THE COMPACT MUON SOLENOID (CMS) DETECTOR

PROPOSAL 892

UNITED KINGDOM

Bristol University; Brunel University; Imperial College, London; CCLRC Rutherford Appleton Laboratory; Univ of the West of England*; Univ of Strathclyde*

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INTRODUCTION AND OVERVIEW

The UK groups in CMS have lead responsibilities for two major CMS subsystems: the Electromagnetic Calorimeter Endcaps, and the Tracker readout electronics, as well as for the design and implementation of the Global Calorimeter Trigger system. The UK also plays a central role in the development of software for reconstruction and physics analysis, and in the development of GRID-based computing facilities.

The construction phase of the experiment follows an assembly sequence that allows a complete detector (except for some elements of the Endcap Muon system) to be ready for the first LHC beam in April 2007.

Civil Engineering and Assembly

Civil engineering works at Point 5 (located at Cessy, France) are advancing well. The second phase of the construction of the surface hall has started with the removal of the crown of the experiment shaft and the extension of the SX slab. The surface control room building should be delivered to CMS in January 2005. Concreting of the floor of the two underground caverns, UXC5 (for the experiment proper) and USC5 (for the counting rooms and services) is advancing, and they are expected to be given to CMS in summer 2004, when the installation of infrastructure will start. The CMS experiment cavern will thus be ready to receive detector elements around July 2005. Problems have been experienced with water ingress in two shafts, PM54 (services) and PX56 (experiment). While the ingress in PM54 is small and is not considered critical, the problem in shaft PX56 has to be repaired. The repair is foreseen straight after the delivery of UXC5/SX5 complex in summer 2004.

Magnet

All five barrel-yoke rings and six endcap-disks of the magnet yoke have been assembled on the surface at Point 5. The outer vacuum tank is installed in the central barrel-wheel, while the inner vacuum tank is currently in a vertical position, wrapped in super-insulation, ready to be equipped with the inner thermal shield in October 2003. Current leads have been manufactured and tested to 20kA at Saclay. The power converter has been delivered and the power circuit will be tested starting in December 2003. The dummy thermal load and the 6000 litre cryostat have been installed on the central wheel and the outer cryogenics will be tested early next year.

All 21 lengths of the reinforced conductor (superconducting strands, pure Al insert and Al alloy reinforcement) have been produced at Techmeta, France. The first two coil modules have been completed and coupled together in Ansaldo (Genova, Italy). The fifth and last coil module should be delivered to CERN in June 2004.

Tracker

All module components have entered production. A third of the sensors from Hamamatsu have been delivered, and the rate of delivery is approaching that required.

Difficulties encountered in packaging of electronic chips and manufacture of pitch adaptors have been resolved and the production is now proceeding. All contracts for opto-electronics have been signed. The procurement of a large part of the mechanics is well advanced.

System tests of the tracker modules have been successfully carried out in May 2003 using the ‘25 ns bunched’ beam. A series of prototype FED modules have been under test since the beginning of 2003. The manufacture of pre-series FEDs will commence early in 2004.

The 0.25 μm deep-sub-micron (DSM) pixel readout chip (ROC) was received in August 2003. The chip works well and minor corrections will be implemented in the next submission. Pre-production modules using DSM ROCs will be made in 2004 and the mass production should start early in 2005.

Electromagnetic Calorimeter

About 21000 of the 62000 crystals for the ECAL barrel have been delivered and are being used to construct modules containing 400 or 500 crystals in CERN and Rome. Twenty nine modules have been produced out of 144. More than 120000 of the 140000 APDs have been delivered and the production is due to end in early 2004. 6900 VPTs have been delivered to RAL and most have been tested to 1.8T.

Mass production of the silicon sensors for the endcap preshower detector has started in Russia and India (about 27% of the sensors have been produced and tested) and is starting in Taiwan. Very encouraging performance has been attained with the DSM chips (PACE3 and K-chip).

Hadron Calorimeter

Both HCAL half-barrels have been assembled at Point 5. Both of the endcap-absorbers have been mounted and optics (scintillators and fibres) installed. All of the HO optics have been delivered to CERN.

All 36 steel absorber wedges for the HF have been produced and delivered to CERN. The support structure for one side has been manufactured in Iran.

Muon Detector

About 90% of the 482 endcap cathode strip chambers have been assembled in sites in China, Russia and the US. Roughly half have been tested with on-board electronics. Over a quarter of the chambers are at CERN and after final tests about 20% have been installed of the magnet yoke disks

CIEMAT, Aachen and Legnaro are continuing to produce barrel drift tubes at the required rate of 18 chambers per year per site. Production at Torino is expected to begin soon. Around 100 chambers (40% of the total) have been assembled and over seventy of these have been delivered to CERN.

Production of the barrel RPCs is proceeding well. Over 100 chambers (20% of the total) have been assembled and about 70 are at CERN. Two final RB1 chambers have been operating in the gamma irradiation facility for over 6 months and so far have integrated a charge corresponding to approximately the first 5 years of LHC operation. Good performance has been observed.

Trigger and Data Acquisition System

Many full-function trigger card prototypes have been manufactured and final validation tests are being done. Integration tests of detector primitive generators, trigger system and DAQ are under way. Tests with a 25ns bunched 'LHC-like' beam have been very valuable to establish latencies. Software is now been developed for testing and operation.

The Data Acquisition and High-Level Trigger Technical Design Report was approved by the LHCC. Front End Readout Link (FRL) prototype boards are being tested and preproduction has started. FED and Readout Builder (RB) demonstrators are running at CERN. The first Event Filter sub-farm prototype is running under realistic conditions.

TRACKER AND DATA ACQUISITION

UK Role

The CMS silicon tracker is a large silicon microstrip detector of about $220m^2$ area arranged in a cylindrical geometry around the beam pipe, with petal-like module arrangements in the endcaps. The system now contains almost 10 million microstrips, each read out by an analogue front end chip (APV25) serving 128 channels, which samples and stores any signal present at the input every 25ns in a pipeline memory for up to 4µs. Following a trigger, analogue pulse height data from every detector channel are transferred via analogue optical links, with no zero suppression, to an off-detector digitising module in an underground counting room adjacent to the experimental cavern, approximately 100m distant from the tracker. The CMS systems are designed to be able to cope with trigger rates of up to 100kHz. The Tracker also contains a pixel detector inside the innermost microstrip layers but there is no UK involvement in this part of the detector.

The Tracker contains approximately 15,000 silicon microstrip modules, comprising mainly two sensors wire-bonded together, a front-end hybrid with readout and service chips, carbon fibre frames and pitch adapters to match the sensor wire bond pitch to the readout chip. To construct such a large number of modules to a uniform quality in the relatively short time available, CMS adopted an industrial style method of manufacture. Despite the widely dispersed community, a series of identical manufacturiung centres were set up in a few central locations and these centres are responsible for assembling, using automatic tooling, the modules from components provided to them by other sites. There is a strong emphasis on uniformity and quality control, but only recently has it been possible to demonstrate production capability because all module components were not finalised. In particular, the front-end hybrid took longer than anticipated.

The hardware deliverables for which the UK has major responsibilities are in the electronic readout system. We are technically responsible for design and development, and shared procurement, of the APV25 front-end readout chip and other ancillary chips fabricated in the same 0.25µm CMOS process used throughout the tracker, and the Front End Driver (FED) VMEbus readout board. We also have shared responsibility for software required to operate and monitor the system, both online and offline. In addition to various monitoring tasks we are delivering the FEDs with the firmware and software required to integrate them into the CMS system.

General tracker progress and project status

Over the last year, the tracker has begun to ramp up module production with the objective of ~1000 modules per month by October 2003. A number of small problems, each requiring attention to overcome, hampered progress initially but by the summer it was believed that remaining problems had been addressed and module production began in earnest, with great success. Production rates were still limited by available components but it appeared that essentially all targets had been met. Unfortunately in early September a new problem was encountered which forced a temporary halt to further assembly until it was solved.

The multi-layer kapton-metal front end hybrid is mounted by lamination to a substrate for mechanical support with an integral kapton flying lead and a miniature connector. It was discovered that there was a weakness in the metallization of the region close to the connector and many hybrids showed evidence of cracking even during careful handling. The hybrid manufacturers and assembly company responded rapidly and it was quickly identified that the origin of the problem was in nickel plating of the copper prior to gold plating. It was established that this leads to brittleness in the cable. The solution was to glue a FR4 “rigidifier” to prevent cable flexing. The manufacturing process has been modified to laminate this piece to the hybrids in future.

A second recent high priority issue is sensor production. The 300µm thick TIB (Inner Barrel) sensors are manufactured by Hamamatsu, Japan. So far one third of the production has been completed on schedule with very high quality deliveries and there are no concerns about the remainder. The TOB (Outer Barrel) and TEC (End-cap) detectors are equipped with 500µm sensors produced by ST, Italy. In this case, production was slow to ramp up and the quality of deliveries did not match CMS requirements. It is important that a high production yield be achieved since manpower is insufficient to re-test each sensor completely for the full production period. Rejections are now mainly due to high leakage currents in many strips.

Several actions have been taken over the last year which raised quality significantly, but the present acceptance rate by CMS is still too low, although many batches are 100% accepted. CMS is in discussion with ST to resolve this. The ultimate challenge is to construct almost 16000 modules by the end of 2004 in an unavoidably large number of variations (26 types with 14 sensor masks, 24 pitch adapters, 3 hybrid layouts, etc.)

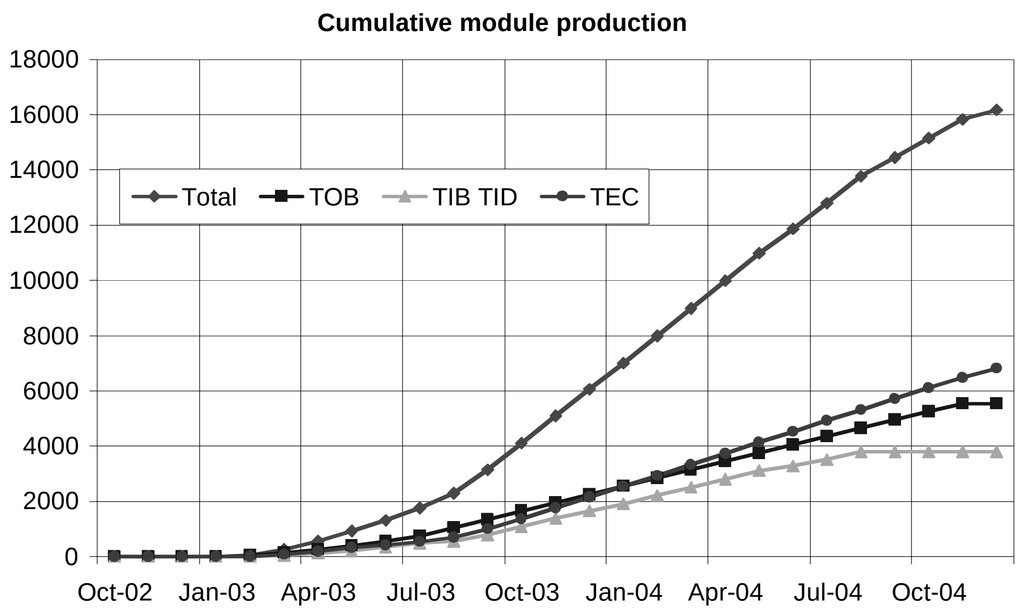

Figure 1. The target production rate of CMS tracker modules based on availability of components and module assembly capacity.

Regarding electronics, all ancillary ASICs are available from final production wafers and have been packaged. High yields were measured and there are no concerns about availability. There has been further good progress with the UK part of the project since the last report.

Front End Electronics

ASIC development

During 2002 and 2003, we experienced lower than expected yield on some lots of APV25 wafers. In most cases yield was in excess of 50%, considered highly acceptable for a large chip, and there was no evidence from any of our studies to show long term weakness correlated to lower yield wafers. Nevertheless, since a similar pattern of behaviour was observed on some other projects, intensive studies were carried out for possible correlation between yield and measured chip parameters. No obvious link was found.

During early 2003, IBM in Burlington, USA began intensive investigations of wafers and individual die which we had identified as abnormal. Several Failure Analysis techniques were used. It now is demonstrated that the explanation for the yield behaviour is variable thickness of an Inter-Layer Dielectric (ILD) attributed to unique features of large high energy physics chip designs which typically use much more of certain metal layers than most designs processed by IBM. It was discovered that the presence of the extra metal has an impact on some of the Chemical Metal Polishing stages of the process which are essential to planarise wafers to ensure a high degree of flatness, which is required for reliable lithography.

IBM processed wafers to study the effect in detail which we subsequently measured in our usual way and thus optimised the ILD etching. Since then we have observed the highest yields ever from APV25 wafers, with typical average lot yields exceeding 80% and individual wafers having yields of up to 95%. Deliveries of 48 wafers per month are proceeding to complete APV25 production by April 2004. Imperial College tests two wafers each day on most working days. This schedule is considerably more aggressive than anticipated in early 2003 but is still not expected to present difficulties.

FED developments

The last year saw a lot of progress with the Front End Driver. Eleven modules have been assembled and until recently no major problems had been experienced. The first FED was delivered to CERN in early November to integrate into our DAQ system, then subsequently into large scale assembly test centres, of which the first will be in Pisa in January 2004. This is good progress since the very first two FEDs were delivered only in the third week of January 2003. Only a small number of minor faults were found with the design and tests have been proceeding according to plan.

In June a FED was equipped for the first time with all 8 optical receiver modules and a 24-channel FED tester designed and manufactured at Imperial College was brought into operation in July. In late August a first integration test was carried out at Imperial, in which FED, FED tester, XDAQ software were fully operated together for the first time.

A 96-channel tester exercises all FED channels simultaneously. It generates known sequences of APV-emulated data with controllable amplitudes and patterns allowing comparison of the data going into the FED with that emerging from it. Because of the complexity of the optical inputs and need for precise temperature control, it is only possible to fit 24 channels onto a single 9U board so 4 boards, now complete, are needed to operate the FED. More detailed analogue and digital tests are under way and evaluation of long term behaviour can be studied.

One problem identified during studies of the analogue performance of the FED, was traced to the commercial ADC. An undershoot was visible <u>before</u> the pulse, which was quite unexpected. Faults in the FED design and layout were eliminated and we concluded the ADC was not behaving as it should, which was acknowledged by the company after investigations. The ADC can be operated in two modes, with a 1V or 2V differential range. Fortunately, the postgraduate student who discovered and measured this effect demonstrated that the 1V mode does not exhibit the phenomenon. Since the FED is designed to use the ADC in the 2V mode, only a small simple change is required. All other aspects of the analogue behaviour are acceptable.

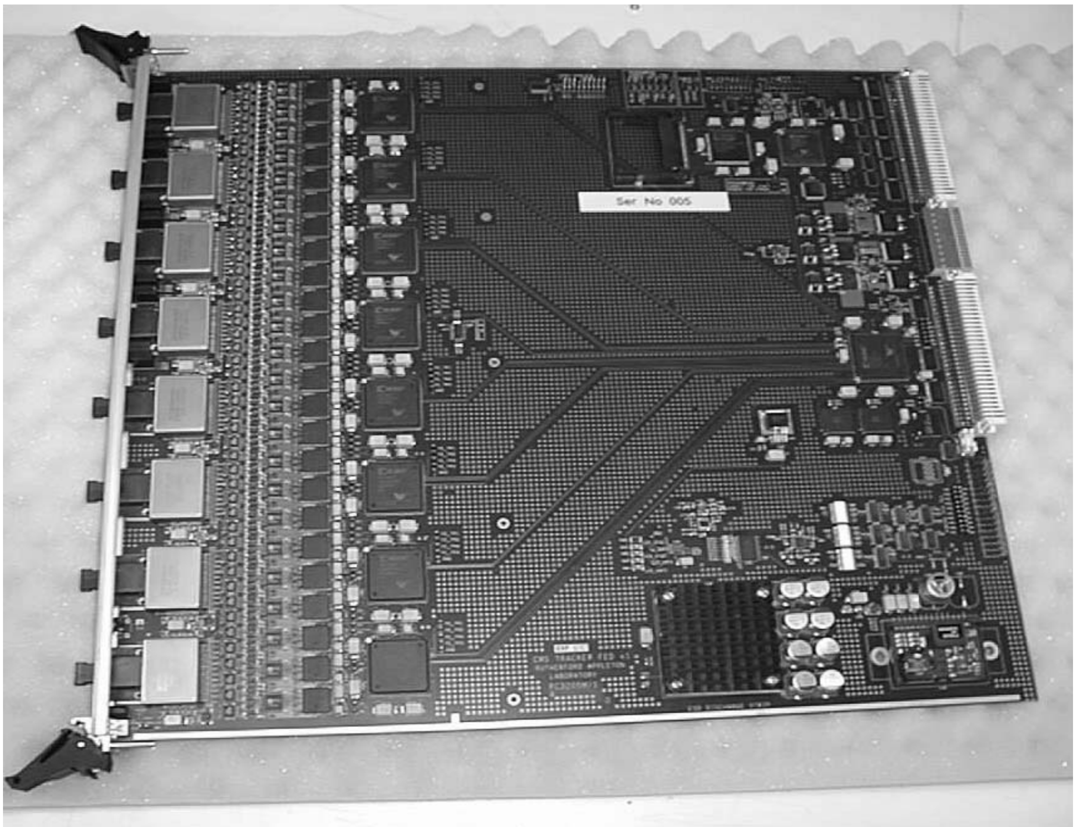

Figure 2. The first assembled final Front End Driver containing all optical receiver modules.

Until very recently the assembly quality had been without problems. Since no problems had been experienced with five FEDs, 6 more were ordered. All six boards were delivered in early October but had shorts between power and ground, traced to solder flowing incorrectly under some of the FPGAs. The assembly company identified contamination of the metal finish on the PCB as the origin of the fault and observed that solder does not properly wet the metal. In fact, the metal finish on these modules was changed from gold to tin, partly because of expected better long term behaviour, but also because contamination of the gold on boards for other projects. However, these manufacturing problems are not expected to prevent the current schedule being met.

We are now planning the procurement of the ~500 FEDs needed by the tracker system. This will take place in early 2005 following a pre-production order of ~20 FEDs to study in a fully populated crate.

The second major aspect of the FED development effort has been to provide software to allow the FED to be installed in a common CMS system. This task has being shared between Imperial and RAL very successfully.

Software

Offline software

UK institutes continue to make important contributions to the development of off-line Tracker software. A UK physicist leads the Tracker `Data Handling' group, which is responsible for all Tracker offline test-beam analysis software, and for all offline simulation and reconstruction software related to the Tracker readout and data acquisition system.

This year saw the group releasing a flurry of CMS notes. Physicists from IC and RAL participated in a test-beam analysis of the effect of Highly Ionizing Particles (HIPs) on the Tracker performance. This analysis resulted in a change in the front-end hybrid electronics, so reducing inefficiency induced by HIPs to a very low level. A Brunel physicist completed a study of the effect on the Tracker hit resolution of the finite dynamic range of the Tracker FEDs. This confirmed that the current dynamic range does not adversely affect the resolution. An ex-Imperial College physicist wrote a note that compared the performance of various pedestal/noise calibration algorithms.

More recently, Brunel and RAL have been collaborating with a physicist at CERN, in attempts to run the CMS reconstruction program on the (computer) `filter unit' during Tracker test-beams. This goal, which required writing a considerable amount of new software, will bring us closer to the final CMS software environment, since when LHC switches on, the reconstruction program running on the filter unit will be responsible for high level trigger decisions and data quality monitoring. Completing this task will be a major goal of the coming year.

Online software

The DAQ software for the tracker has been developed under XDAQ, which is a distributed computing framework independent of hardware choice. XDAQ enables the different aspects of the DAQ software to be loaded into any number of host machines seamlessly. A simple system encapsulating the readout chain has been developed, which is made up of Trigger Control; FEC; FED; Readout Unit; Event Manager; Builder Unit; Filter Unit; Monitor Writer; Zebra Writer; Trigger Supervisor (main control). Each of these parts, whether software representations of hardware or purely software, is represented by an instantiation of a C++ class.

These classes are then loaded into the XDAQ framework by the help of an XML configuration file which describes the set-up, number of devices and settings for each. Each of the hardware classes employ either the HAL (Hardware Access Library) or a custom hardware access library written by L. Mirabito (Lyon), in order to communicate with the VME memory space of the devices.

The FED part of this system has been developed at Imperial College while RAL have been developing firmware (ID) and low level software (PPD). Integration of the new FED classes developed between IC and RAL in a collaborative effort has been very successful and the final goal is to provide a completely self contained software package for the new FED which will seamlessly integrate with current DAQ systems at CERN.

ELECTROMAGNETIC CALORIMETRY

Overview

The UK has the lead responsibility for the design and construction of the CMS crystal Endcap Electromagnetic calorimeters (EE). This work is being carried out in close collaboration with institutes from Russia together with groups providing common items that will be used in both barrel and endcap regions of the detector.

The endcap calorimeters comprise a total of 14,648 slightly tapered lead tungstate crystals, each approximately 3x3x22 cm^3 in size, read out with one inch diameter Vacuum Phototriodes (VPTs). The majority of the EE crystals are contained within identical 5x5 units (25 channels) known as supercrystals (SCs). The crystals are supported within the SCs by thin walled (400 mm) carbon fibre alveolar structures.

Current status

The CMS ECAL Endcap calorimeter has made steady progress in the areas of VPT and mechanics procurement, in the design for the electronics integration on the Dee backplates, and in the preparation for supercrystal and Dee assembly.

As of 31 Dec 2003, a total of 6900 vacuum phototriodes (500 pre-production, 6400 production) had been delivered to RAL, corresponding to 45% of the total. Nearly 6700 tubes have been tested to 1.8T at RAL and a sample of 733 tubes tested at 4T at Brunel, as shown in Figure 3. Most of the devices showed excellent performance in the acceptance tests.

The UK is responsible for the VPT high voltage system. Work is in progress to design a cost effective cable, connector, and HV filter system from the counting room to the VPTs. A number of possible cables and connectors have been appraised. A final choice is expected as soon as the last sequence of high voltage tests has been completed. This work is on the CMS critical path due to the need to pre-cable the Endcap yokes in 2004. The orders for cables and fittings will need to be submitted ahead of this exercise.

In 2003 a set of 100 EE pre-production crystals was received from the main crystal producer in Bogoroditsk, Russia. 45 of these crystals have been measured for their light yield properties in the ACCOS test facility at CERN and at the Crystal Laboratory at Imperial. The crystals have good light collection uniformity. The remaining 55 crystals have been measured at CERN and will also be appraised at Imperial.

The EE major mechanics contract for 4 backplates, 4 ring flange supports to the Hadron Endcap Calorimeter, and 600 positional spacers, was signed with a UK company on 18 Aug 2003 for £450k following an international tender exercise. The company has successfully produced a test model and has been given permission to proceed with the rest of the contract. The mechanics for the first Endcap is due at CERN on 14th May 2004.

The supercrystal mechanics contract is now complete, with only minor items such as brackets yet to procure. Work continues to prepare the SC regional centre for production.

There has been substantial progress in the design for the integration of the ECAL electronics and cooling into the Endcap sections of the detector. The internal routings of cables within the EE, to the EE patch panels, must be well understood by the end of 2003. The cable exit positions from the EE patch panels will determine the occupancy of the cable trays that pass over HE. This information will be crucial for the pre-cabling of the CMS Endcap carts in 2004. An example of the integration work is shown in Figure 4.

The mechanical aspects of electronics integration will be complemented by work on E0′, a test bench of up to 4 supercrystals, to be eventually fitted with the new ECAL electronics readout.

The TA1 group at CERN has started to prepare the Dee assembly lab in close collaboration with Imperial College and RAL. An area has been secured in building 168 (adjacent to the UK liaison office). The TA1 group will manage the mechanical assembly of Dees at CERN before shipping to building 867 for electronics integration. The TA1 group has surveyed the OPAL Endcap frames for use on CMS. The purchase of a loader arm to mount supercrystals onto Dees is under way in the UK. A view of the assembly area with the frames is shown in Figure 5.

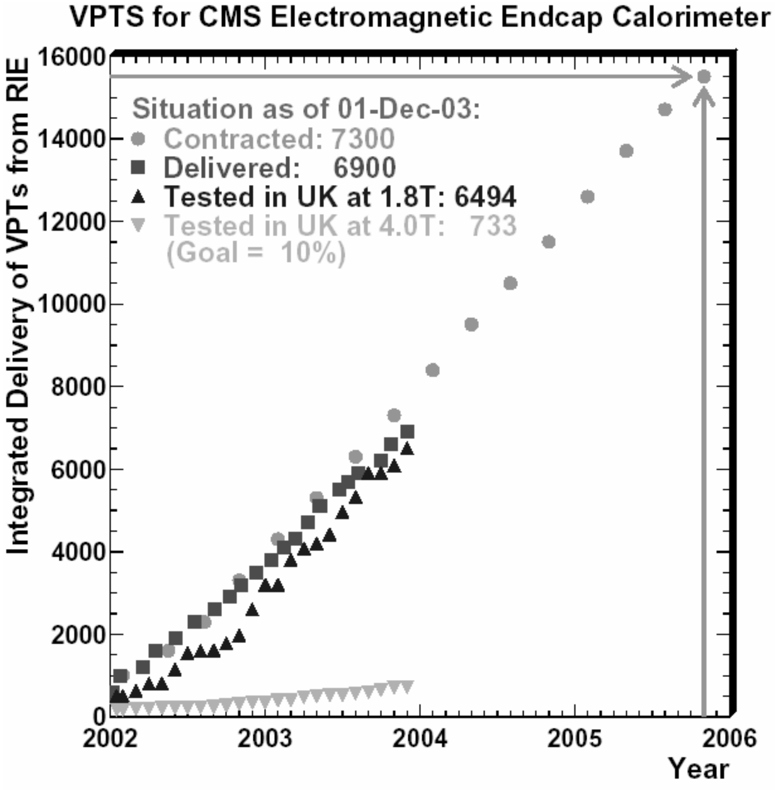

Figure 3. Delivery of Vacuum Phototriodes

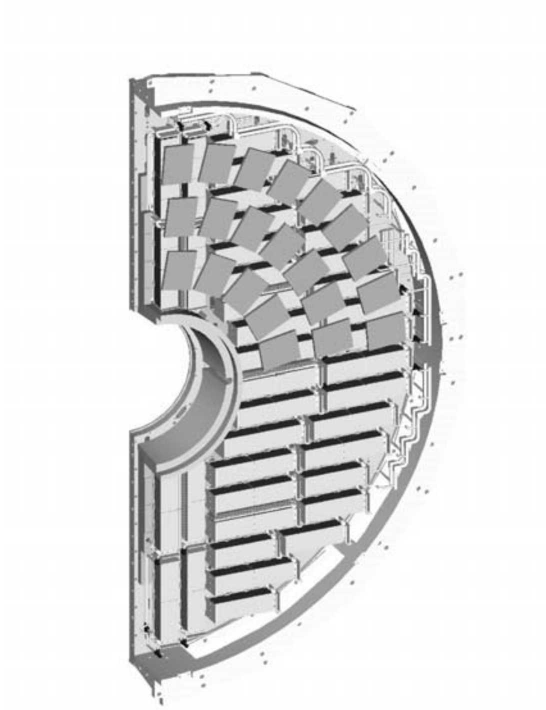

Figure 4. An example of the detailed 3D design work on the back of a Dee.

Figure 5. Preparations for the Dee assembly area at CERN

ECAL electronics

A major review of the ECAL electronics was conducted by CMS in early 2002, prompted by concerns about the technical status of the readout system and its cost. Consequently, a modified architecture was proposed which substantially reduced the number of optical links - one of the main cost drivers. The revised system makes maximal use of developments from the CMS Tracker electronics, including the control system and, especially, ASICs implemented in the IBM 0.25µm CMOS technology. Imperial College and RAL engineers took on the design of several critical elements. In particular they have developed a new digital chip, FENIX, and a new amplifier in radiation-hard 0.25µm technology. Although this was a very late stage for such a revision, the re-design proceeded extremely rapidly and is no longer on the critical path of the overall ECAL project.

At the very front end of the revised readout system an amplifier senses signals from the APD or VPT and the output is digitized with a 12-bit ADC. To cover the full ~16-bit signal dynamic range multiple ranges are needed. This is accomplished by providing three outputs with different gains. The existing commercial ADC chip originally chosen was not matched to this and considerable cost savings could be realised by a dedicated circuit. CERN developed a new multi-channel chip with 12-bit ADCs in 0.25µm technology, with the aid of a specialist design house. This is coupled to a multi-gain amplifier (MGPA), also in 0.25µm technology with 3 different gains, and selection of the appropriate one after the ADC. The digital logic to do this is straightforward and is incorporated into the ADC chip. The first version of the ADC did not reach the full design performance, but the causes are now understood and will be corrected in the engineering run now in progress.

The amplifier was designed at Imperial College and laid out by the RAL microelectronics group. The MGPA was submitted on the same MPW run as the ADC and FENIX in February 2003. The production yield was high and the test results are extremely good. It easily meets the stringent CMS linearity and noise requirements. The energy equivalence of the noise, measured with a 50-channel prototype of the electronics installed on an ECAL Super-module at CERN, averages 45 MeV (compared with the target of 50 MeV). Very minor improvements have been implemented on a final version which is expected in Spring 2004. The MGPA has another significant advantage compared to the old system: for the first time the

Endcap ECAL (VPT) readout can be implemented simply by altering two external components on the front end board, whereas the previous system required a new chip.

The FENIX chip follows the very front end to provide several basic functions; it is configurable between them to minimize development cost and time and optimize production and spares. These functions are storage of digitised raw data, transmission of trigger primitives extracted from raw data to the L1 trigger cards, and transmission of 10 samples of raw data for 5 crystals per event. Each front-end card contains seven FENIX chips. The FENIX functionality is defined by VHDL code, developed on an FPGA by groups at CERN and LLR, France. In parallel, the design of the FENIX ASIC was undertaken by RAL ID. A board with an FPGA emulating the FENIX chip was produced and operated in RAL and, subsequently, in CERN. The FENIX chip design has been completed and fabricated on a CERN multi-project IBM run and is currently under test. The initial results show that it works according to design. An engineering run incorporating some minor changes has been submitted. The RAL ID group has also designed and delivered prototypes of the associated Front-End printed circuit board.

GLOBAL CALORIMETER TRIGGER

The calorimeters provide two types of information to the Level-1 trigger: electron/photon and jet candidates, collectively known as trigger 'objects'; and sums of transverse energy and its components over the whole region up to $|\eta|=5$. The job of the Global Calorimeter Trigger (GCT) is to sort the different types of object, passing on the best four of each type for use in the Level-1 decision, and to calculate total and missing energy for the whole detector. These functions will be performed using a single, generic design of trigger processor module making extensive use of Field-Programmable Gate Array (FPGA) technology. The logic of the GCT is illustrated schematically in Figure 6.

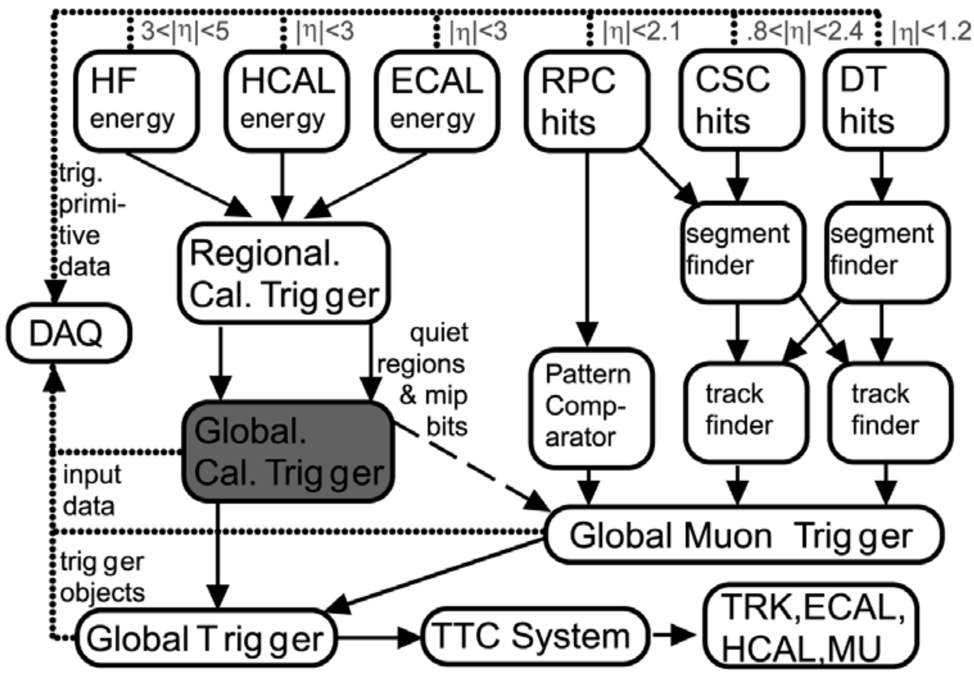

Figure 6. Schematic diagram of the CMS Global Calorimeter Trigger

The final processor design for the GCT has demanding requirements on data input/output capabilities as well as logic performance. The input data of 5040 bits per beam crossing will be received by eight processor modules, giving an input rate of more than 25 Gbit/s per module. Recent developments in commercial serialiser/deserialiser (serdes) chipsets allow us to achieve this density using readily available, low cost components. Following an extensive programme of technology evaluation in the UK, the prototyping of GCT components has begun during 2003. The two main components of the system are the generic processor modules and the input modules. A first set of prototypes of the input modules has been tested extensively. During the summer some of these modules were taken to Vienna and to Wisconsin and a successful series of tests of the interfaces to the Global Trigger and Regional Calorimeter Trigger was undertaken. Figure 7 shows the setup for testing the links to the Global Trigger, with a GCT prototype module sending data to a Global Trigger receiver prototype via gigabit serial links.

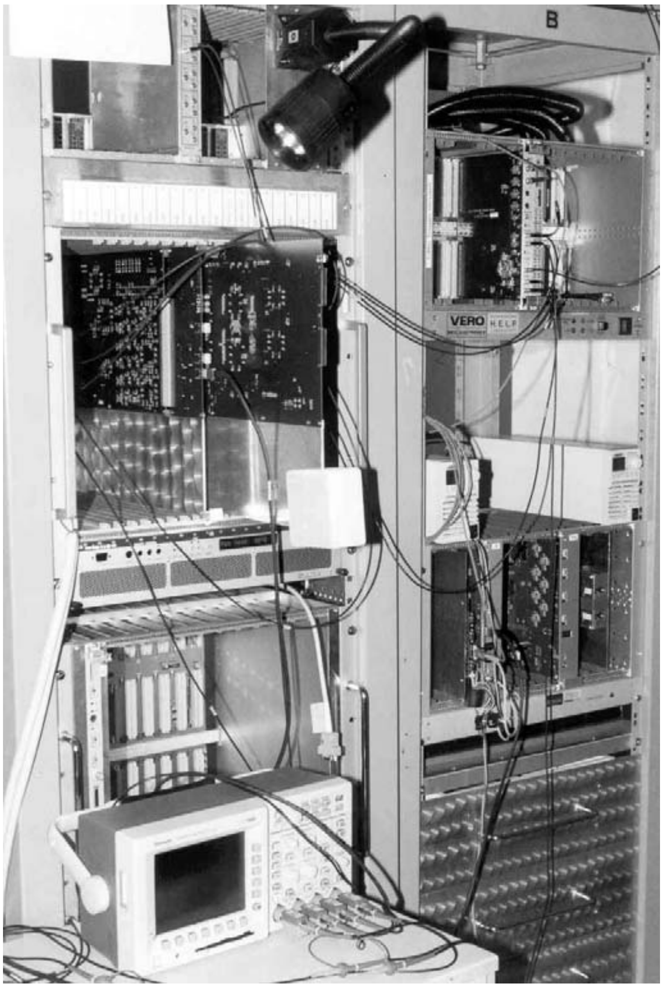

Figure 7. Testing of the GCT input module prototypes and the interface to the Global Trigger in Vienna, July 2003. The GCT components are on the right of the photograph.

The design of the processor module was completed during 2003. The module contains 17 FPGAs from the Virtex-II family from Xilinx, including four large 3-million gate devices to perform the algorithm processing. An aggregate data input/output capacity in excess of 100 Gbit/s is provided by serdes devices at the front and rear of the module. Testing of the first prototypes is now under way. Production of the final GCT components is scheduled to take place in 2004 so that the system can be installed, along with other central components of the trigger system, during 2005.

PHYSICS AND COMPUTING

Physics Reconstruction and Selection

The PRS project

After completion of the work on the DAQ TDR in December 2002, which gave detailed results on the complete selection chain from the Level-1 trigger through the High Level Trigger, the four original 'detector' PRS groups – e/gamma, muon, b/tau and jets/missing energy – were augmented by the addition of four new 'analysis' PRS groups: Higgs (led by a UK physicist), Standard Model, SUSY and beyond the Standard Model, and Heavy Ions. The aim is to organize physics, reconstruction and selection studies, including development of the necessary Object Oriented software, towards the milestone of the Physics TDR, due at the end of 2005.

The Physics TDR is meant to be a test of the validity and readiness of software and computing, as well as of the collaboration's knowledge and skills. It will be organized in two volumes. Volume I will cover detector response, physics objects, calibration, alignment etc. This is the work of the detector PRS groups. Volume II will cover high-level analysis and will be divided into two parts. The first part will deal with a small number of very full analyses, to demonstrate how we can do physics. This again is work for the detector PRS groups. The second part will cover general physics topics, giving an overview of what physics can be done by CMS. This is the part for which the new analysis PRS groups were created.

The broad aims of the work towards the Physics TDR can be summarized as follows:

1. Complete the physics reconstruction and selection software of CMS.

2. Complete the simulation software, obtain a detector parameterization, and build it into a new fast simulation.

3. Engage the collaboration, activating and training the maximum possible number of people.

4. Create a strategy for physics as a function of luminosity.

5. Put in place, ahead of time, all the recipes and methods that will be used to commission CMS for physics.

ECAL – e/gamma Group

The ECAL-e/gamma group is responsible for all ECAL software and reconstruction and physics-related tasks, including calibration, test-beam analysis and simulation. A UK physicist has led the ECAL-e/gamma group since its inception, and the ongoing UK contribution consists of one physicist and one student working full-time, plus a number of additional part-time contributors.

Work this year has required the detailed definition of the data samples to be simulated for the 2004 computing data challenge (DC04). These Monte Carlo samples will also be used for physics studies for the Physics TDR. This has necessitated seeking agreement of the many interested parties, and organizing the definition of samples totalling some 20M events, which have now been generated (mostly with PYTHIA), then simulated using both GEANT3 and later GEANT4. The simulation of the digitization, the final step, will begin in 2004.

Much attention and work has been devoted to breaking down the work required to build and complete the ECAL software into well defined packages that can be taken on by groups and institutions. This effort culminated in a Tasks and Responsibilities document that was presented and made available in the December CMS Week. One of the challenges of this effort is the range of software covered: while it easy to assign specific hardware related software to an institution, this is not an appropriate model for physics studies, and the field encompassed by ECAL-e/gamma spans these extremes.

A substantial contribution has been made in following and co-ordinating the studies of many groups of physicists at many institutions.

One of the most important milestones in 2003 has been the replacement of the old (Fortran based) GEANT-3 particle transport and detector simulation program, by its Object Oriented GEANT-4 successor. This has required detailed verification of the transported geometry model, and comparison of new results with old. UK physicists have played an important role in this work. A UK physicist was responsible for the implementation and testing of the ECAL geometry in the new CMS GEANT4, OSCAR program.

UK students and physicists have also contributed to the test-beam work where a new software framework for analysis has been developed this year, in preparation for the testing and pre-calibration of complete super-modules in 2004. Energy resolution, and the details of energy reconstruction from the 40MHz ADC time samples of the new front end electronics, is being studied by UK students.

Work by UK physicists on the end cap trigger tower mapping has continued, although final results have been delayed by serious delays in the Computing and Core Software (CCS) implementation of the new (POOL based) persistency mechanism which has now replaced the commercial Objectivity package. The delays, which are widespread in both the CCS and PRS domains, result from serious staffing shortages, which are widely acknowledged, and to alleviate which considerable efforts are being made.

A UK student has started investigating some of the aspects of ECAL inter-calibration. This is an area where a much more widespread and coordinated effort is needed in the future.

After an ECAL geometry workshop in November, which highlighted the need for a new maintainable OO-based geometry description, a UK physicist took on the responsibility of providing the software for the Endcap geometry description.

Higgs group

The newly formed Higgs group is led by a UK physicist. A further UK physicist and three UK students are working on Higgs decay channels, and on the related radion channel, which also falls within the scope of the group. The radion study, "Search for the radion decay into a Higgs boson pair with final states $\gamma\gamma$+bb, $\tau\tau$+bb and bb+bb" was presented at a CMS plenary Physics meeting in the December CMS week.

As in the case of the ECAL-e/gamma group, detailed Monte Carlo requests for the Higgs group have been prepared, organized and submitted for production in preparation for the DC04 data challenge. A UK physicist has produced an interface for the dedicated leading order event generators ALPGEN, MadGraph, and CompHep, so as to be able to produce event samples within the CMS production environment.

A UK physicist was convenor of the Higgs group at the 2003 Les Houches Workshop, and produced results for the workshop proceedings, which were approved, on the subjects of radion $\rightarrow$ hh $\rightarrow$ $\gamma\gamma$ + bb channel, and the expected precision of tan(β) measurement in MSSM $H \rightarrow \tau\tau$ and $H^+ \rightarrow \tau\nu$ channels.

A collaboration has been initiated with Southampton theorists to study the effects of SUSY particles on the generation and decay of SUSY higgs particles. No comprehensive study of these effects has previously been performed. The collaboration will also encompass possible CP violation effects in the Higgs sector, particularly in NMSSM models.

Other physics work

Jet reconstruction algorithms based on 'energy flow', making maximum use of precision tracking and electromagnetic calorimetry, are likely to play a major role at the LHC. A UK physicist has led one recent study of the use of these techniques in CMS and the results of this study have been approved for outside presentation at a recent CMS Physics Meeting

A UK physicist coordinates the Gauge Coupling subgroup of the CMS Standard Model Physics Group. A further UK physicist and two students are active in this group, investigating triple and quartic gauge couplings.

GRID computing for CMS

The CMS work plan for GridPP is organised into three distinct but overlapping areas: workload management, data management and monitoring/metadata management. The tools and approaches developed are exercised in the context of large-scale data challenges, with a leading UK contribution.

CMS will shortly be undertaking its most ambitious data challenge to date. 'DC04' requires the month-long operation of a 25% scale worldwide computing system. In the UK, we will execute tens of thousands of jobs to produce ~40TB of simulated and reconstructed data at T1 and T2 sites. We have made extensive tests to store and replicate this data using regional centre resources, during which we had to solve problems associated with the Replica Catalogue service and took part in 'DC04 Pre-Challenge' production which made extensive use of the Tier 1 centre at RAL and resources at Imperial College. Over 70 million fully simulated and digitised events were produced and stored.

We are completing the implementation of a web portal for Monte Carlo production and analysis that will enable CMS users to flexibly submit production and analysis jobs via a web interface. This will lead to initial work on a Grid-enabled analysis interface for CMS users.

After production-scale deployment and stress testing of the POOL object store product as part of LCG, we have begun the task of integrating the POOL catalogue component with CMS Grid data management, monitoring, and workload management systems. A prototype Grid-aware event buffer and WAN data streaming system is being implemented, facilitating prompt reconstruction and calibration tasks at the CMS T0 and T1 centres. An interface is being developed between the existing CMS data management system (SRB) and Grid middleware.

We will continue the integration of the CMS COBRA (COBRA is the realization of the CMS OO Software Architecture for High Level Trigger, Simulation, Reconstruction, and Analysis) framework with the Grid, via RGMA. We have recently achieved a dramatic improvement in the number of messages that can be handled using RGMA and work closely with the EDG development team to continually improve the reliability and performance of this key middleware.

CONCLUSION AND SUMMARY

The CMS experiment is making steady progress towards the completion of the detector in time for the LHC start-up in 2007. The projects with direct UK involvement, the ECAL Endcaps, the Silicon Tracker, and the Global Calorimeter Trigger have all taken major strides towards completion in the past twelve months.

The production of tracker modules has been ramped up in 2003 towards the long-term objective of 1000 modules / month. Significant successes have been achieved in the production of the APV25 wafers and the Front-End Drivers (FEDs), for which the UK tracker groups are responsible. The typical yield obtained from the APV25 wafers has been increased during the year from around 50% to over 80%, and APV25 production is expected to be completed by April 2004. Fully-equipped FEDs were tested successfully in 2003, with a number of problems being overcome, and the procurement of the total of about 500 devices will go ahead early in 2005, with a pre-production order in 2004. In addition, excellent progress has been made in the development of FED software.

The ECAL Endcap project has also moved forward significantly. The delivery of VPTs from the supplier in Russia is approaching 50% of the total requirement, and is proceeding according to the agreed schedule. Work has begun on the design and implementation of the VPT high-voltage system. The procurement of the supercrystal mechanics is almost complete, and 100 pre-production Endcap crystals have been received, allowing supercrystal production to begin in 2004. There has been a substantial revision of the ECAL readout electronic system, on a very short timescale, to which UK physicists and engineers have made substantial contributions by exploiting their experience of the 0.25µm CMOS technology gained on the CMS Tracker. This will ensure that the system meets the demanding CMS precision requirements at a much reduced cost.

Prototyping of components for the Global Calorimeter Trigger began during 2003, with extensive, and successful, tests on the first prototype input modules. In addition, the processor module design was completed during the year, and prototype testing is in progress.

The UK groups continued to make substantial contributions to CMS physics and software during 2003. A significant achievement, in which UK physicists played an important role, was the replacement of the Fortran- and GEANT3-based detector simulation program by a new simulation based on Geant4 and written in C++. UK groups are extremely influential in CMS Grid computing activities, playing a major role in the development of Grid software, as well as in Monte Carlo production and Data Challenges.

UK physicists and students have a leading role in the newly-formed Higgs physics working group, as well as in many other physics studies, and are well-placed to make major contributions to the CMS Physics TDR, whose publication is due at the end of 2005.

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