CEPC Detector R&D Project

4.2 Muon and pre-shower µRWELL-based detectors

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| Last saved by on | 1/8/21 4:26:00 PM |
| Revision number: | 3 |
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Change history

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| **Revision** | **When** | **What changed and why** |
| 1 | 17/12/2019 | First draft |
| 2 | 28/04/2020 | Second draft added simulation task and INFN Torino |
| 3 | 07/01/2021 | Third draft with addition of front-end electronics task |

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 **1.1** **Vertex Prototype**. 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).

4.2 : Project Objectives

The µRWELL technology, developed at LNF-INFN (*“The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD”, G. Bencivenni et al 2015\_JINST\_10\_P02008*), has been identified as a very promising technology to realize both the muon apparatus as well as the pre-shower. The muon detector will provide complete coverage for detecting very penetrating particles, most of them being muons, having traversed the calorimeter. The µRWELL based pre-shower system is used to identify and measure electromagnetic showers initiated in the material of the solenoid before reaching the calorimeter. The information from the pre-shower is essential to recover a good energy resolution from the dual readout calorimeter. µRWELL detectors can obtain a position resolution of the order of 50-60 um with a time resolution of about 5 ns. The muon detector does not need such a precise position resolution and µRWELL detectors with a larger strip pitch than what will be used for the pre-shower will be employed. For both the muon detector and the pre-shower system a modular structure of µRWELL detectors of dimensions of about 50x50cm2 is envisaged. These detector dimensions should be a good compromise between the industrial engineering and production and the large overall dimensions to be covered, especially for the muon detector.

The objectives of the R&D projects are relative to the four different tasks listed in the following section.

We also anticipate that the simulation studies will be used to optimize the overall detector design.

4.2 Muon and pre-shower detectors : Sub-projects Description

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| **Project ID** | **Title** | **Description** |
| 4.2.1 | Industrialization of large size µRWELL detectors with bi-dimensional readout | The µRWELL technology has been extensively characterized in laboratory measurements and has undergone several beam tests and is now a rather mature detector technology. Its characteristic of high space and good time resolution, high efficiency and high gain with a single amplification stage have been clearly demonstrated.  The purpose of this task is to optimize the engineering design of the detector and bring the technology and know-how to industry for a future mass production. For this purpose, we have started a collaboration with the ELTOS company in Arezzo, Italy, more than 2 years ago. The ELTOS company is specialized in PCB production and has already produced the anodes and cathodes of several µRWELL prototypes in the past. The next step was to perform the coupling of the µRWELL kapton foil with the well scheme with the anode PCB. Eltos has already achieved this step for several small size (10x10 cm2) µRWELL prototypes with the original layout with a single resistive layer. Several other layouts of µRWELL detectors, up to dimensions of about 40x50 cm2, have been produced and tested subsequently. From the original single resistive layer, dubbed “low rate” version, capable of particle rates up to about 30-50 kHz/cm2, we have then also developed newer high-rate designs that allow higher particle rates, up to about 10 MHz/cm2. The high-rate layouts employed have proved effective but unfortunately of difficult industrialization. For this reason, and the fact that the low rate version is highly sufficient for the particle rates expected at the CEPC, we decided to continue the development of the low rate layout. This is layout that we would now like to fully co-develop and produce with ELTOS. The next step we want to achieve is the production of larger size detector prototypes, ~50x50 cm2, with strip length of 50 cm, at affordable and competitive costs. |
| 4.2.2 | R&D on DLC sputtering and optimization of the resistive coating | The Diamond Like Carbon (DLC) sputtering technique is what has been used until now to produce the resistive layer of the µRWELL kapton foils. All the recent µRWELL detector prototypes we have built employ this technique for their resistive layer.  The DLC resistive layer is responsible for the avalanche quenching and the charge distribution at the anode. Testing detectors with different resistivity will allow to optimize the chamber and readout design. For each IDEA’s system (i.e., muon and pre-shower) five detectors, with resistivity ranging from 10 to 200 MOhm/square, will be tested. This will be the first systematic DLC resistivity scan with m-RWELL detectors; the test will give precious information about performance and data size of the different configurations; the data will also be used to tune our simulation for further design optimization.  We are discussing with CERN the possibility of acquiring a dedicated sputtering machine that would allow to make DLC depositions up to Kapton surfaces of 60x200 cm2. |
| 4.2.3 | Bi-dimensional readout | We have recently built two small µRWELL detectors, 10x10 cm2, with two readout layers with a strip design, the first layer placed at 90o degrees with respect to the following one, in order to be able to read the x and y coordinates independently. The next step will be to optimize the design of such a detector to achieve a similar signal size and resolution for both coordinates. The following step will be to increase the size of the detectors with bi-dimensional readout up to the size that we want to employ for IDEA of about 50x50 cm2. The strip pitch is what determines mostly the possible spatial resolution of a µRWELL detector. For the pre-shower system we need a spatial resolution, in both x and y coordinates, of the order of (or better than) 100 µm. The strip pitch envisaged is therefore of 400 µm. For the muon system the requirement of spatial resolution can be relaxed and the envisaged strip pitch is 1.0-1.5 mm. |
| 4.2.4 | Front-end electronics | The IDEA muon detector would have, taking into account the considered strip pitch of the detectors, between 4 and 6 million channels. It is therefore extremely important to develop a custom-made front electronics, based on a dedicated ASIC, in order to significantly reduce the electronics costs. The BESIII experiment at BEPCII at IHEP has developed a custom-made ASIC, called TIGER, for the front-end of their cylindrical GEM-based tracker. Since the signals produced by a µRWELL detector are rather similar to the ones produced by a GEM, we will equip a large area (~40x50 cm2) µRWELL with a TIGER-based readout. The µRWELL detector will have a strip pitch similar to the one we want to employ for the IDEA muon detector and strips length about half the length of the IDEA ones. This makes for a test-bench for the TIGER very similar to the final muon detector configuration. From tests with the TIGER with a cosmic bench and possibly later on a muon test beam, we will derive the information needed to develop a dedicated ASIC for the µRWELL. |
| 4.2.5 | Simulation and tracking algorithm of a µRWELL-based muon detector | Implementation of this detector in a fast simulation context to study physics potential for tracks tagging and long lived particles identification. Development of a full simulation model in Geant4 to study more realistic performance and optimization of detector design. |

4.2 Muon and pre-shower detectors : CEPC Relationship

This R&D on µRWELL detectors is an integral part of the needed R&D program for the muon and pre-shower systems of the IDEA detector concept. IDEA has been proposed an accepted by both very large circular e+e- colliders proposed: CEPC in China and FCC-ee at CERN. The R&D is the same for both colliders.

4.2 Muon and pre-shower detectors : Project Schedule

Task 4.2.1 should be completed by 2024. Intermediate milestones will be the construction of smaller size µRWELL prototypes.

Task 4.2.2 should be completed by 2022.

Task 4.2.3 is a prerequisite for the completion of Task 4.2.1. It is scheduled to be completed towards the end of 2022-23.

Task 4.2.4 will in start in 2021 and is scheduled to be finished by 2024.

Task 4.2.5 will run in parallel to the other three tasks until 2024. First results will however be available already in 2021.

4.2 Muon and pre-shower detectors : Funding Availability

Task 4.2.1 will receive significant funding within the framework of the AIDAinnova project, specifically for the pre-shower and muon detector of IDEA. The funding, that will be available from April 2021 for a period of 4 years, is around 120 keuro.

Task 4.2.2 has received some funding (8 keuro) from INFN CSN1 as co-funding of the RD51 project at CERN. It has also received funding (25 keuro) from INFN CSN1 for the construction of 2 sets of 5 medium size µRWELL prototypes each with a different value of the resistivity of the DLC coating by the end of 2021.

For task 4.2.3 we envisage to ask for dedicated funding from INFN CSN1 in 2022 and in 2023.

For Task 4.2.4 we have received in 2020 funding from INFN CSN1 (20 keuro) for building a large-size detector equipped with the TIGER readout. This step will be a pre-requisite for later developing a µRWELL-dedicated ASIC. For this purpose, we will receive a funding of 100 keuro also coming from the AIDAinnova project. Completion of this task is expected by the end of 2024.

Task 4.2.5 will receive a funding of 40 keuro from the AIDAinnova project, for the development of an advanced machine-learning based track reconstruction algorithm for µRWELL detectors.

We also received significant funding from another European project, Cremlin+, to build a cylindrical µRWELL detector to serve as the main tracker for the proposed Super Charm-Tau Factory of the Budker Institute for Nuclear Physics in Novosibirsk, Russia, to be developed and tested by groups from INFN Frascati and Ferrara.

4.2 Muon detector : Leadership Arrangement

Paolo Giacomelli INFN Bologna

Gianluigi Cibinetto INFN Ferrara

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4.2 : Manpower Resources

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| **Type** | **Average FTE Expected** |
| Faculty | 2.0 |
| Postdoc | 1.5 |
| Students | 1.0 |
| Engineers | 0.3 |

Four INFN sections are involved in this R&D: Bologna, Ferrara, LNF and Torino.

Bologna can count on an undergraduate and a PhD student, and three faculty members.

Ferrara can count on 3 PostDocs, 1 PhD student and two faculty.

LNF can count on 1 PhD student and three faculty members.

Torino can count on 1-2 faculty.