CEPC Detector R&D Project

3.1.1 Crystal Calorimeter

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| Document Responsible: |  |
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| Revision number: | 3 |
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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 |
| 3 | 06/01/2021 | Updates on the wording, objectives/timelines and taskforce |
|  |  | < Add further lines to table as required > |

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 . 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).

 : Project Objectives

A novel highly granular crystal electromagnetic calorimeter (ECAL) has been recently proposed in the context of the particle-flow oriented detector design for future lepton colliders, firstly raised 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 flavor physics programs (at the Z-pole) as well as searches for new physics.

3.1.1 : 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) | * 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 the superconducting magnets positioned between ECAL and HCAL;
* To study how to make good use of the timing information to improve the PFA performance.
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| 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 of closing-by incident particles;
* To evaluate the performance of hadronic showers with different ECAL options and an HCAL option;
* To study how to utilize the timing information of showers for the particle identification, shower separation, response compensation, etc.;
* To explore potentials of detecting Cherenkov photons with a crystal-SiPM detector unit and study the performance of the “dual-gated” readout scheme.
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| 3.1.1.3 | Impacts of upstream materials and ECAL services (simulation) | * To study the impact from materials in the tracker system to the crystal ECAL performance and compare between tracker options;
* To evaluate the impact to the crystal ECAL performance from the cooling plates between sensitive layers.
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| 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 MIP calibration, the dynamic range, timing and study possible solutions to mitigate non-linearity effects;
* To develop test stands to characterize SiPM and crystals, and to 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.
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| 3.1.1.5 | Calibration and monitoring schemes | * To identify a 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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| 3.1.1.6 | Development of a small-scale crystal calorimeter prototype  | * To construct a small prototype with a matrix of crystal bars photo-sensors and front-end electronics;
* To perform cosmic-ray calibration and beam tests for the prototype to evaluate the performance of the prototype, including energy linearity, energy resolution, positioning resolution, etc..
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 : CEPC Relationship

This crystal calorimeter option has been proposed for applications in the future lepton colliders, including the CEPC. Till now the major task force working on the R&D is from the CEPC community.

 : Project Schedule

The Project ID 3.1.1.1 addresses key questions on the PFA performance based on a common software framework for future lepton colliders (e.g. CEPCSW). It is expected to perform PFA performance studies in the scale of next few years at the same time when the software evolves.

The Project ID 3.1.1.2 and 3.1.1.4 have been focused since 2019, where several items were finished within 2020. Through the exercises in these two projects, it is expected to develop software tools and accumulate knowledge essential to the address the challenges in Project ID 3.1.1.1. The outcome of the Project ID 3.1.1.4 will also help the Project ID 3.1.1.6.

Major objectives in the Project ID 3.1.1.3, 3.1.1.5 and 3.1.1.6 are expected to achieve major progress in the next two years, depending on the person power situation.

 : Funding Availability

The R&D programs are supported by a grant from the CAS Center of Excellence in Particle Physics and a starting funding program of Dr. Yong Liu (IHEP) during 2019-2022.

 : 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.

 Crystal Calorimeter: Manpower Resources

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

Faculty members: Dr. Chunxiu Liu (0.1 FTE), Dr. Yong Liu (0.4 FTE), Prof. Junguang Lv, (0.3 FTE),

Dr. Manqi Ruan (0.3 FTE), Dr. Shengsen Sun (0.1 FTE), Dr. Linghui Wu (0.1 FTE);

PhD students: Fangyi Guo (0.5 FTE), Yuexin Wang (0.5 FTE);

Master student: Baohua Qi (0.5 FTE).

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| **Type** | **Average FTE Expected** |
| Faculty | 1.3 |
| Postdoc | 0 |
| Students | 1.5 |
| Engineers | 0 |