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 remainder of this section gives a brief overview of some of the highlights of 2004. More detailed reports of the status of the projects with UK involvement are given in subsequent sections.

New Collaborators

During the course of 2004, three new members joined the collaboration: the Institute for Experimental Physics, University of Hamburg, a consortium of four Mexican Universities, and Brown University, Rhode Island. They will contribute to the Silicon Tracker project.

Civil Engineering and Assembly

The civil engineering work at Point 5 (located at Cessy, France) is now nearing completion. The service cavern (USC55), that houses the off-detector electronics and first level trigger, has been delivered and installation of the infrastructure is underway. PM54, the access shaft for this cavern, has been equipped with the stairway and services. The main experimental cavern (UXC55) is scheduled for delivery to CERN in February 2005 and is on course to be ready when the major elements of CMS are lowered underground, starting early in 2006.

Magnet

All five sections coil of the 4 Tesla superconducting solenoid have been completed and delivered to CERN. Assembly of the coil sections into a single unit is underway and the completed coil will be inserted into the yoke of the magnet in June 2005. Cool down will start in September in preparation for a full test of the magnet system on the surface, starting in October 2005.

Tracker

A beam test has been conducted at PSI on the Pixel Detector readout, up to and beyond the full LHC counting rate. At a track rate of 25 MHz/cm^2, corresponding to LHC conditions at a radius of 4 cm from the crossing point, the data loss was only 0.8%.

For the Silicon Strip Tracker, the carbon fibre support structures (of which there are four different kinds) have all been delivered. The first detector modules have been attached to a prototype shell of the inner barrel and tested with electronics. Integration on to the real inner barrel shell is about to start and integration on to the outer barrel is already underway.

There have been continuing problems, now resolved, with the front-end hybrids for the readout. The consequent delays have disrupted the Tracker assembly schedule and strenuous efforts are under way to bring this back on track.

Electromagnetic Calorimeter

Implementation of the new readout architecture has gone extremely well and production of the components for the barrel is now under way. Construction of ‘bare supermodules' (units comprising 1700 channels) has continued and 16 out of the full complement of 36 have now been produced. One of these was fully equipped with readout, services, and laser monitoring system and tested in a high energy electron beam in October and November. The full design noise performance and energy resolution were achieved.

At the start of 2004, problems were encountered with the production and delivery of lead tungstate crystals. Delivery of crystals is proceeding smoothly once more, at a rate of 1200 per month, and more than half the full complement of 61200 Barrel crystals has now been delivered. Nevertheless, crystal delivery remains on the critical path for completing the ECAL, and, following successful tests of pre-production crystals, an additional supplier will be engaged to accelerate production.

Hadron Calorimeter

The 18 wedges of the first of the two forward hadron calorimeter modules have now been completed and installed within the cylindrical support structure. This is mounted on a table that allows it to be opened and closed very precisely about the beam pipe. A trial insertion of the 'HO section' of the barrel section, located between the coil and the first layer of the iron return yoke, has been successful.

Muon Detector

All of the Cathode Strip Chambers (CSC) for the Endcaps, including spares, have now been produced and delivered to CERN. More than 25% of these have been installed and commissioned with cosmic rays. Production of the Barrel Drift Tube Chambers (DT) at CIEMAT, Aachen and Legnaro is proceeding at the required rate (18 chambers/year/site) and more than 60% have been delivered to CERN. Installation has been under way for several months. The proportion of Resistive Plate Chambers delivered to CERN stands at more than 40%.

The Endcap RPC system has been descoped to keep within available funding, limiting coverage to $|\eta| < 1.6$. Gap production is underway in Korea and Pakistan.

Trigger and Data Acquisition System

Most of the full-function trigger prototypes have been manufactured and final validation tests have been completed. The trigger system passed an Electronics Systems Review in May, authorizing the start of production of the trigger system, which has begun. Integration tests of detector primitive generators, trigger system and DAQ are underway. Tests with structured 'LHC-like' beam (25ns bunched beam) have been very valuable to establish latencies and detailed models of trigger performance. Software is now being developed for testing and operation

The 1:8 scale DAQ pre-series system consisting of a Readout Builder (64x64), 1/8 of Data-to-Surface components, 1/64 of Filter Farm and 14 water-cooled racks has been installed in a computing room in a barrack (recovered from OPAL) at Point 5. The Electronic System Review, held in May 2004, gave approval for the launch of production of the Front-end Readout Links and Fast Monitoring Modules.

TRACKER AND DATA ACQUISITION

Overview

The CMS tracker is a system of 9.3 million silicon microstrip sensors, containing pixel detector layers at small radius. The UK hardware contributions are in the electronic readout system for the microstrips, shown schematically in Figure 1, in the form of the APV25 front end electronics and the Front End Driver modules which digitise data for transmission to the Data Acquisition System.

The CMS system employs analogue readout. Each microstrip is read out by a charge sensitive amplifier whose output voltage is sampled and stored in an analogue pipeline for 3-4µs. Each APV25 channel contains preamplifier and shaper followed by a 192 location memory into which samples are written at 40MHz.

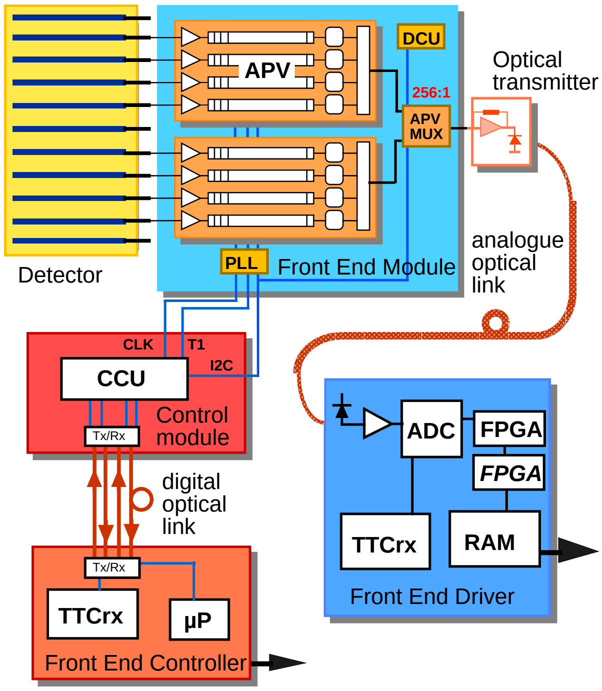


Figure 1. CMS Tracker readout and control system

Pulse height data, without zero suppression, are transmitted from the front-end via linear semiconductor lasers over fibre optic cables to the counting room adjacent to the underground cavern. The optical data are converted to electrical and digitised on the Front End Driver (FED) which performs several signal processing operations and stores data locally until required by the CMS data acquisition.

General tracker progress and project status

Sensors and hybrids are the major influences on module production at full rate and the ultimate delivery of the tracker to the CM experimental site.

Delivery of Hamamatsu Inner Barrel (TIB) thin (320µm) sensors has now been completed on schedule. The quality has been excellent.

The Outer Barrel (TOB) and Endcap (TEC) STM thick (500µm) sensors were the focus of considerable effort. A series of problems were encountered, including high leakage currents, short term fluctuations, common mode noise on modules, scratches, high flat-band voltage, mechanical stress dependence and aluminium corrosion. Most of the production has been transferred to Hamamatsu as a result and deliveries are scheduled to be completed by October 2005.

Front end hybrid production started with a pre-series in May 2003 but there have been a number of problems which have delayed module production.

In September 2003 cracks of metal lines near the connectors were found. The problem was solved introducing a stiffener under connector. In January 2004, a problem of weak bonds was encountered, traced to poorly tuned bonding parameters at the assembly company, and poor substrates. In April 2004, a problem with vias between metal layers was identified. During the autumn of 2004, this was solved by enlarging the via diameter and an improved metallization process.

The tracker will ramp up module production by March 2005. Improvements in the organization to maximise efficiency in completing construction are under way.

ASIC production

APV25 production was completed on schedule in May 2004. At that point a total of approximately 116,000 'Known Good Dies' (KGD) had been produced from about 160,000 total dies on 445 wafers, with almost 96,000 KGD from the final production order of 288 wafers. The quality was high, as shown in Figure 2, once some manufacturing issues with early lots had been understood.

It was expected that this order would meet all the requirements for APV25s in CMS but losses due to the yield of good hybrids forced a revision of this number. CMS will procure additional wafers to be delivered in 2005. Work continues to validate radiation hardness of the chips by x-ray irradiation of sample die, but no surprises have been found.

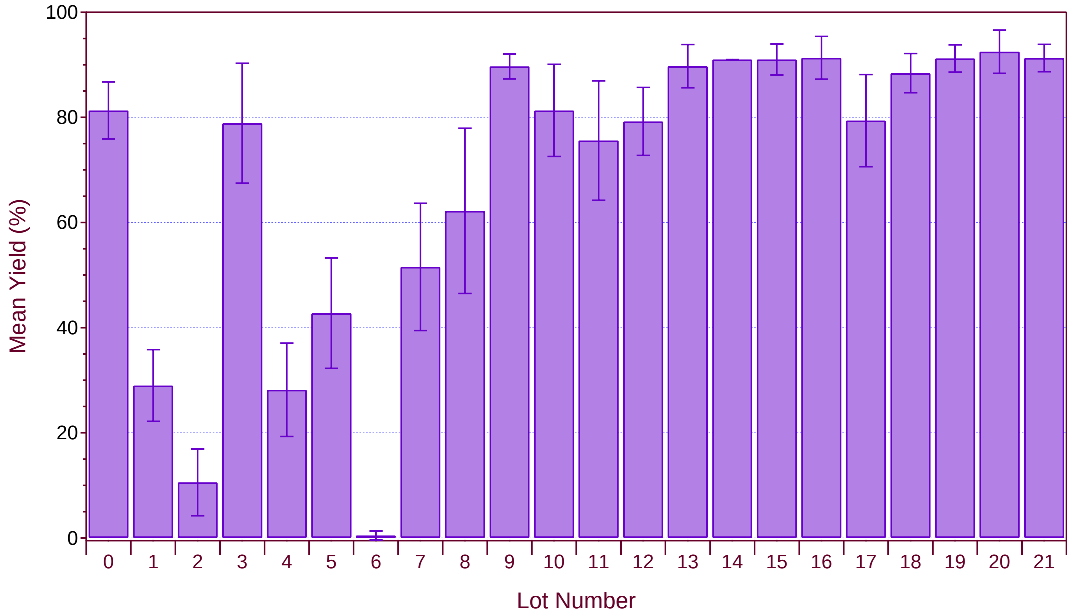


Figure 2. Mean yield as a function of the lot number. Error bars correspond to the standard deviation.

Front End Driver developments

Progress on the FED has been excellent. The first version prototype boards (FEDv1) delivered in early 2004 have performed well in all tests. It is believed that all hardware issues have been identified and remaining features simply require completion of firmware and software. A 25ns beam test was undertaken in June 2004 when four FEDs were successfully operated in the CMS Tracker system, when a lot of data were acquired. A further successful 25ns beam test took place in October 2004.

Two boards of the final design (FEDv2) were delivered in August on schedule. A further 25 pre-production boards are currently in manufacture. Most of those boards will be distributed around April 2005 to CMS collaborators to be used in large scale assembly tests of the tracker in the main integration centres.

To ensure high quality of deliveries, software has been developed to test those functions of the board which cannot be addressed by JTAG boundary scan. This will be installed in the company to verify the boards, isolate faults and correct them prior to delivery. Final acceptance tests, using the optical inputs will then be carried out after delivery.

Procurement of 500 boards will begin in March 2005 and all deliveries to CERN will be completed by the end of 2006.

More detailed plans are being developed for the commissioning phase. The underground counting room (USC55) will be "ready for crates" in December 2005. A Prevessin area will be in use in early 2005 and a large scale integration activity will follow up work now under way in 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 and CERN 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.

The UK has also undertaken leading roles in the appraisal of lead tungstate crystals and the first test beam appraisal of an ECAL Barrel Supermodule. The UK has led the ECAL e/gamma section of the Physics Reconstruction and Selection (PRS) group of CMS.

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 1 Dec 2004, a total of 9200 vacuum phototriodes (500 pre-production, 8700 production) had been delivered to RAL, corresponding to 59% of the total. Nearly 9000 tubes have been tested to 1.8T at RAL and a sample of 1140 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. The orders for HV cables and fittings from the CMS control room to the detector have been placed, in readiness for the pre-cabling of the Endcap yokes which will start in Q1 2005.

In Jan 2004, 50 EE pre-production crystals were received from a second potential producer, the Shanghai Institute of Ceramics (SIC). These crystals have been measured for their light yield properties in the ACCOS test facility at CERN and at the Crystal Laboratory at Imperial, both before and after irradiation. In addition the

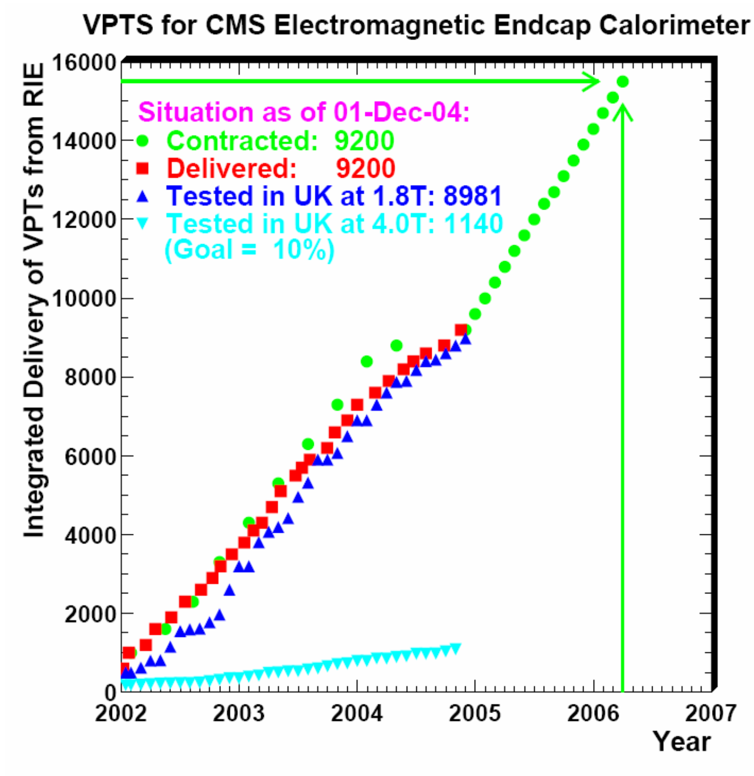


Figure 3. Delivery of Vacuum Phototriodes

crystals were extensively studied under high beam irradiation conditions at CERN. These crystals meet the CMS specifications and further progress is being made to ensure that all future batches are consistent with specification.

The EE major mechanics contract for 4 backplates, 4 ring flange supports (to the Hadron Endcap Calorimeter), and 600 positional spacers, has made very good progress. The four backplates and the positional spacers have been all completed together with the associated Dee cooling circuits.

An EE highlight in 2004 was the delivery of the first two pairs of Dee backplates and ring flanges (support-rings) to CERN, and their successful dry mount on the Hadron Endcap at SX5 (see Figure 4). The Dees were mounted to a precision of 0.1 and 0.3 mm in the horizontal and vertical respectively. This dry mount demonstrated that all holes line up and that the dowelling scheme works.

The TA1 group at CERN has completed the first Dee dry assembly in the 'Crystal Laboratory' (building 168, adjacent to the UK liaison office) in close collaboration with Imperial College and RAL. A view of the Dee dry assembly area, with the loader arm to mount supercrystals onto Dees is shown in Figure 5, together with a photograph of a Dee after all the Supercrystal positional spacers have been mounted.

An important milestone for the whole ECAL project was passed this autumn by the complete assembly of an ECAL barrel Supermodule, comprising 1700 crystals and the associated final ECAL readout electronics. The Supermodule was exposed to electrons, muons and pions at the H4 test beam at CERN (Figure 6). Excellent performance was achieved. The noise per channel was approximately 40 MeV and the resolution, as shown in Figure 7, was found to be 0.45% for electrons at 180 GeV.

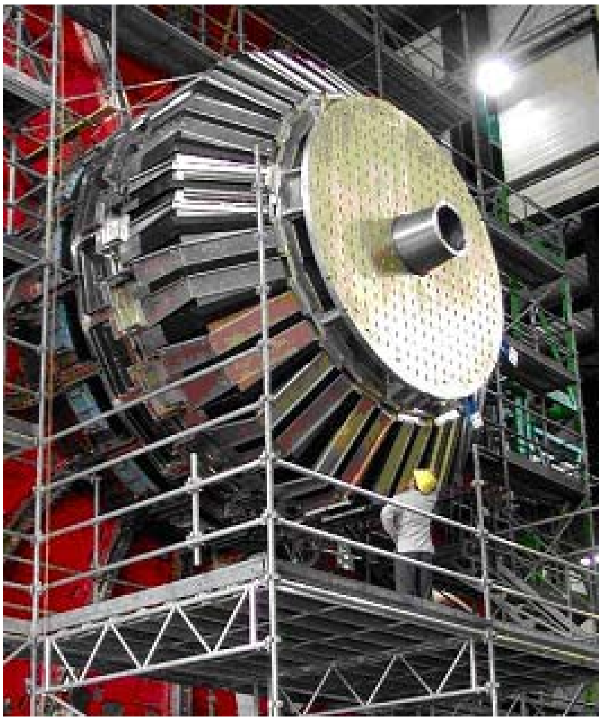


Figure 4. The EE backplates and their support rings mounted on the front face of HE+ in September 2004. At the centre can be seen the support cone for the Preshower (ES) detector, and at the perimeter an be seen the ducts for the EE and ES services.

Figure 5. A Dee under preparation in the Crystal Palace at CERN, and, right, a Dee with its set of positional spacers with 4 SCs under trial mounting.

ECAL crystal studies at Imperial College and Brunel

During 2004 the UK received a sample of 20 endcap crystals produced at SIC. Ten crystals were gamma irradiated at endcap dose rates at Brunel University, and their recovery was monitored at Imperial College after a delay of about 45 minutes. Recovery time-constants have been measured and found to be in good agreement with measurements performed by other laboratories. The parameter R (ratio of scintillation response to monitoring light response) was measured for these crystals and found to have a mean value of 1.1 with a fractional variation of 10%. This value of R is significantly lower than that for crystals from the main supplier, BTCP. An upgrade to the LED monitoring equipment at Imperial College has been completed and cross-check measurements are in progress.

At Brunel the induced optical absorption of two SIC crystals were measured within ten minutes of irradiation ceasing. In both of these crystals some rapid "reverse annealing" was seen near the UV transmission edge. No such anomalous behaviour was noted around the peak emission wavelength.

ECAL Electronics

The first version of the Multi-Gain Pre-Amplifier (MGPA) was delivered in early 2003. Tests at Imperial College showed that the chip was working well and satisfying the ECAL gain, linearity, pulse shape matching and noise requirements. This was verified at CERN where the chip was operated together with the new multi-channel ADC chip on a prototype of the 5-channel VFE card. One chip was irradiated at IC to 5 Mrads, where the only measurable degradation was found to be a 3% reduction in gain. Some minor modifications were made to the chip for the final version, the only significant change being the inclusion of an on-chip reference current circuit, previously supplied externally. The final version of the chip was submitted on an engineering run at the end of 2003, and delivered in Spring 2004. The performance was verified to be unaffected by the changes, allowing the main production to be launched. Chips from 48 wafers are presently being packaged. This will be enough for the complete ECAL.

The FENIX ASIC is also in production, being packaged under contract from CERN. Test vectors have been successfully transferred to a test house, so chips will no longer be tested at RAL.

The Front-End (FE) card has been revised with minor modifications for the launch of mass production and all the files exported to CERN for production.

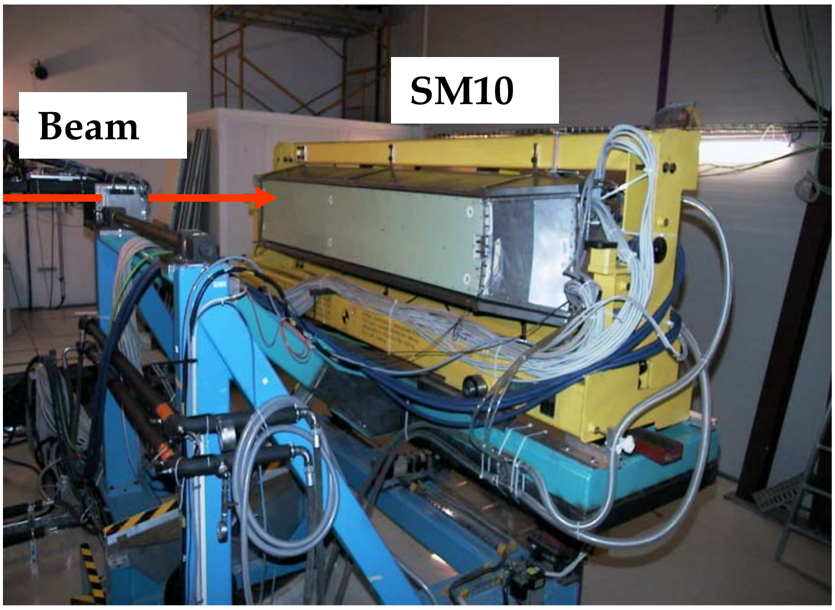
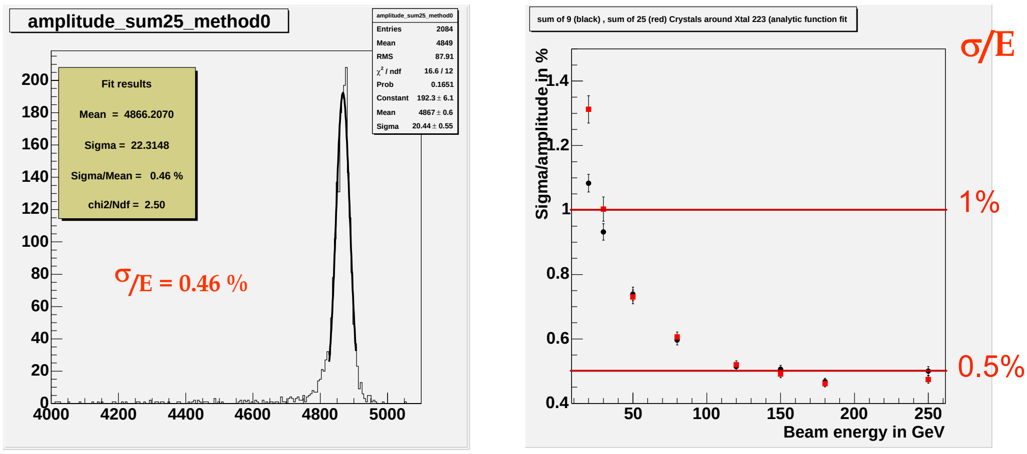


Figure 6. SM10 installed at the H4 test beam at CERN.



Xtal 223, 180 GeV, sum of 25

Xtal 223, sum of 9 (black) and 25

Figure 7. Resolution of 0.46% for 180 GeV electrons, and, right, resolution as a function of energy for electrons up to 250 GeV.

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 8.

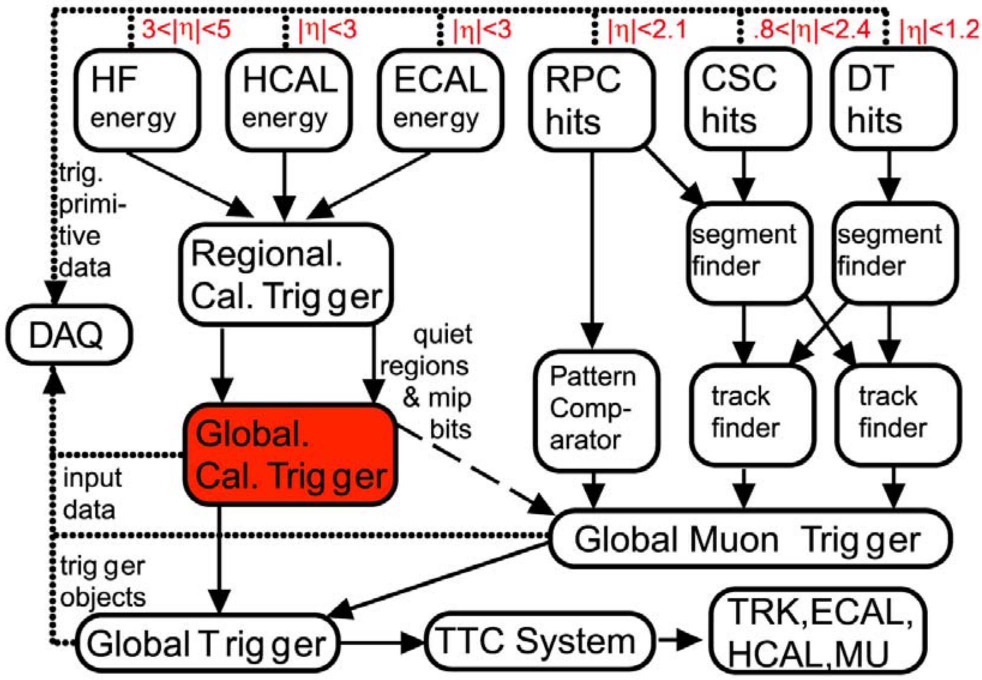


Figure 8. Schematic diagram of the CMS Global Calorimeter Trigger.

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. Prototype work on all components of the system is now well advanced, and preparations are under way for production and installation during 2005.

In addition to the generic FPGA-based processor module, the GCT requires two other types of component. The input data will be received by 18 Input Modules and converted to a compressed, serialised format to achieve the required density for transmission to the processor modules. The distribution of timing and synchronisation signals, together with overall monitoring of the system operation, is performed by a single Communications Module. Final prototypes of both modules are shown in Figure 9.

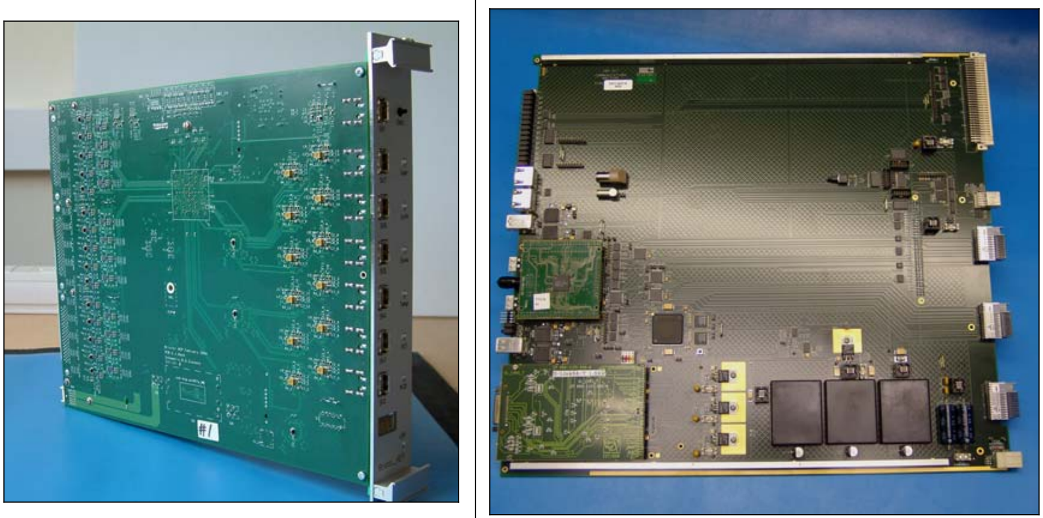


Figure 9. Final prototype modules for the GCT. The Input Module is on the left, and the Communications Module on the right.

The first prototype processor modules were delivered at the start of 2004. Using these prototypes, the operation of the FPGA and serial link technologies has been demonstrated successfully in a full scale system. Much of the firmware needed to operate the GCT has been implemented and debugged. A second iteration prototype processor has been designed. Detailed plans have been developed for integration with other components of the trigger during 2005.

PHYSICS AND COMPUTING

Overview

In CMS, Physics and Computing effort takes place under the auspices of CPT, whose joint Technical Board combines the steering committees of the Physics Reconstruction and Selection (PRS) project, the Computing and Core Software (CCS) project, and the online part of the Trigger and Data Acquisition (TriDAS) project.

The structure of the CPT project has recently come under review, with a proposal to reorganise all technical software effort under a common management currently under consideration by the collaboration. A decision on the reorganisation will be made early in 2005.

Core Computing and Software

The CCS project is responsible for the design and delivery of the computing and software infrastructure of CMS. In addition to the deployment of the CMS computing centres around the world, CCS is responsible for the provision of reliable end-to-end services for data management and workflows. In all areas of the project, CMS collaborators work closely with the CERN LCG project, which is responsible for the coordination of the basic service layers of the LHC computing fabric.

CMS has now identified several major ('Tier-1') computing centres around the world that will take responsibility for data-intensive processing tasks such as second-pass reconstruction and high-statistics analysis. Each Tier-1 centre will also fulfil a custodial function for part of the raw dataset. The UK proposed to host such a centre. In addition, a specialised 'Tier-0' centre at CERN will perform first-pass reconstruction of CMS events in real time during CMS running. A second layer of around 25 smaller 'Tier-2' centres will be hosted by CMS Institutes, and will form the main resource for simulation and final-stage analysis work. They will rely upon close links with Tier-1 centres to obtain and store data. A formal agreement between computing centres, in the shape of the LCG MoU, is in preparation, and will be signed in late 2005. This will ensure the delivery of the resources required at LHC start up.

A new CMS management body, the Computing Coordinator Committee, has been set up in order to coordinate and oversee the deployment of the worldwide computing system, and to act as the internal review body for the Computing Technical Design Report (CTDR) to be published in mid-2005. A UK physicist chairs the CCC.

CMS has recently published a comprehensive description of its computing model, in response to an ad hoc LHCC review of LHC computing. The model resulted from intensive work by a group of experienced physicists and computing specialists from both within and outside CMS. In particular, the opportunity was taken to exploit the expertise gained during the construction of the Tevatron experiments' Run-II computing systems. The computing model was fully reviewed by an LHCC committee, and was agreed to be realistic in its scope and scale. Work on the computing model continues, and will form a major input to the Computing TDR.

The UK has made substantial contributions to CCS activities, and will increase its input during 2005/6. The Bristol group is responsible for the bulk data movement service for CMS, and has produced a prototype toolset known as Phedex, which is in heavy use throughout the collaboration. Phedex exploits software agent technologies to reliable move and track large data streams between the online farm and the Tier-0, Tier-1 and Tier-2 computing centres, in accordance with flexible policies set down by the collaboration. The Imperial College group have produced a tool (Gross) for submission of analysis jobs onto LCG computing resources in a flexible and user-friendly way. Along with similar developments in INFN, this product will form the baseline solution for distributed user analysis at LHC startup. The Brunel group has contributed to the distributed monitoring of CMS workflow, and is now starting to look at topics related to metadata handling.

The level of computing resource available to CMS in the UK has continued to increase, though it is apparently that the resource available in 2007/8 will be smaller than originally hoped. CMSUK continues to work closely with the UK Tier-1 and Tier-2 centres in order to achieve a reliable provision of the services required for data challenges in 2005 – 7 and full-scale data taking in 2008.

Physics Reconstruction and Selection: The PRS project

The aim of the PRS project in CMS is to organize physics, reconstruction and selection studies, and develop the Object Oriented software needed so as to be ready for data taking at LHC startup. The original four detector software and reconstruction groups (ECAL-e/gamma, Tracker-b/tau, HCAL-jetMET, and Muons) have been supplemented by four analysis groups (Higgs, Standard Model, SUSY and beyond the Standard Model, and Heavy Ions).

The next major milestone for the PRS project is 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. In 2003 and 2004, preparation for the tasks involved has helped provoke considerable evolution of the "Computing Model", the "Event Data Model", and the plans and ideas for analysis tools and methods. This development and, where necessary, rethinking is continuing, but inevitably results in some delays to the initial workplan. It is possible that some of the less essential elements of the Physics TDR may have to be sacrificed. What is considered most essential is the understanding of detector response and the software to reconstruct physics objects, and the methods and software to perform calibration and alignment and the related tasks that will allow the raw hardware perform the task of a precision instrument when LHC turns on.

A particular task for the PRS groups in 2004 was the development, in conjunction with CCS, of a "DST" data persistency format to contain reconstructed physics object data.

ECAL-e/gamma group

The group continues to be led by a UK physicist, and UK involvement and contribution to the ongoing activities is increasing.

Much of the group's work this year has been centred around the development of the DST. For the DAQ TDR, the focus was on triggering electrons and photons, which were reconstructed and selected through the full Level-1 and HLT trigger path. The wish to have "offline objects" also in the DST, opens new questions and leads to the exploration of previously uninvestigated kinematic regimes with new detector response features and challenges: low p_T (p_T<15 GeV) electrons, and very high energy (E>1 TeV) electromagnetic objects, are examples. Much work remains to be done, but a serious effort has started.

Coordination and organizational effort has used the coming Physics TDR as a focal point. One result of this was the full day workshop held during the ECAL week in October. The day was organized into four sessions:

i) detector response, readout, trigger, commissioning and operation,

ii) intercalibration, calibration and alignment,

iii) electron and photon objects,

iv) ECAL- e/gamma detailed physics channels.

The speakers were asked to describe the work needed for the Physics TDR, rather than detailing current results. The schedule was very tight, with 32 talks in the agenda, including introductory overviews at the beginning of each of the four sessions.

Work on calibration and alignment is recognized as a CMS and CPT priority. For the ECAL, the needs are a) agreed concrete plans and details of intended database use to allow the development of database software by CCS, and, b) detailed full simulation studies of intercalibration algorithms and methods that will allow the extraction of intercalibration constants from physics data. The methods, techniques, and precision targets will inevitably change with increasing luminosity; and this must be planned for. The final intercalibration precision target is very challenging (~0.5%), and small unlooked for effects cease to be ignorable as the target is approached. Much of the necessary work has now been launched, using the very large Monte-Carlo event samples fully simulated for the DC04 data challenge. UK physicists and students are closely involved in a number of aspects of this work.

During 2004 UK physicists made notable contributions to ECAL test-beam analysis. A total of about seven weeks of data taking were used for studies of crystals from new producers (from SIC in China, and from Apatity in Russia). Investigations were made of radiation induced changes in crystal transparency, and our ability to track it with the laser light monitoring system. Analysis of this data was performed by a UK physicist in collaboration with a colleague from CERN.

A newly appointed UK physicist has begun work on tackling the issues of amplitude reconstruction from the timeframes of 40 MHz digitizations, with particular emphasis on relating the tools used in the beam tests, where the signal is asynchronous with respect to the ADC clock, to the tools that with be needed for synchronous running in CMS.

Higgs group

The group continues to be led by a UK physicist, and UK involvement and contribution to the ongoing activities is increasing. At present, 10 UK physicists are working on Higgs boson channels for the CMS Physics TDR. Such channels are: stop stop Higgs; $qq \rightarrow qqh$ with $h \rightarrow \tau\tau \rightarrow l$+jet and $h \rightarrow$ invisible; tth with $h \rightarrow \gamma\gamma$; and MSSM $A \rightarrow \tau\tau \rightarrow 2$ jets. A UK student took part in the study on the triggering at Level 1 of $H \rightarrow bb$ events in the diffractive production of the Higgs boson. UK physicists participated in HERA-LHC and TeV4LHC Workshops in 2004.

In order to review and put in place the concrete plan of the work for the Physics TDR the Higgs Review day was held at the end of September 2004. The preliminary content of the Higgs chapters for the TDR was presented by the Higgs group coordinator. The Review was split into two main parts devoted to Standard Model and MSSM Higgs searches. In the individual presentations the speakers were asked to address, in particular, the questions about systematic uncertainties and evaluation of the background from the data to maximum possible extend. The collaboration with phenomenologists at various steps of Higgs chapter preparation was clearly identified. The list of Higgs boson channels considered for the TDR include discovery channels at 10 fb^{-1} and channels to measure the Higgs boson properties at medium 30-60 fb^{-1} and ultimate 300 fb^{-1} luminosity.

During 2004 the Higgs group started working with the first available datasets to become available from the 2004 Data Challenge. The HiggsAnalysis subsystem was created in the CMS reconstruction program ORCA to hold ORCA and Root analysis code for a number of the individual Higgs boson channel analyses.

The work has continued in 2004 on the preparation and submission for production of the Monte Carlo requests to fulfil the Higgs boson search program for the Physics TDR. UK physicists made considerable efforts for preparation of the requests with leading order event generators MadGraph and ALPGEN used for the background generation.

Other physics work

Jet energy calibration

A UK physicist started tau-jet energy calibration studies in 2004 and first preliminary results have been reported in the December 2004 CMS week.

Standard model physics

At Bristol a small group has been working on a number of topics under the umbrella of the Standard Model Group. We have revived an interest in studying direct photon production ($qg \rightarrow q\gamma$) which will be studied in the first few weeks of running and gives a measure of the gluon distribution function. We are studying the signal with three different PDFs and background from 2-jet events where one jet fragments into a leading π^0 and fakes a photon.

An addition to this study is an investigation into the radiative decay $W^{\pm} \rightarrow \pi^{\pm}\gamma$. The theoretical branching ratio in the Standard Model is $\Gamma(W^{\pm} \rightarrow \pi^{\pm}\gamma)/\Gamma(W^{\pm} \rightarrow e^{\pm}\nu) \approx 3\times10^{-8}$. This is beyond the reach of CMS but we can almost certainly improve on the current limit, and any observation of this signal would be an indication of new physics. The main background to this decay will come from direct photon events where most of the jet energy appears in one charged pion so this complements the direct photon work.

A third topic is the search for Lepton flavour violating tau decays. So far we have concentrated on the decay $\tau \rightarrow \mu\gamma$. One major source of background to this decay is expected to be $\tau \rightarrow \mu\gamma\nu\nu$. Figure 10 shows the reconstructed $\mu\gamma$ invariant mass distributions for the signal (black) and background (blue). Previous CMS work in this area has concentrated on W decays but we are looking at Z decays to investigate if the constraints of requiring another τ in the event and the Z mass can help reduce the combinatorial background.

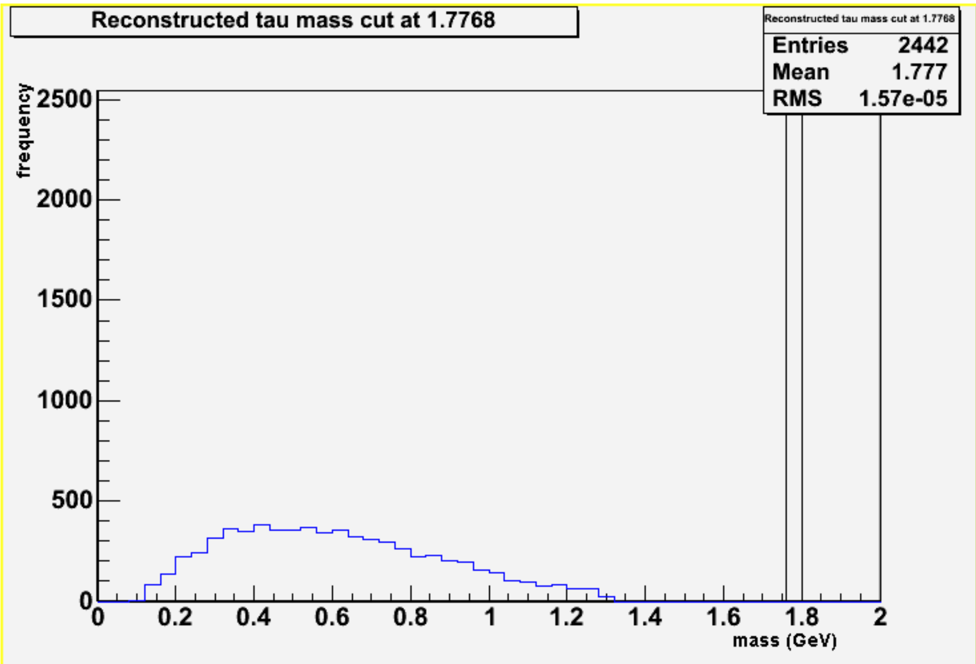


Figure 10. The reconstructed neutrino-muon invariant mass distributions for the signal (black) and background (blue).

Gauge couplings

UK physicists, in collaboration with physicists from CERN and Croatia, have formed the Gauge Coupling Working Group, a sub group of the Standard Model Group. This group is co-ordinated by a UK Physicist.

Physicists from Bristol and Brunel contributed to the full day CMS Standard Model workshop on the organization of work required for the Physics TDR. UK physicists have responsibility for the analysis of the sensitivity of CMS to the Wγ and Zγ anomalous couplings.

Physicists from Bristol and Brunel have used the DC04 data to study the main background to the Wγ channel, W + jet. A Bristol physicist and student have been integrating the anomalous coupling generator for the Wγ channel with the full simulation and reconstruction software of CMS.

A Bristol student has completed a study of the Zγ anomalous couplings using a fast detector Monte Carlo simulation. This study shows that an order of magnitude improvement over the Tevatron on evaluating the sensitivity of CMS to these anomalous couplings will be possible.

A Bristol student has undertaken the first study of the sensitivity of CMS to quartic couplings.

UK physicists are contributing to the 2005 Les Houches Workshop on Physics at TeV Colliders.

CONCLUSION AND SUMMARY

While the ECAL and Tracker projects have faced significant challenges during the past twelve months, the projects under the control of the UK groups have enjoyed considerable success. The procurement of tracker sensors and ASICs is close to completion, and a number of potentially serious problems have been overcome. Very good progress has been made with the ECAL endcap major mechanics and the delivery and testing of VPTs, while orders have been placed for cables and other equipment for the associated high voltage system. Satisfactory endcap crystals have been received from a second potential producer.

UK physicists and students have been increasingly active in the Physics Reconstruction and Selection project; UK physicists lead the ECAL-e/gamma group and the Higgs group, and many Higgs channels are being studied in the UK, in addition to a variety of Standard Model physics processes. A UK physicist is the co-ordinator of the Gauge Couplings group. The UK groups are therefore well placed to make a strong contribution to the Physics TDR, which is due to be published at the end of 2005.

PUBLICATIONS

Journal papers

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