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Construction of a Super-Microscope – The CMS Experiment at CERNs Large Hadron Collider

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1. Introduction

The research goals of particle physics are to explore the basic physics laws that govern the fundamental building blocks of matter. This research is carried out using complex and technologically very challenging experiments at high-energy particle accelerators. Experimental results during the past two decades have shown outstanding quantitative agreement between data and the prediction of the Standard Model (SM) of particle physics. Despite this impressive experimental verification, the SM is incomplete, as it leaves fundamental questions unanswered. The next important step in addressing these questions will be the Large Hadron Collider (LHC), presently under construction at CERN, the European Particle Physics Laboratory in Geneva, Switzerland.

The LHC will be the world’s most powerful particle accelerator, colliding protons at an unprecedented energy of 14 TeV (1 Tera-electronvolts = 10^{12} eV). Protons travel – 100 meters underground – around the 27-kilometer ring 11,000 times per second at nearly the speed of light. The LHC will also be the world’s most powerful microscope, with a resolution thousands of times smaller than the diameter of the proton (Fig. 1). The very high energies and very small distances accessible at the LHC will be similar to the conditions of the early universe, some tenth of a billionth of a second after the Big Bang.

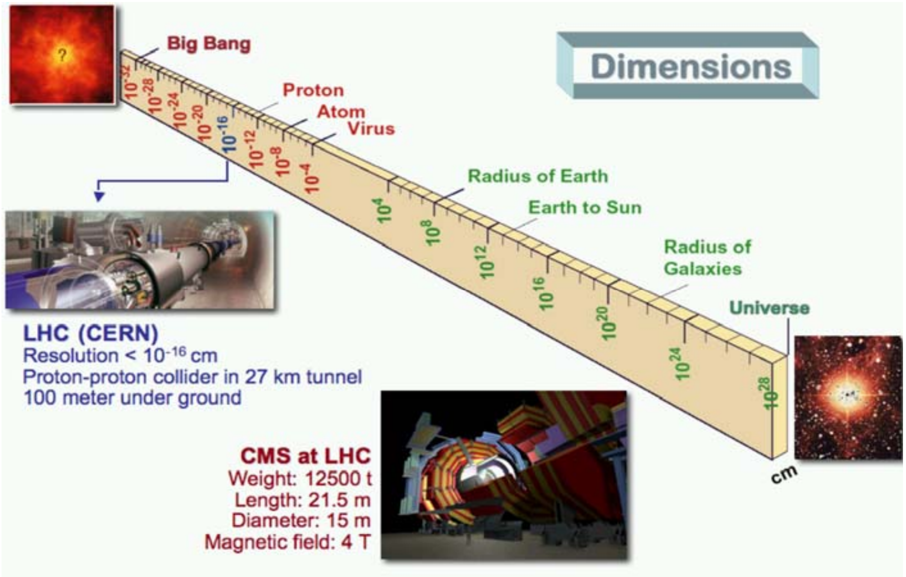

Fig. 1. Dimensions in physics

The start-up of the LHC, scheduled for the end of 2007, will be one of the most exciting events in particle physics for the years to come. The LHC will allow studying fundamental physics questions at unprecedented energies, giving access to the production of new heavy particles and new phenomena. Thus, particle physicists will have the possibility to embark on a new era of discoveries.

2. The CMS Experiment

The Compact Muon Solenoid (CMS) experiment, approved at the June 1997 CERN Council session as one of the two general-purpose detectors for the LHC, is presently under construction (Fig. 2). Cutting-edge technologies are used by CMS to exploit the discovery potential offered by the LHC [4].

To study the mysteries of matter, space and time, the LHC will produce hundreds of millions of collisions per second (Fig. 3). CMS will measure the energy and momentum of the particles emerging from these collisions with high precision. CMS consists of a powerful inner tracking system based on silicon technology (micro-strip and pixel), a scintillating crystal calorimeter followed by a hadronic sampling calorimeter made of plastic scintillator tiles inserted between brass absorber plates, and a high magnetic field (4 T) superconducting solenoid [2] coupled with a multi-layer muon system.

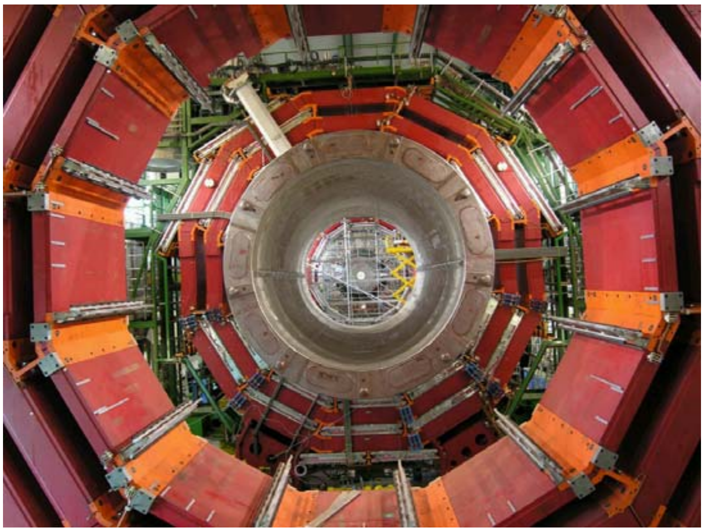

Fig. 2. Picture of CMS taken at its construction site at LHC

The CMS experiment is carried out by a large international collaboration. At present about 2,500 scientists of 181 institutes and research laboratories from 39 countries worldwide are involved in the CMS collaboration.

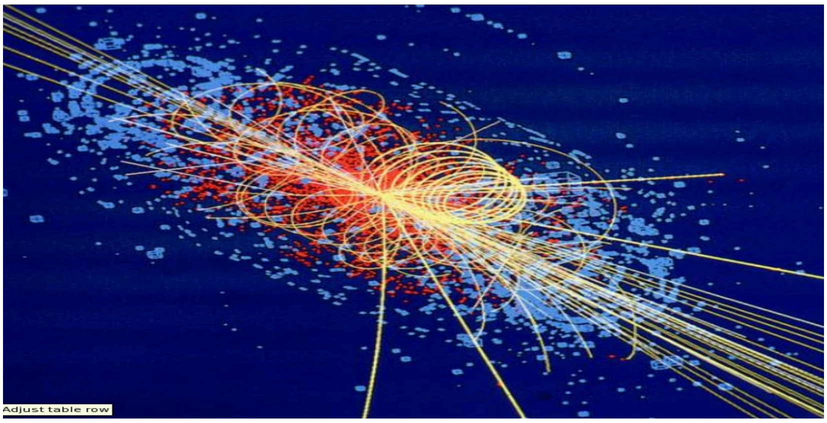

Fig. 3. A simulated proton-proton interaction in the CMS detector at LHC

3. Collaboration between CLMI – BAS, and ETH – Zurich

The collaboration between the Central Laboratory of Mechatronics and Instrumentation of the Bulgarian Academy of Sciences (CLMI – BAS) and the Laboratory for High Energy Physics (LHP) of the Swiss Institute of Technology (ETH Zurich) has a long and successful history. It started in 1987 in the framework of the L3 experiment at CERNs Large Electron Positron (LEP) collider. Physicists, engineers and technicians of both institutes were involved in the construction as well as in the operation, data taking and maintenance of the L3 detector. About 225 scientific papers were published by L3 with CLMI–BAS as signing institute, demonstrating the high scientific output [9].

After the closure of LEP in November 2000, our common work focused on the construction of the CMS detector [1]. LHP is one of the leading institutes in CMS and carries major responsibilities for the construction of the Electromagnetic Calorimeter (ECAL) [3], which is one of the key detector elements of the CMS experiment, consisting of 75,848 Lead Tungstate ($PbWO_4$) crystals. An overall view of the ECAL is given in Fig. 4. It is subdivided in a barrel part (crystal dimension: 23×2.2×2.2 cm) and two endcaps (crystal dimension: 22×2.47×2.47 cm).

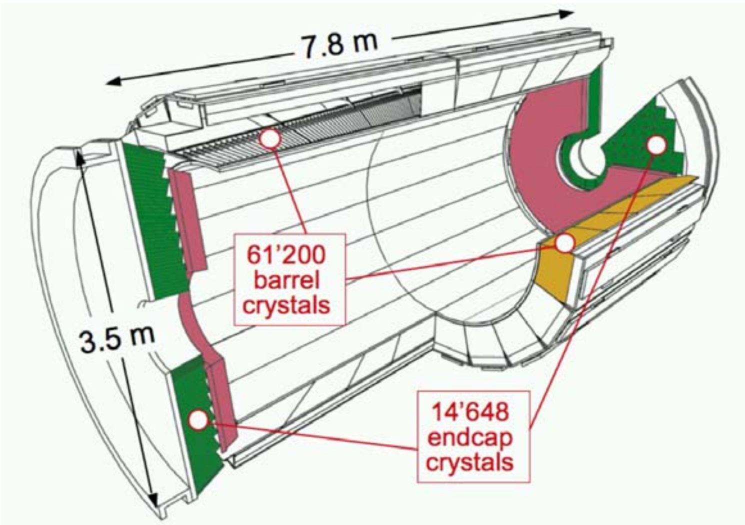

Fig. 4. Overall view of the CMS electromagnetic calorimeter

The mechanical design is based on modularity and on the use of high-strength, low-Z materials, where alveolar submodules (Fig. 5, left) of 2×5 fiberglass cells containing individual crystals are the smallest subunits in the barrel. Such submodules are assembled into modules (Fig. 5, centre). Supermodules (Fig. 5, right) consist of four modules, held by a U-shaped spine at the outer ECAL radius, and contain 1 700 crystals. The barrel part consists of 36 supermodules.

The ECAL has to acquire low-level optical signals with high speed and precision, generate every 25 ns digital energy sums for the CMS trigger system and store the data during the trigger latency of about 3 μs. The high-radiation environment of up to 5 MRad imposes a major design constraint. At the same time, high-speed and wide dynamic range readout required forefront design techniques and semiconductor processes. To fulfil simultaneously the requirements of radiation hardness, high performance, large channel count and low cost, all necessary integrated circuits were custom developed in 0.25 μm technology.

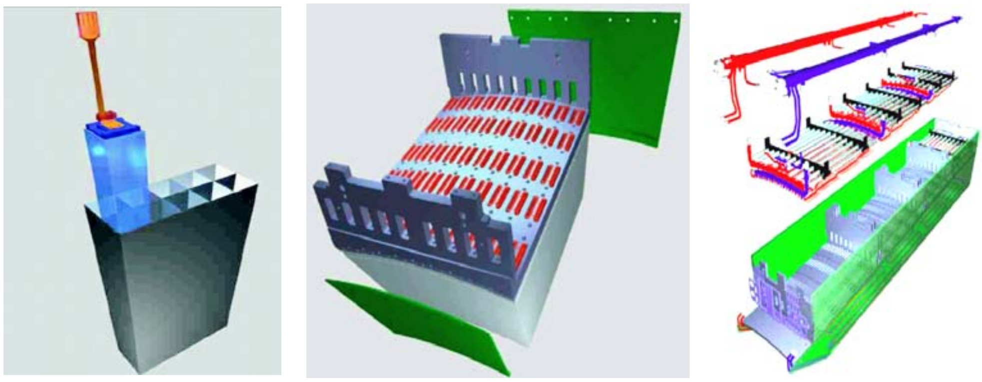

Fig. 5. Stages of an ECAL supermodule assembly. Left: Alveolar submodule during insertion of the first crystal; Centre: Complete module; Right: Expanded view of a supermodule with cooling circuits

The ECAL on-detector electronics (Fig. 6) is arranged to serve groups of 5×5 channels, corresponding to a trigger tower in the barrel and to a super-crystal in the endcaps. It consists of five Very Front End (VFE) boards, one Front End (FE) board, one Low Voltage Regulator card (LVR) and a motherboard, which connects to the photo-detectors, Avalanche PhotoDiodes (APDs) and Vacuum PhotoTriodes (VPTs) in the barrel and endcaps, respectively. While the VFE boards amplify shape and digitize the signals of five channels using 12 bit, 40 MHz analog to digital converters, the energy sum of the 25 crystals is calculated in the FE board and the data stored in pipelines during the trigger latency [10, 11]. Two Gigabit Optical Hybrids (GOHs) per trigger tower are used to transfer the data and trigger information to the off detector electronics.

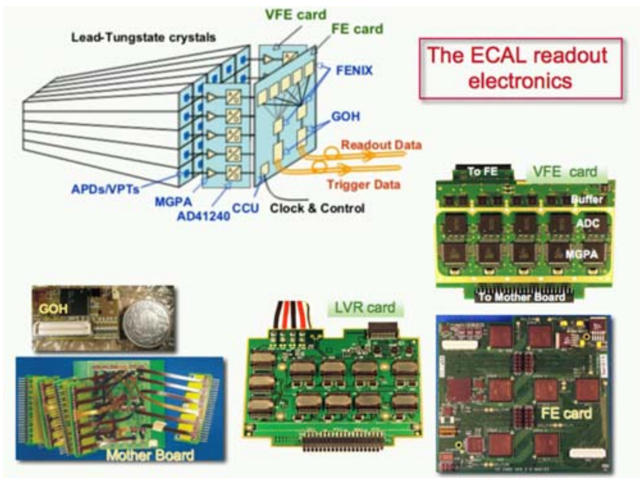

Fig. 6. Components of the ECAL readout electronics

The installation of the electronics in the ECAL supermodules is carried out under the responsibility of the ETH group at the ETH electronics integration center at CERN. Each supermodule comprises the mounting of 548 printed circuit boards, 17 low-voltage distributions and 12 fibre patch panels, as well as the testing of all installed components (Fig. 7). In the framework of our collaboration agreement, 9 colleagues from CLMI – BAS are strongly involved in the challenging task of electronics integration – under LHP leadership.

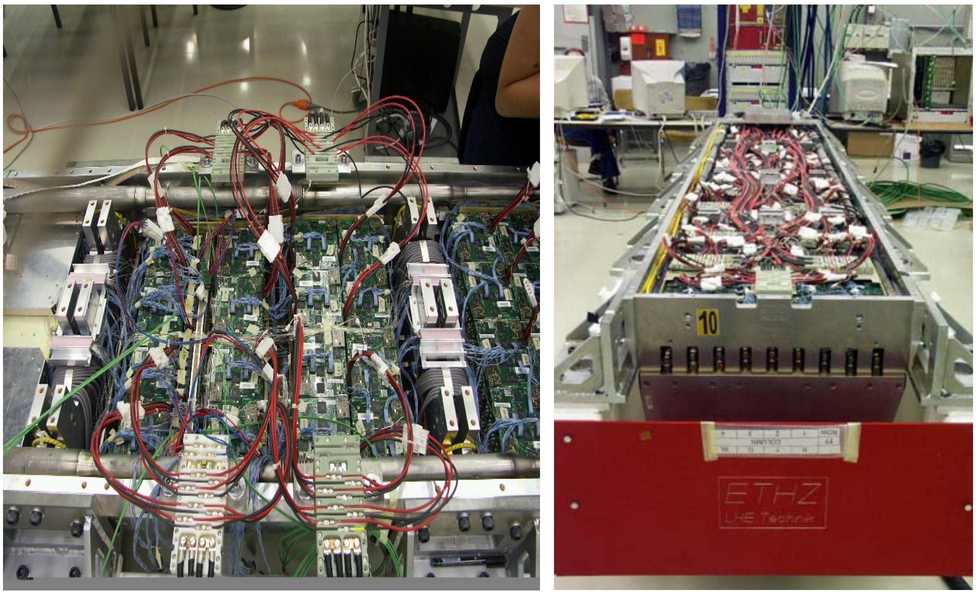

Fig. 7. Different steps during the integration of the readout electronics into supermodules

4. Conclusion

The construction of the LHC and its experiments is one of the largest scientific projects ever undertaken. Particle physicists have a long history of international collaboration, and the LHC is another important example. Since its foundation in 1954, CERNs basic concept was that strengthening the links between the scientists of the various countries and pulling together resources symbolizes the pooling of some of the intellectual power of contemporary Europe. With the LHC project, CERN became a truly world laboratory. It is fundamental science that has a vital role to play in the process of innovation. Furthermore, basic research is an essential part of higher education in science and engineering.

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Построение супер микроскопа – CMS эксперимент к большому адронному ускорителю в CERNe

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(Р е з ю м е)

В Европейском центре ядерных исследований (CERN) в Женеве, Швейцарии, осуществляется построение большого адронного ускорителя (LHC), который имеет возможность ускорить протоны до 14 TeV. Это позволить изучение фундаментальных вопросов ядерной физики. Один из двух детекторов общего предназначения к ускорителю является компактный мюонный солленоид (CMS), в построением которого принимают участие физики, инженеры и техники из 39 стран мира, включая Швейцарию и Болгарию. Описывается электромагнитный калориметр, один из основных элементов детектора CMS, с возможностями использовать большой потенциал в этой области, предоставленный ускорителем LHC.