CEPC Detector R&D Project

3.1.1 Crystal Calorimeter

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Change history

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| **Revision** | **When** | **What changed and why** |
| 1.1 | 18/12/2019 | First draft using the universal .docx template |
| 2 | 06/05/2020 | Updated objectives, funding situations and person power |
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Readme first

1. Please do not delete or modify this section or its structure.
2. Only change text enclosed by (and including) angled brackets “< … >”.
3. Don’t change field directly, instead modify the document options, under File🡪 Properties (or similar)
   * Enter name of person that wrote the document in Document:Summary: Author
   * The project ID number, should follow the rules provided to you earlier. The number should be changed in Document:Custom: PBS.
   * The project name should be changed in Document:Summary: Subject.
4. In Section [*Project Objectives*](#ProjectObjectives) provide a brief description of the project goals, i.e. why and what is being produced, for PBS item **3.1.1** **Crystal Calorimeter**. If this project includes identifiable sub-projects you can indicate them in the [*Sub-projects Description*](#SubprojectsDescription) Section, otherwise submit a separate document for each of them. The sub-project IDs are free for you to define.
5. Finally, remember to update the [*Change History*](#ChangeHistory).

3.1.1 Crystal Calorimeter: Project Objectives

A highly granular crystal electromagnetic calorimeter (ECAL) is relatively newly proposed in the context of the particle-flow oriented detector design for future lepton colliders, which was first proposed and discussed in the CEPC Topical Workshop on Calorimetry in March, 2019. One major motivation is to achieve an optimal intrinsic energy resolution using the homogeneous calorimetry design with scintillation crystals while maintaining the capability to the particle-flow algorithms (PFA) for precision measurements of jets with finely segmented detector cells. One major physics motivation is to be sensitive to low-energy photons, which can help the electron energy measurements (with Bremsstrahlung corrections) to improve Higgs recoil mass measurements. Another motivation is to be able to trigger on single photons, which can play an essential role in the rich flavor physics programs (when the CEPC runs at the Z-pole) as well as searches for new physics.

Crystal Calorimeter: Sub-projects Description

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| **Project ID** | **Title** | **Description** |
| 3.1.1.1 | Performance with jets in Particle-Flow Algorithms (e.g. CEPC full simulation with Arbor PFA) | * To study the PFA performance of the crystal ECAL option for precision measurements of jets; * To optimize crystal segmentations to achieve a reasonable balance among performance, power consumption and cost; * To study the PFA performance in a new detector option with a full silicon tracking system, a crystal ECAL 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; * To study how to make good use of the timing information to improve the PFA performance. |
| 3.1.1.2 | Performance with single particles (simulation and hardware) | * To study the two major designs of crystal readout, including the double-ended readout of long crystals, using timing information at two ends to determine hit positions, and single-ended readout of short crystals; to develop digitizers and reconstruction algorithms in order to compare the performance, e.g. separation power of closing-by incident particles; * To evaluate the performance of hadronic showers with both crystal ECAL and the CDR baseline HCAL, including the shower staring position, energy resolution, etc.; * To study how to utilize the timing information of showers for the particle identification, shower separation, response compensation, etc.; * To evaluate the performance with shorter crystals (in longitudinal depth) and applications with necessary corrections for the energy leakage; * To explore potentials of detecting Cherenkov photons with a crystal-SiPM detector unit and study the performance of the “dual-gated” readout scheme. |
| 3.1.1.3 | Impacts of upstream materials and ECAL services (simulation) | * To study the impact to the crystal ECAL performance due to materials in the baseline tracker system (TPC) and compare with the alternative option with full silicon sensors; * To study the energy correction power of electrons that radiate photons through Bremsstrahlung in the upstream tracker in a magnetic field; * To evaluate the impact to the crystal ECAL performance from the cooling plates between sensitive layers. |
| 3.1.1.4 | Studies of photo-sensors (e.g. SiPM) and front-end electronics for readout (hardware and simulation) | * To quantify the requirements on the SiPM and electronics, including the number of detected photons per MIP, the dynamic range, timing, possible solutions to minimize non-linearity effects, etc., based on the Geant4 simulation; * To develop small-scale prototypes as well as test stands to characterize SiPM and crystals, validate simulation models; * To cooperate with an electronics team at the University of Heidelberg and perform studies on the low-power front-end electronics dedicated to the SiPM readout developed within the CALICE collaboration. |
| 3.1.1.5 | Mechanics design | * To coordinate the work for a first design of mechanics of the ECAL (and HCAL accordingly), 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. |
| 3.1.1.6 | Calibration and monitoring scheme | * To identify an optimal calibration scheme for SiPMs, crystals and readout electronics; * To estimate required calibration precision, long-term stability and their impacts to the ECAL performance (e.g. energy resolution). |
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3.1.1 Crystal Calorimeter: CEPC Relationship

This technology option was proposed for applications in the CEPC. Till now all the task force within in working on this option is from the CEPC community.

3.1.1 Crystal Calorimeter: Project Schedule

The Project ID 3.1.1.1 contains ultimate questions on the PFA performance to be addressed, thus needs long-term studies and strong cooperation of both hardware and software teams. It is expected to make several solid studies on the PFA performance in the scale of several years, strongly depending on the available person power working on the particle-flow algorithms.

The Project ID 3.1.1.2 and 3.1.1.4 are two major focuses since 2019 (except the timing studies, due to the limited person power). Most items are expected to be finished within 2020. Through the exercises in these two projects, it is expected to develop software tools and accumulate sufficient knowledge that will be essential for the Project ID 3.1.1.1.

In the Project ID 3.1.1.5, the coordination work for the full CEPC detector mechanics design was started with a mechanics engineer Quan Ji (IHEP) in early April 2020. It is planned to have a first mechanics design of the CEPC detector within 2020.

Major objectives in the Project ID 3.1.1.3 and 3.1.1.6 are expected to achieve major progress in the next two years, depending on the person power situation.

3.1.1 Crystal Calorimeter: Funding Availability

Currently Prof. Junguang Lv (IHEP) has received a grant program from the CAS Center of Excellence in Particle Physics for the CEPC calorimetry optimization, and the funding (with a total budget 4M CNY for 3 years, 2019-2021) can support the crystal ECAL R&D project. A starting funding program of Dr. Yong Liu (IHEP) can also support this project.

3.1.1 Crystal Calorimeter: Leadership Arrangement

The China and US teams will continue to work closely.

In China, Dr. Yong Liu (IHEP) coordinates the work on the design, hardware development and simulation closely related to hardware. Dr. Manqi Ruan (IHEP) coordinates the efforts on the performance studies of full detector simulation and performance.

In the US, Prof. Christopher Tully (Princeton University) plays a leading role in efforts of the crystal calorimeter design and optimization. They primarily focus on the dual-readout capability and performance of the crystal ECAL, a practical mechanical support, as well as on the PFA optimization. There are several other people working on relevant generic detector R&D such as Sarah Eno, who we are in correspondence with.

3.1.1 : Manpower Resources

The situation of person power at IHEP is listed as following.

Faculty members: Dr. Chunxiu Liu (0.3 FTE), Dr. Yong Liu (0.4 FTE), Prof. Junguang Lv, (0.3 FTE),

Dr. Manqi Ruan (0.3 FTE);

PhD students: Yuexin Wang (0.5 FTE), Baohua Qi (0.5 FTE, a new PhD student candidate, expected to start in the autumn semester in 2020).

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| **Type** | **Average FTE Expected** |
| Faculty | 1.3 |
| Postdoc | 0 |
| Students | 1.0 |
| Engineers | 0 |