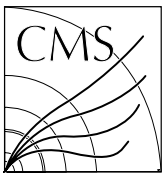

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

COMPACT MUON SOLENOID COLLABORATION

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Subject: Certification of IHEP contributions in the CMS HGCAL project

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To whom it may concern,

I am writing to certify the strong involvement of IHEP Beijing group in the endcap High-Granularity Calorimeter (HGCAL) upgrade project. This project forms a large and essential part of the wider Phase 2 upgrade of the existing Compact Muon Solenoid (CMS) detector, that will allow CMS to profit fully from the higher instantaneous luminosity brought by the HL-LHC upgrade.

The HGCAL will replace several of the present CMS sub-detectors: the silicon/lead endcap pre-shower detector, the lead-tungstate crystal electromagnetic endcap calorimeter, and the plastic/brass endcap hadron calorimeter. HGCAL is a novel sampling calorimeter, based on a large-scale deployment of silicon modules, positioned between dense layers of absorber. The silicon modules will be complemented with plastic scintillator tiles instrumented by silicon photomultipliers (SiPMs) in regions of the detector where particles arrive with lower intensity.

Prof. Huaqiao Zhang has led the HGCAL activity at IHEP Beijing since 2015, and the IHEP Beijing group has been engaged successfully in several key aspects of the project, namely:

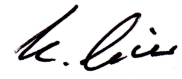
- Setting up of a silicon module assembly centre (MAC)
- Performance tests of silicon sensors
- Beam tests of HGCAL prototype modules

The setting up of the module assembly centre (MAC) in Beijing is very well advanced. All of the equipment is in place that is required for mass production of the thousands of silicon modules needed for HGCAL: gantry machine for automated module assembly, wire-bonding machine, optical inspection and coordination measurement machine, and a silicon module test-stand. All of this equipment has been installed and commissioned in a Class 1000 clean room that is dedicated to this project. The preparation of the MAC has been completed on time to meet the project milestones, and a first full-size silicon module has been assembled successfully in the IHEP MAC in June 2021. This module made use of the latest versions of 8-inch silicon sensors from Hammamatsu and the latest prototype custom circuit boards ("hexaboards") developed at CERN, based on v2 prototype HGCAL readout chip.

As part of the preparation for the setting up of the MAC, the IHEP Beijing group was also deeply involved in test-beam campaigns during 2016-2018 in CERN, DESY, and FNAL. In these test-beams, IHEP contributed greatly to the setting-up, operations and shift-taking, as well as the subsequent data analysis. Details of the IHEP activities include the implementation of a GEANT4 simulation of the test-beam, calibration with minimum ionizing particles (MIP-calibration), and energy measurements. The test-beam campaign has been successful in demonstrating that the chosen HGCAL technology does indeed meet the expected level of performance. In terms of electromagnetic energy resolution, the results of the test-beams confirm that the specification in the Technical Design Report of $25\%/\sqrt{E}$ are met (in this case with silicon sensors having 300 micron thickness). A timing resolution of 50ps was also measured in these tests, matching the specification for the timing precision of the prototype readout ASIC that was used in these tests. Again, this gives great confidence in this detector concept that allows for the simultaneous measurement of energy, position, and timing of incident particles.

The IHEP Beijing group has also been closely involved in the early performance tests of silicon sensor prototypes, with this R&D aiming to validate the planar silicon detector technology for the expected levels of radiation exposure expected in the HGCAL during HL-LHC operation. Silicon diodes of different thicknesses from the 6" silicon wafer sensor line of Hammamatsu were irradiated with neutron fluences of up to 10^{16}n/cm^2. The level of radiation damage observed matched expectations, confirming that this sensor technology is indeed well understood, and will have a lifetime sufficient to last the full extent of CMS operations with the HL-LHC. The most recent measurements, now being made on silicon sensors from 8-inch wafers, reconfirm the conclusions of the earlier measurements that the 8-inch technology is also sufficiently robust for our purpose.

Yours faithfully,



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