CEPC Detector R&D Project

3.3 Dual-readout Calorimeter

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Change history

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| **Revision** | **When** | **What changed and why** |
| 1 | 17/12/2019 | First draft |
| 2 | 30/03/2020 | Update on funding status and planning |
| 3 | 10/01/2021 | Update |

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 **3.3** **Dual-readout 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).

3.3 Dual-readout Calorimeter: Project Objectives

The 20-year-long experimental research program on dual-readout calorimetry of the DREAM/RD52 collaboration has yielded a technology that is mature for application at CEPC. The results show that the parallel, independent, readout of scintillation and Čerenkov light, makes it possible to cancel the effects of the fluctuations of the electromagnetic fraction in hadronic showers, heavily affecting the energy resolution of the present calorimetry technologies. In conjunction with high-resolution em and hadronic energy measurements, excellent standalone particle-ID capability was demonstrated as well.

Those results strongly support the conviction that a matrix of alternating scintillating and clear fibres, inserted in copper or lead strips and readout by Silicon PhotoMultipliers (SiPMs), will be able to provide performance more than adequate for the physics program at the CEPC collider. A pointing geometry may allow for unprecedented transverse sampling granularity. Photon pairs could be identified and reconstructed down to a separation of less than 1 cm. Moreover, timing measurements should provide the capability to reconstruct the longitudinal shower development position. A 100 ps time resolution should result in a position resolution of about 5 cm.

The objectives of the R&D projects are relative to five tasks listed as follows.

3.3 Dual-readout Calorimeter: Sub-project Description

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| **Project ID** | **Title** | **Description** |
| 3.3.1 | Mechanics | In order to arrive to an executive design and engineering drawings of a realistic detector, the following issues need to be clarified:  a) dimensions and construction method of the building elements of the absorber structure;  b) the procedure for the assembly of single towers;  c) the definition of a sensible breakdown of a full coverage 4π geometry.  All depends on the choice of the absorber material, one among brass and iron being, at present, the baseline.  The gluing of capillary tubes seems to be a viable solution for the construction of O(10×10 cm2) modules and an R&D programme in this direction is ongoing, with fundings from INFN, University of Sussex and RBI. A 1 m long single (brass) module will be built, in the next months, to be tested at DESY. A beam period was allocated at the end of 2020 but, following the COVID-19 crisis, the schedule needs to be revised as soon as possible.  In parallel, a 3-year R&D project will be submitted during next year for the construction of a “hadronic-size” prototype as well as for addressing the issues related to the construction of projective modules (including engineering drawings of a possible 4π detector).  In February 2020, the National Research Foundation of Korea (NRF) granted a 5-year funding of about 2M USD for building a full-scale “hadronic-size” projective prototype.. |
| 3.3.2 | Fibres and optical elements | The fibre selection needs to target the proper tuning of light collection yield and attenuation-length properties. Since scintillating and Čerenkov light production processes have yields that differ by orders of magnitude, the transmission chain critically needs to tackle possible optical cross-talk of scintillation in Čerenkov signals. A suitable choice of core material, numerical aperture (i.e. cladding structure) and light filtering, properly matched with the sensor PDE, should allow to obtain a yield of ~100-400 p.e./GeV, with manageable attenuation-length effects. Qualification of fibres, optical coupling and light sensors will be part of the R&D plans. |
| 3.3.3 | Light sensors and  readout electronics | A SiPM-based readout provide several advantages: no fibres sticking out (i.e. no tail oversampling), operation in magnetic field, larger light yield with respect to standard PMTs, very high readout granularity. On the other hand, being digital detectors, SiPMs may show saturation, non-linearity, after pulsing, cross-talk. The R&D program will address these points with a market survey of sensors and front-end ASICs. The large dynamic range (a single fibre collects O(10%) of the em shower signals) requires high-density sensors (small cell size). This is a requirement also in the case that we need to guarantee a linear response. Indeed, to reduce the huge number of readout elements, the analog grouping of sensor outputs will be exploited, making impossible to apply non-linearity corrections.  A readout chain based on modular (innovative) elements will be tested with specific efforts for the assessment and optimisation of the timing performance. The possibility of using a sampling ASIC is also being considered. In this context, the collaboration with CAEN and, as far as possible, with other producers, will be carried on. Hamamatsu SiPMs, with 15 μm cell pitch, and the CAEN DT5550W readout system, based on the Citiroc1A ASIC, are the baseline choices for the 2020 prototype. |
| 3.3.4 | Simulations and detector performance | A complex (Geant4) simulation programme is being pursued in order to assess both the standalone and the combined performance of dual-readout calorimeter implementations. Square (testbeam) modules, according to real and possible prototypes, have been and will be simulated for comparison with data. At the same time, simulations of a 4π detector will be carried on in order to estimate at best the possible performance in a real experiment concerning:  1. Energy resolution for electrons, gammas, single hadrons and hadronic jets both standalone and with a preshower detector;  2. Angular and position resolution, in particular for the identification and separation of the two photon showers from π0 decays;  3. Reconstruction of the longitudinal shower development position through timing measurements;  4. Particle identification of single e, π, μ, γ, both isolated and within jets;  5. Identification and reconstruction of final states from hadronic τ-decays;  6. Identification and reconstruction of final states from Z/W/H→jj, H→ZZ\*/WW\*→4j, H→γγ, Z/H→ττ decays. |
| 3.3.5 | Data selection and processing with deep-learning algorithms | Development of deep-learning algorithms (over convolutional neural networks) exploiting timing information, for online and offline data selection and processing. The performance assessment will concern the same final states as in task 3.3.4. |

3.3 Dual-readout Calorimeter: CEPC Relationship

This R&D on dual-readout calorimetry is an integral part of the program for the calorimeter system of the IDEA detector concept. IDEA is included in the CDRs of both high-energy circular e+e- colliders presently under discussion: CEPC in China and FCC-ee at CERN. The R&D is the same for both colliders.

3.3 Dual-readout Calorimeter: Project Schedule

In the present planning for the fibre-sampling calorimetry, all the tasks are meant to be completed by 2025. The prototype under preparation is presently planned to be tested at DESY in the next month. Nevertheless, due to the COVID-19 emergency, no solid statement on the dates can be done. The test beam period is expected to be postponed (probably to summer or autumn 2021). Further planning, including the schedule for the hadronic-size prototype, will need to be reassessed as soon as possible. At present, the delay is meant to be of the order of months. On the other hand, the schedule strongly depends on the amount of funding and resources that will be secured.

3.3 Dual-readout Calorimeter: Funding Availability

The first stage of the project (the 2020 prototype) has received funding from INFN CSN1 (~40 k€), from RBI (about 15 k€) and from the University of Sussex (about 5 k€). RBI has retired in late 2020 from the collaboration due to lack of manpower and funds. Small amount of funding from University grants has also been made available.

A request of about 100 k€ has been also presented for the AIDA++ proposal, mainly thought to be used for hiring young manpower.

About the building of a hadronic-size prototype, a request will be submitted for EU grants and to European funding agencies in 2021 (INFN, Royal Society).

In South Korea, a R&D fund of about 2M USD has been granted, from March 2020 over 5 years, by the Korea National Research Foundation (NRF) for building a full-hadronic-scale projective prototype, addressing the main engineering, operating and readout issues. Additional soft funding is also available for simulation study to support postdoc positions and graduate students in each institute.

3.3 Dual-readout Calorimeter: Leadership Arrangement

Project leader: Roberto Ferrari INFN Pavia

Technical coordinator: Romualdo Santoro Università dell’Insubria Como and INFN Milano

Group leaders/contacts:

Hwidong Yoo South Korea Consortium (Kyungpook National University, Korea University, University of Seoul, Yonsei University, includes also Iowa State University)

Romualdo Santoro Università dell’Insubria Como and INFN Milano

Gabriella Gaudio INFN Pavia

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Stefano Giagu Università di Roma “La Sapienza” and INFN Roma 1

Paolo Giacomelli INFN Bologna

Iacopo Vivarelli University of Sussex

3.3 Dual-readout Calorimeter: Manpower Resources

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| **Type** | **Average FTE Expected** |
| Faculty | 4.2 |
| Postdoc | 2.21 |
| Students | 6.81 |
| Engineers | 1.32 |

1. The number for students and postdoc includes positions that will be funded within the R&D project (i.e. for which at present funds are not guaranteed).

2. The number of engineers includes technical manpower from institute workshops that are not engineers but are nevertheless actively participating to the design efforts.