prototypes and measurements can also provide solid inputs to validate the simulation. An inexhaustive list of key issues and critical R&D tasks have been initiated and needs further iterations, which are briefly described in the following:

Software, reconstruction and computing With the collaborating efforts on fast and full simulation tools, common software frameworks and computing systems, develop reliable software tools to validate the crystal calorimeter and reconstruction algorithms optimized for different layouts.

Performance with single particles (simulation and hardware)

- Study the electromagnetic showers with realistic detector layouts and calibration schemes to achieve the goal of energy resolution of around $3\%/\sqrt{E(\mathrm{GeV})} \oplus 1\%$;
- Evaluate the performance of hadronic showers with the crystal ECAL and HCAL options (e.g. CALICE AHCAL or SDHCAL options), including the shower staring position, energy resolution, etc.;
- Study how to utilize the timing information of showers for the particle identification, shower separation, response compensation, etc.;
- Explore potentials of detecting both Cherenkov and scintillation photons with a crystal-SiPM detector unit and study the performance with the dual-gated or dual-readout schemes.

Performance with jets in Particle-Flow Algorithms

- Study the PFA performance of the combined calorimeters with the crystal ECAL and one high-granularity HCAL option (e.g. CALICE AHCAL or SDHCAL) for precision measurements of jets;
- Optimize the crystal segmentation to achieve a reasonable balance among performance, power consumption and costing;
- Study the PFA performance in a new detector option with a full silicon tracking system, a crystal ECAL an HCAL and the superconducting magnets positioned between ECAL and HCAL and set requirements on the material budget of magnets and cryostats for a given magnetic field strength;
- Study potentials of the timing information to improve the PFA performance.

Impacts of upstream materials and ECAL services (simulation)

- Estimate the impact to the crystal ECAL performance from materials in the tracking system (either the TPC option or the alternative option with full silicon sensors);
- Study the energy correction of electrons that radiate photons through Bremsstrahlung in the upstream tracker in a magnetic field;
- Evaluate the impact to the crystal ECAL performance from the services including cooling and mechanics.

Studies of photo-sensors (e.g. SiPM) and front-end electronics for readout

- Quantify the requirements on the SiPM and electronics, including the MIP response, the dynamic range, timing, possible solutions to mitigate non-linearity effects, etc.;
- Perform studies on the low-power front-end electronics dedicated to the SiPM readout;
- Develop small-scale prototypes as well as test stands to characterize SiPM and crystals, perform beam tests and validate the simulation.

Calibration and monitoring scheme

- Investigate calibration schemes for SiPMs, crystals and readout electronics;
- Estimate the calibration precision, long-term stability and their impacts to the performance.

Mechanics and cooling design

- Coordinate the work for a first design of mechanics (with cooling) of the ECAL, given the boundary conditions of other sub-detector systems, and provide inputs to evolve the design with iterations of the ECAL layout and the boundary conditions.

Contacts

Wider collaborations would be highly desirable. The contact persons from the high-granularity crystal calorimetry studies for the Snowmass 2021 are listed as following:

General Sarah Eno, Yong Liu, Christopher Tully, Jianchun Wang
CALICE Technical Board Chair Lucia Masetti
Software and computing Gang Li
Reconstruction and PFA Manqi Ruan, Marco Lucchini
Crystal Dual Readout Yihui Lai
Simulation and Performance Yuexin Wang

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[7] The CALICE Collaboration: Twiki Page 1