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CMS is a general-purpose detector designed for use in the large hadron collider (LHC) at CERN. The electromagnetic calorimeter will play an important role in electron and photon energy measurements. The benchmark process to evaluate and optimize its performance is $H \rightarrow \gamma\gamma$ in the intermediate mass range ($90 < m_H < 150$ GeV). For this purpose, each element of the readout chain has to be optimized. This paper discusses the readout chain of the CMS electromagnetic calorimeter and preliminary results obtained from prototype components.

Table 1
Comparison of scintillating materials

	NaI(Tl)	BGO	PbWO ₄
density (g/cm ³)	3.67	7.13	8.28
radiation length (cm)	2.59	1.12	0.89
interaction length (cm)	41.4	21.8	22.4
decay time (ns)	230	300	30
emission peak (nm)	410	480	450
relative light output	100	18	1.3

1. CMS Electromagnetic Calorimeter Overview

The CMS electromagnetic calorimeter (ECAL) [1] will be situated between the central tracker and the hadronic calorimeter, within a 4T magnetic field. The ECAL will consist of a barrel detector and two endcaps, corresponding to a length of 21.6m and a diameter of 15m.

In order to obtain the best possible energy resolution, lead tungstate (PbWO₄) scintillating crystals have been chosen as the active medium. Some characteristics of this scintillator are given in table 1 in comparison with other materials such as NaI(Tl) and BGO (used for the electromagnetic calorimeter of the L3 experiment at LEP).

The advantages of PbWO₄ scintillator include

its density which permits a compact calorimeter (small Molière radius and radiation length) and its short light decay time. The electromagnetic calorimeter will be composed of upwards of 76000 23cm-long truncated pyramidal crystals (~ 26 radiation lengths). Each crystal will be placed in a 5×2 ($\eta \times \varphi$) rigid alveolar structure (in order to maintain a crystal-to-crystal distance of $500\mu\text{m}$, made of glass fiber and covered with a special coating to diffuse the scintillation light. From the mechanical point of view, these alveolar structures will be assembled to form modules (of either 400 or 500 crystals) and supermodules (a group of 4 modules representing 85×20 crystals in $\eta \times \varphi$).

Each half-barrel contains 18 supermodules disposed in φ . Figure 1 gives a 3D-view of the CMS electromagnetic calorimeter.

2. Readout Design

Much of the readout chain must be mounted within the CMS detector in order to minimize external noise contributions. As a consequence, the design of the chain is subject to several constraints coming from the LHC and the CMS detector itself.

The hadronic nature of the collider (proton-proton) presents a very hostile radiation environment. For the highest anticipated luminosity ($10^{34} \text{ cm}^2\text{s}^{-1}$) and for 10 years of operation,

Figure 1. 3-D view of the electromagnetic calorimeter. Overall dimensions are 21.6m length and 15m diameter.

the expected doses just behind the crystals are **60kGy** with a neutron flux of $7 \cdot 10^{14} \text{ n/cm}^2$ at $\eta=3$ (endcaps) and approximately **2kGy** and $2 \cdot 10^{13} \text{ n/cm}^2$ for the barrel. A second constraint comes from the design center-of-mass energy ($\sqrt{s}=14 \text{ TeV}$). To provide the desired resolution over the full energy range of physics events, an ECAL readout channel must be capable of measurement between 50 MeV and 2 TeV. Finally, the inter-bunch spacing of 25ns requires the chain to be fast enough to minimize pile-up of events.

The readout chain inside the detector must be insensitive to the 4T magnetic field and must maintain a power consumption below 2W per channel because of the temperature dependance of the light yield of the crystals ($-2 \text{ \% / } ^\circ \text{C}$).

In summary, the detector-mounted very front-end readout must be :

- radiation-hard,
- 40MHz-compatible,
- capable of a wide dynamic range,
- insensitive to magnetic field,
- capable of low power consumption.

3. Readout Chain Description

3.1. On-detector readout

As we have seen in section 1, the first element of the readout chain is the PbWO_4 crystal. Its relatively low light yield (see table 1) demands a photodetector with an internal gain to collect a sufficiently large signal. Two types of photodetector have been chosen according to the pseudo-rapidity η :

- In the endcap region ($1.479 < \eta < 3$), **vacuum phototriodes (VPT)** are well-suited to the high radiation rates and their magnetic field sensitivity is small up to 4T. Their gain ranges between 10 and 30, depending on the angle between their electric field direction and the magnetic field of the CMS solenoid.
- In the barrel region ($0 < \eta < 1.479$), radiation rates are less important than in the endcaps, so avalanche photodiodes (APD), insensitive to magnetic field, have been chosen. The operating gain will be approximately 50-100. Two APDs are needed in order to cover the face of the crystal and increase the signal.

The design constraints listed in the previous section require the following properties of the

Figure 2. Schematic view of the electromagnetic calorimeter electronic chain.

readout electronic chain : radiation hardness, wide dynamic range and low power consumption. The chosen solution is a floating point preamplifier (FPPA) [2] [3], a wide dynamic-range, low-noise and low-consumption preamplifier with four relative output gains (x1, x4, x8 and x32) followed by a digital logic circuit working at 40MHz. Every 25ns, the system selects the best non-saturated gain output. The FPPA is linked to a commercial Analog Devices AD9042 sampling analog-to-digital converter (ADC) to produce a 15-bit word (12 bits from ADC conversion, 2 bits saying which gain has been used and one more flag bit to provide for temperature and leakage current measurements). The FPPA chip is built in the DMILL $0.8\mu\text{m}$ BiCMOS technology. A backup solution in Harris UHF1x is under study. The FPPA allows the use of a 12-bit ADC to cover dynamic range of 16 bits.

The digital signal is carried out of the detector volume using a 20-bit serializer via 80-meter standard optical fiber 62.5μ multimode ribbon. To lower consumption, the 20 bits are serialized at 40MHz with a delay loop, but the transmission is made at 800Mbits/s. The device, made in Honeywell CHFET technology, has a power consumption of 100mW with the driver and the VCSEL emitter [4].

In addition, a test pulse generator [6] may be attached to each readout channel and each sub-

module of ten crystals will be equipped with a temperature sensor.

3.2. Upper-level Readout

The signals are received in the counting room via optical fibers. The fibers from 100 readout channels are connected to a VME module. In the barrel, one VME crate will be used for each supermodule of 1700 readout channels.

After deserialization, the digital signals are directed towards both a trigger path and an acquisition path.

The trigger begins with a linearizer (which converts the compressed data (12+3 bits) to a 16-bit format. As a barrel trigger tower is composed of 5×5 crystals in $\eta \times \varphi$, we first define a strip, which is the sum of 5 readout channels in φ . Then, the signals of 5 neighboring strips are sent to the Trigger Primitive Generator (TPG). This device determines the first-level trigger by performing particle identification and applying an energy threshold. TPG signals are sent to form the calorimeter trigger of CMS.

Data are pipelined and buffered awaiting the trigger decision. For selected events, the bunch crossing is identified and all data are sent to the global data acquisition system (DAQ), and part to a local DAQ (temperature, test-pulse, monitoring, raw data) as well.

4. Preliminary Readout Performance

Prototypes have been tested in high-energy beams (electrons and pions up to 150 GeV) at CERN. Tests on particular parts of the readout as well as radiation hardness tests, have been performed. In the following, we describe the most significant results.

4.1. Very Front-end Tests

The CMS collaboration has chosen Hamamatsu Photonics avalanche photodiodes to collect light from the barrel of the electromagnetic calorimeter. A schematic representation of this photodetector is shown in figure 3. After electron-hole creation via an incident photon, charge carriers are accelerated in an electric field sufficiently high to allow a multiplication process. APD gain is adjustable over the range of 1 to 200 by applying a bias of up to 600 volts. Many intrinsic parameters of APDs have to be optimized together for use in the CMS detector. The capacitance of ~ 120 pF puts severe constraints on preamplifier design and dark current has to be maintained as low as possible in spite of exposure to radiation. At the same time, the excess noise factor and the nuclear counter-effect have to be minimized and the quantum efficiency has to be well matched to the emission spectrum of the crystals ($\lambda \sim 450$ nm). A schematic drawing of the entire readout chain is shown in figure 2.

In addition to many measurements on the APDs themselves, a prototype corresponding to a 7×7 PbWO₄ crystal matrix, with each crys-

Figure 3. Schematic of an avalanche photodiode

Figure 4. Energy resolution as a function of energy deposited in a sum of nine crystals. A PbWO₄ crystal is readout by one avalanche photodiode.

tal read by one avalanche photodiode, has been tested. The electronic chain was composed of an optimized low-noise preamplifier [5] and a charge ADC. A cooling system stabilizes the temperature at 18 degrees with a precision of 0.1°C .

An energy resolution of approximately $\sigma/E = 0.6\%$ at 100 GeV has been measured for a sum of 3×3 crystals within this configuration of 7×7 . This result has been reproduced many times with several combinations of 3×3 crystals. These tests have validated the concept of PbWO₄ crystals readout by APDs. Figure 4 shows an energy resolution curve which summarizes our results.

4.2. Electronics Tests

Tests with the 7×7 prototype were dedicated to energy resolution measurements. Other prototypes have been built to test the electronic parts of the readout (preamplifier, compressor, etc). Figure 5 represents a preamplifier pulse reconstituted (lower plot) with data from two gain outputs (upper plot).

These results were obtained from the first version of the preamplifier and Floating Point Unit (FPU), as two separate devices. The next version will include the four-gain preamplifier and the FPU in a single chip, called the floating point preamplifier (the so called FPPA). Char-

Figure 5. Pulse reconstruction from FPU data.

acterization tests on preamplifiers have yielded a mean electronic noise value of ~ 4400 electrons, as shown in figure 6.

A prototype of the serialiser/deserialiser has been tested in the course of beam tests at CERN. The final version is currently under design.

4.3. Radiation Hardness tests

Each element of the readout chain has to operate in a challenging environment. At maximum luminosity, a radiation dose of up to 1.2 kGy/year in the barrel (close to endcaps) is expected.

Many facilities such as proton beams, nuclear reactors and high-rates photon sources have been used to perform the following tests :

- **PbWO₄ crystals** Radiation hardness has significantly increased during R&D programs with the supplier. Current crystals are subject to a maximal light-yield loss from radiation damage of only 5 %.
- **avalanche photodiodes** are still sensitive to radiation. Dark current and then electronic noise is greatly increased with exposure to neutrons. A new passivation layer made of SiN₄ instead of SiO₂ has greatly increased the stability of quantum efficiency, which is potentially affected by photon fluxes. **Vacuum phototriodes** are relatively resistant to neutrons and gammas.

Figure 6. Electronic noise distribution over 36 samples.

- The performance of the **preamplifier** and **FPU** designed in DMILL $0.8\mu\text{m}$ BiCMOS technology are unaffected after more than 0.1 MGy and $2 \cdot 10^{14}$ neutrons/cm².
- A **serialiser** designed in the Honeywell CHFET technology has not shown any change in performance after 50 kGy and 10^{14} neutrons/cm².

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REFERENCES

1. J.P. ERNENWEIN in these proceedings.
2. J.P. WALDER, *High dynamic range and low power very front end preamplifier for CMS calorimetry*, 2nd workshop on electronics for LHC experiments, Balatonfured 1996, 61-65.
3. P. DENES, *CMS electromagnetic calorimeter readout*, 2nd workshop on electronics for LHC experiments, Balatonfured 1996, 48-52.
4. Vertical Cavity Surface Emitting Laser from Honeywell HTC, Bloomington, MN, USA.
5. R. STEPHENSON, RAL preprint RL87-019 (1987).
6. J-P. MANDIBURU, CERN/LHCC/98-36 (1998), p.229-233.