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Referee report on the PhD thesis of Anna Zaborowska

Referee: Guillaume Unal, Research physicist at CERN

The thesis of Anna Zaborowska is on "Calorimetry for the future circular collider experiments". In this thesis, studies and optimizations for the design of an electromagnetic calorimeter at a high energy proton-proton collider like foreseen for the future circular collider (FCC) are described. These studies take into account the experience from the LHC experiments and the challenging conditions expected for the FCC experiments. It is an important topic, especially given the context of the discussions towards the European strategy for the future of particle physics.

The thesis consists in five chapters with an introduction and a conclusion.

The first chapter is devoted to a general introduction to the FCC studies. The main physics objectives are summarized. The requirement on detector performance from these physics objectives and from the FCC conditions are presented. Emphasis is given on the requirements for the calorimeter of the experiments. The current FCC hadron-hadron detector concept is introduced. One of the main option of this concept is an electromagnetic calorimeter using the liquid argon technique. The main concepts and idea are exposed very clearly.

The second chapter presents an explanation of the calorimetry technique to measure the energy of high-energy particles. This starts from a description on how high energy particles interact with matter and then introduces the concept of electromagnetic cascade and of the calorimetry technique. The principles of the different kind of electromagnetic calorimeters are reviewed with the implications on detector performance. An overview of the recent large-scale calorimeters built for the LHC experiments is presented, as well as the recent R&D projects focusing on calorimetry, where for instance high-granularity calorimeters are found to be important to perform particle-flow event reconstruction. This chapter is also very clear and shows that Anna understand well the main concepts of calorimetry.

The third chapter describes the simulation software used for the studies reported in the thesis. Emphasis is given on the usage of the GEANT4 simulation toolkit and also on different options to achieve fast parameterizations of the response of a calorimeter detector. Anna worked directly on the implementation of the GEANT4 calorimeter simulation inside the software framework of the FCC detector studies. This was the first required step for the optimization studies described later in the thesis. This chapter shows that Anna masters well the complicated software needed for these studies.

The next chapter is devoted to the optimization studies of the barrel electromagnetic calorimeter for the FCC performed by Anna. The design studied in this thesis is based on the liquid argon detector technology. It is a sampling calorimeter with lead as absorber material and liquid argon as active medium. The main advantages of the liquid argon technique are its very good intrinsic resistance to radiations and its good expected stability of the response with instantaneous luminosity. It is partially inspired by the ATLAS detector electromagnetic calorimeter but differs in two mains points: (i) the geometry is simpler and (ii) the granularity of the readout is significantly higher. The second requirement is mostly driven by the very high pileup conditions (up to 1000 proton-proton interactions per bunch crossing) expected at the FCC. The higher granularity allows on the other hand for a simpler geometry as one can then perform cell-by-cell calibration corrections to accommodate for a non-constant sampling fraction along the shower axis. This point is well explained, and an optimization between the longitudinal segmentation of the calorimeter and the calorimeter geometry (mostly the angle between the incident particles and the absorber plates of the calorimeter) is performed. The thickness of the absorber plates as well as the cell granularity are also studied and optimized. From these studies a set of parameters for the reference design of the electromagnetic calorimeter are derived. The performance of the calorimeter in term of energy resolution and linearity is then studied for this optimized design. The necessary corrections to optimize the energy resolution are derived. The difference between the responses to electron and positrons related to the detector geometry is also studied. The predicted energy resolution is found to match well the requirements for FCC detectors.

Finally, the last chapter describes the software to reconstruct the (simulated) data. The main emphasis is on the algorithm to reconstruct cluster of energy deposits induced by electron and photon showers in the calorimeter. An algorithm inspired by the ATLAS clustering algorithm was implemented by Anna in the FCC software framework and its performance are presented.

In conclusion, this thesis presents very nice and precise studies on the design and optimization of an electromagnetic calorimeter for the FCC. It shows that a concept based on the liquid argon technology with a not too complicated geometry and a high granularity is a very viable option for the FCC detector. This concept fulfills the stringent requirements on energy resolution and on granularity.

The thesis is written very clearly. The work reported is of very good quality. This shows that Anna understands well the different concepts from the calorimetry technique to the simulation framework. The studies reported are original and important for the future FCC studies.

Thus, this thesis fulfills all the necessary requirements for a PhD thesis. Anna Zaborowska should be allowed to move to the next stage of the PhD process.

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