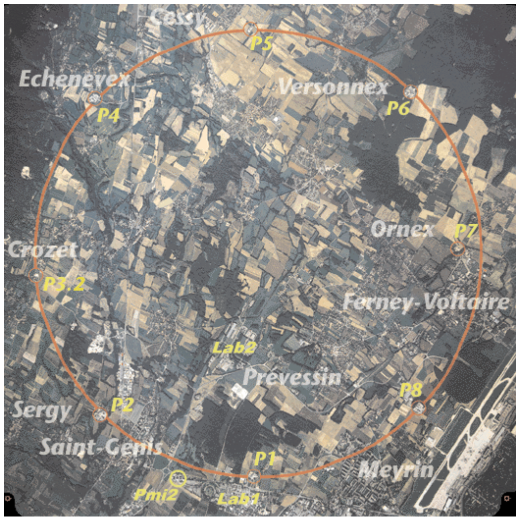
Opto-Electrical Readout in the CMS Hadron Calorimeter



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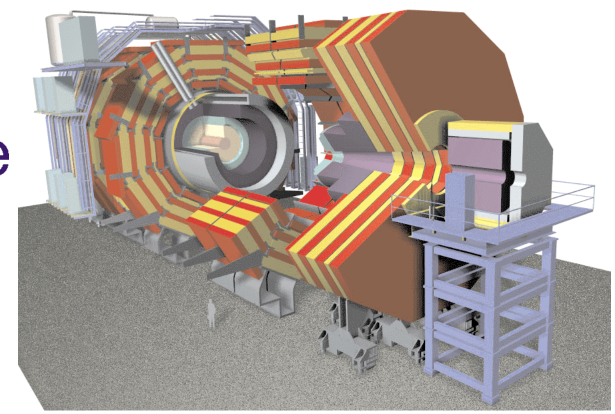
CMS Collaboration



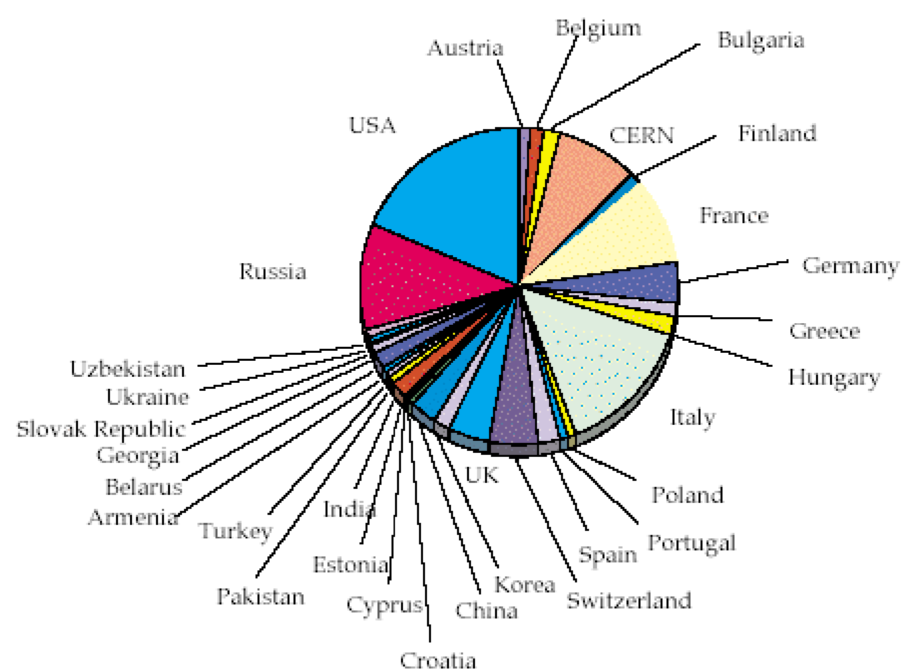
I. Introduction to the Large Hadron Collider (LHC)
II. Introduction to the Compact Muon Solenoid (CMS)
III. Hadron Calorimetry (HCAL)
IV. HCAL Design
V. HCAL Readout System
VI. Conclusions

The CMS Collaboration

The CMS Collaboration

	Number of Laboratories
Member States	60
Non-Member States	51
USA	36
Total	147

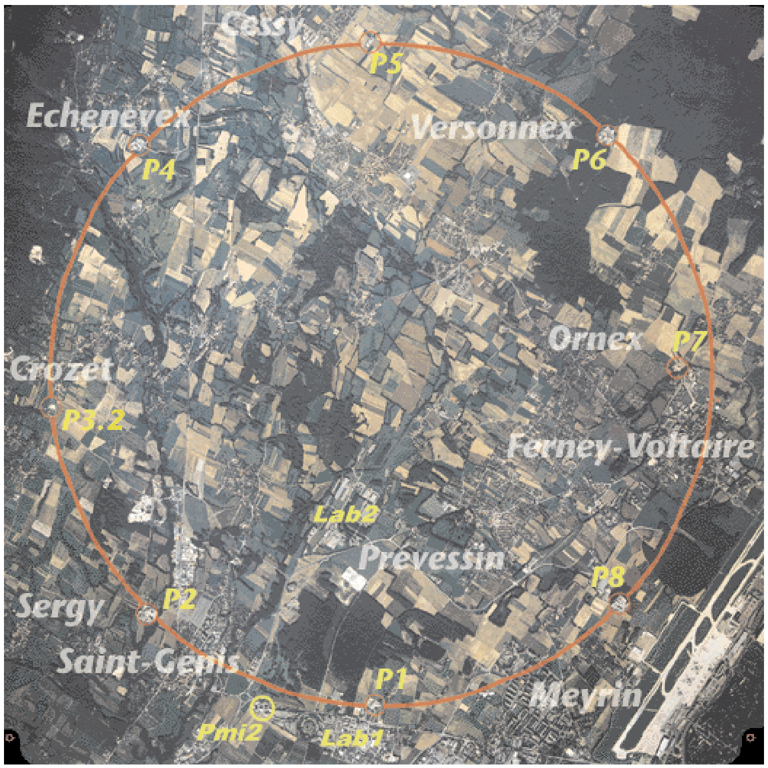
	Number of scientists
Member States	1045
Non-Member States	443
USA	334
Total	1822



1822 Physicists & Engineers
31 Countries
147 Institutions

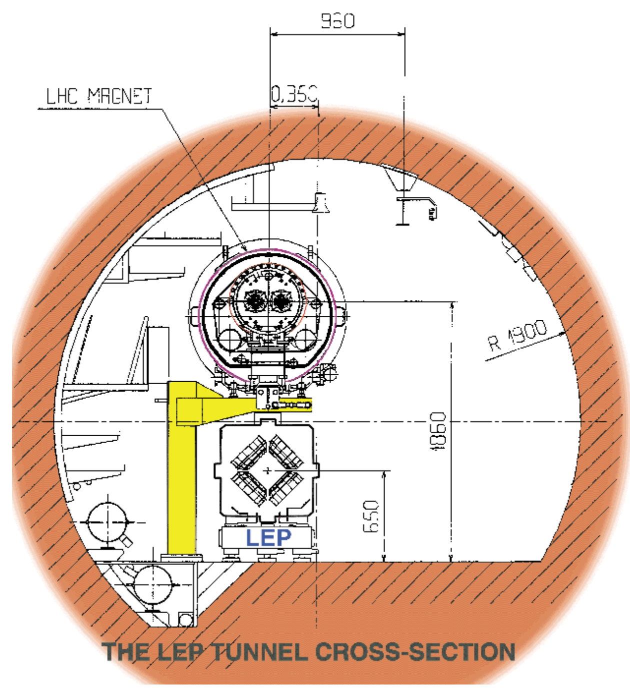
September, 21st, 1999/av
http://cmsdoc.cern.ch/pictures/cmsorg/overview.html

The Large Hadron Collider

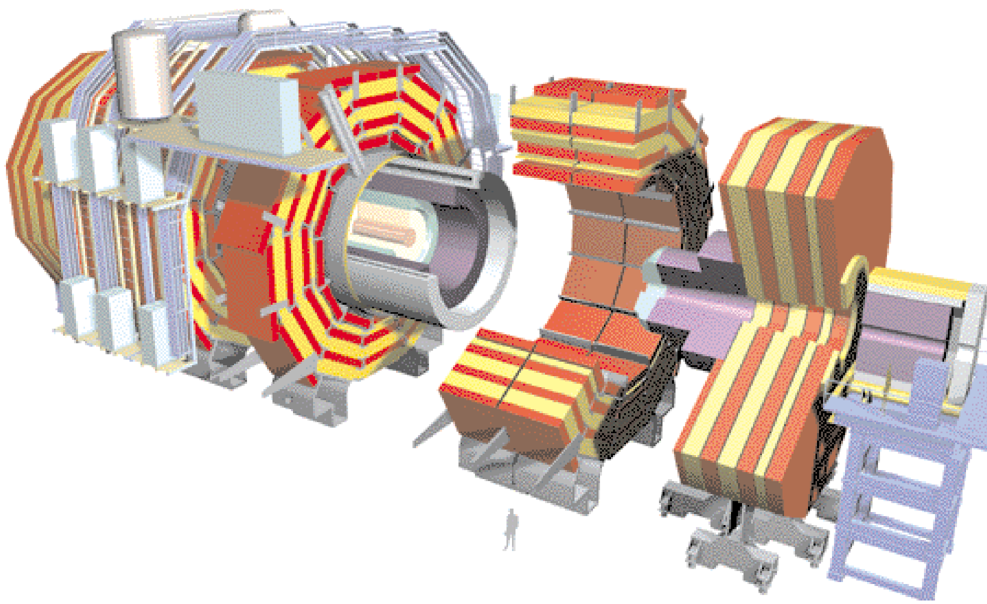


40 MHz machine (25ns bunch crossing)
  25 interactions per crossing
14   TeV proton-proton collider
1.25 TeV ion collider
1.5   TeV electron-proton collider
Luminosity = 10^{34} cm^{-2} s^{-1} $\Rightarrow I_{beam} = 0.53A$

Scheduled for construction in the LEP tunnel



Compact Muon Solenoid



weight : 12,500 tons

diameter : 17 m

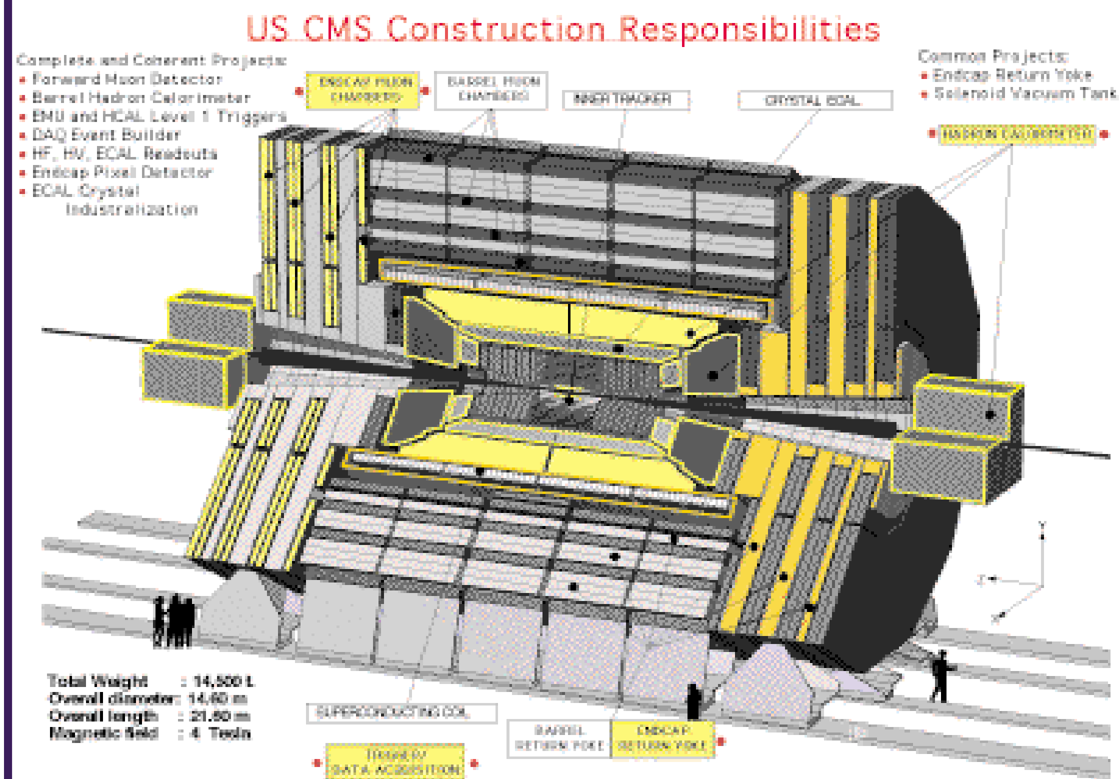
length : 21.6 m

field : 4 T

Design Parameters

- General purpose detector
- large superconducting solenoid
  uniform 4 Tesla field
- Optimized for SM Higgs search
  from 90 GeV to 1 TeV
  electro-weak symmetry breaking
- t, b, & τ physics at lower luminosities
- aspects of the heavy ion program
- measure e, μ, γ,
  $\Delta E/E < 1\%$ for $E > 100$ GeV

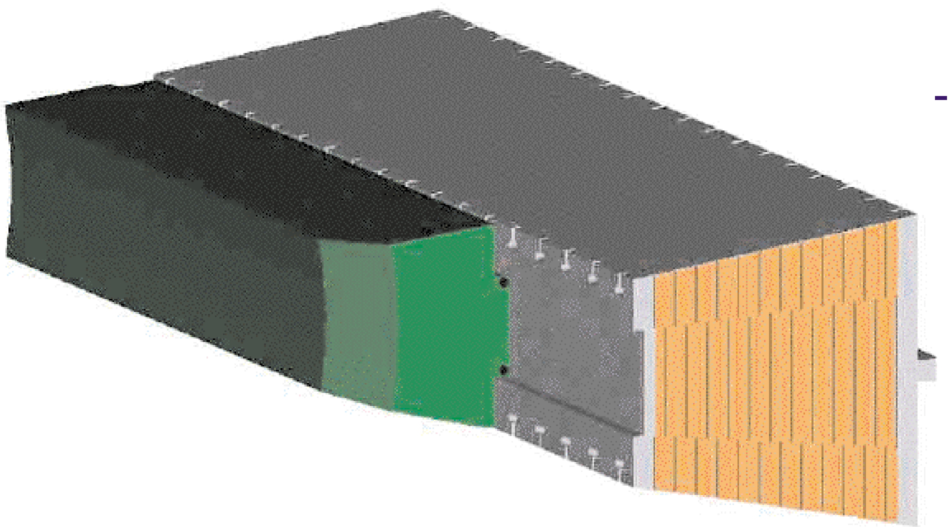
Compact Muon Solenoid



- 4 T Magnet
- Muon Spectrometer
  - compact design
  - maintains momentum resolution
  - excellent coverage out to $|\eta| < 2.5$

- Tracking
  - double sided silicon strips
  - $\Delta p/p \approx 0.1 p_T$ (p_T in TeV)
  - $|\eta| < 2.5$
- Electromagnetic Calorimeter
  - 80k+ high res $pbWO_4$ crystals
    - $H \to \gamma\gamma$ search
  - inside the solenoid
- Hadron Calorimeters
  - inside the solenoid
  - sampling calorimeter
  - brass absorber
  - 10k+ scintillating tiles
  - hermetic coverage $|\eta| < 5.0$
  - forward jet tagging
  - determination of missing energy
  - expected resolutions
    - $\Delta E/E \approx 100\%/\sqrt{E_T} \oplus 5\%$ ($|\eta| < 1.5$)
    - $\Delta E/E \approx 83\%/\sqrt{E_L} \oplus 5\%$ ($1.5 < |\eta| < 3.0$)

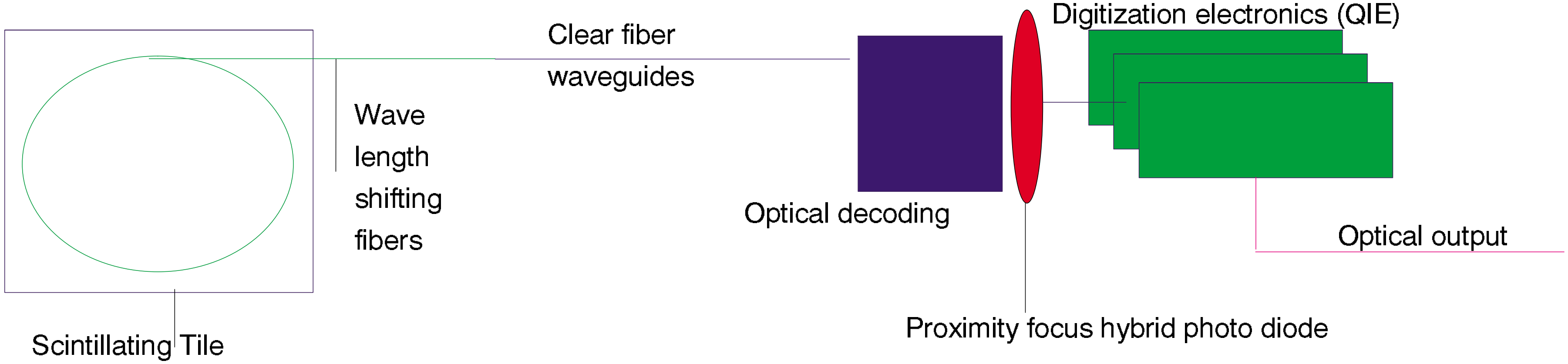
Hadron Calorimetry



- HCAL Barrel and Endcap
  - 36 wedge barrel with 17 layers
    - circular endcap with up to 12 layers
    - fine segmentation
      - 0.087×0.087 towers, 2 depths
    - $|\eta| < 1.5$ in the barrel
    - $1.5 < |\eta| < 3.0$ in the endcap
    - $3.0 < |\eta| < 5.0$ in forward calorimeters
    - "Tail Catcher" outside the magnet
      - $|\eta| < 0.4$
      - shower containment
      - energy leakage measurement

- Thickness
  - $9.2\ \lambda$ at $\eta = 0$
    - 1.1λ (E) + 5.5λ (H) + 1.5λ (C) + 1.1λ (TC)
- Calibration
  - ^{137}CS, diode lasers, and collider data
- Dynamic Range
  - 20 MeV (muons) to 3 TeV (jet max)

HCAL Readout System



Scintillating Tiles

- produce light
- passage of charged particles
- light proportional to energy

WLS Fibers

- capture photons from tile
- transmit at different wavelength

Clear Fiber

- waveguide from wedge to readout

Optical Decoder Unit

- receivers for waveguide bundles
- performs energy summation of projective η towers
  - optical energy summation of all tiles in a tower
- routes light into the photo diode

Hybrid Photo Diode

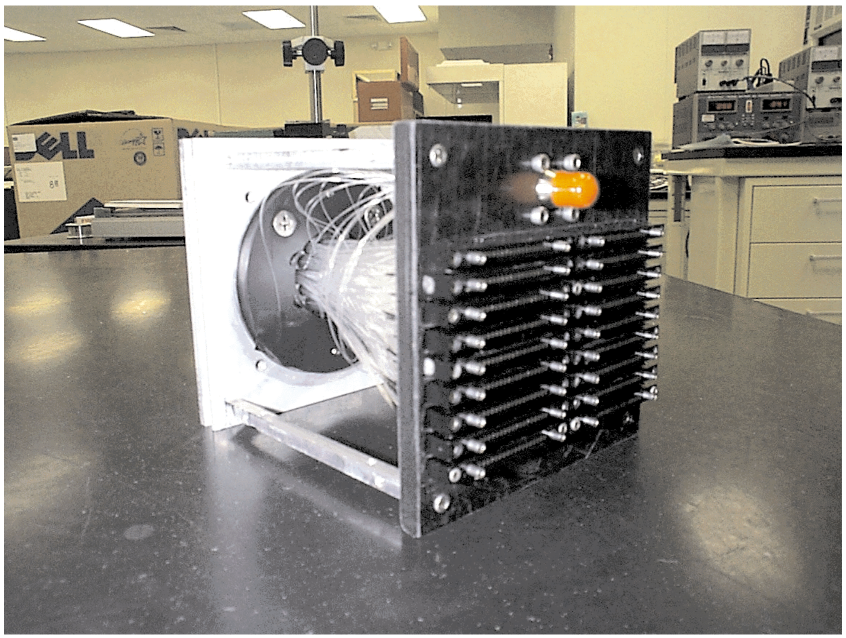
- divided into pixels corresponding to towers
- converts light to an analog electric signal

Digitization Electronics

- digitizes the HPD signal
- built in FADC
- converts back to optical for output to triggers

Different tiles correspond to η bins
Different ODUs correspond to φ bins

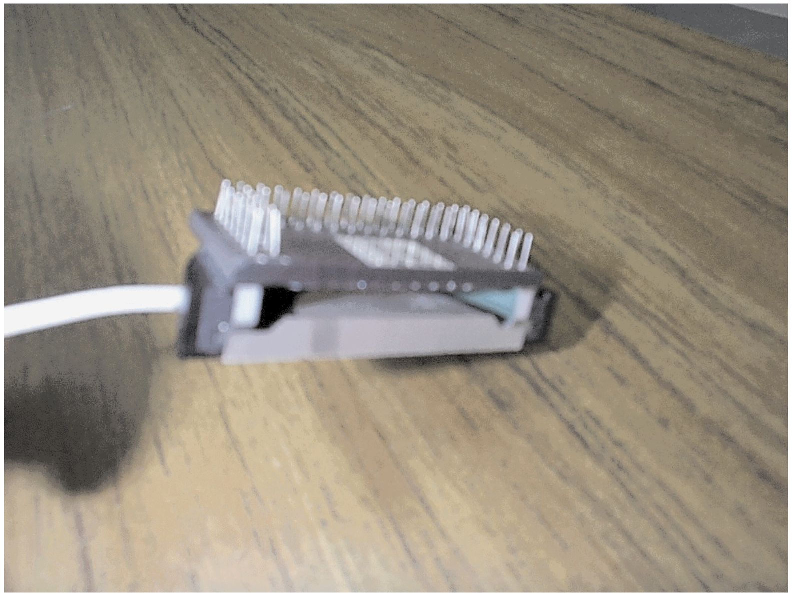
Optical Decoding



- 19 Channel Modules
  - tower summation by routing fibers from all tiles in a tower to the same HPD pixel
  - calibration fiber from diode laser to each pixel
  - 4 nineteen channel modules per wedge
- 73 Channel Modules
  - readout of the pre-sample layer
    - first scintillating tile on the inside face of wedge
    - energy sample prior to the absorber
    - only readout of individual tiles
  - calibration fiber from diode laser to each pixel
  - 1 seventy-three channel module per wedge

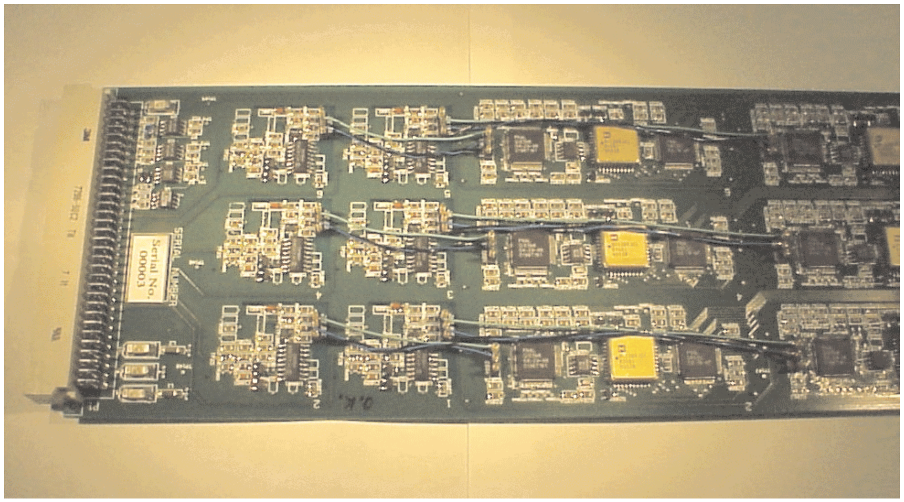
Units are being built with high school science teachers and their students as part of the Quarknet Program in the US.

Hybrid Photo Diode

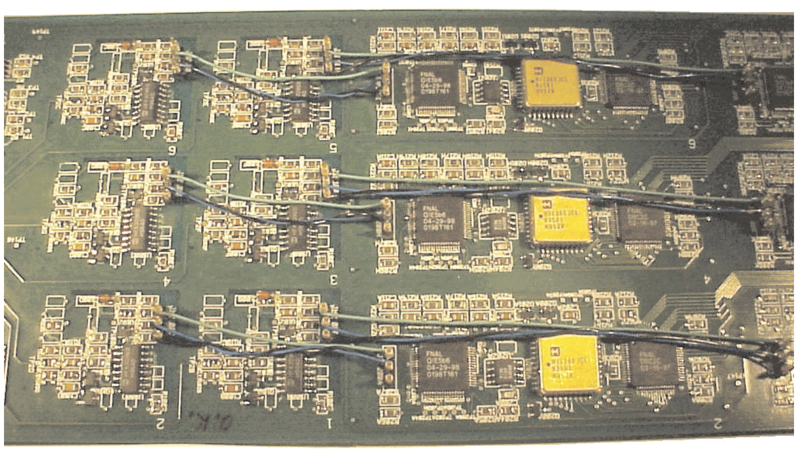


- Image Intensifier
  operated in the electron bombardment mode
- Uniform 10kV potential and 3-4 mm gap
  minimizes magnetic field effects
- Linear gain with applied voltage
  gain of 2000 at 10kV
  decreases by 2% in a 3T axial field
- Linear response
  2% variation of the required dynamic range
  fast response determined by diode source capacitance
  aligned with local field to minimize nonlinear response
- Use fiber optic windows, magnetic package
  reduces dark currents to suitable levels for
  measurement of the DC current signal from calibration
  sources and from minimum ionizing particles

Analog Signal Conditioning

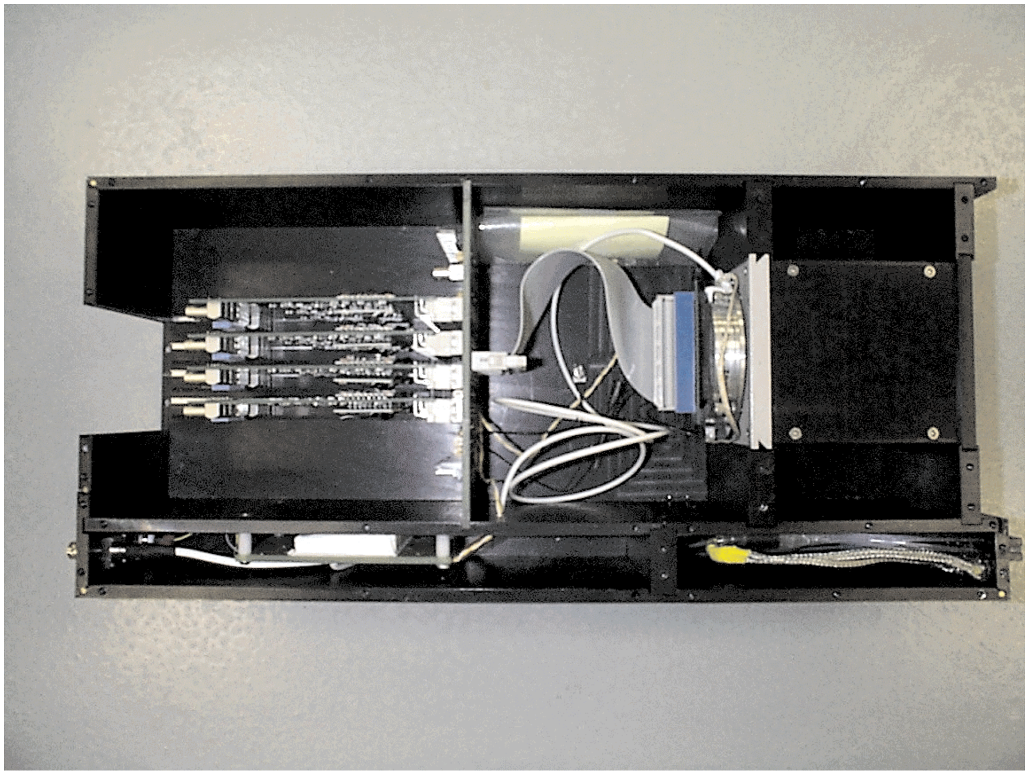


Similar to cards in use at KTeV and CDF



- charge Integrating range Encoding Analog Signal Conditioner
- Multi-range current splitter & gated integrator
- Four Phase pipeline
  - integrates the charge
  - comparison to find capacitor which is 1/2 to full charge, determining the exponent
  - output appropriate capacitor values
  - reset
- Six QIE channels per card
- QIE Output
  - 9 bit range (5 mantissa, 2 exponent, 2 CapID)
  - built in Flash ADC
- Channel Control ASiC
  - combines two QIE channels
  - sends 1 CapID
  - CCA has 16 bit output
  - checks CapID and orbit timing
    - sends error pattern if matches are wrong
    - controls for single event upsets
- On board VecSel
  - laser driver for optical output

The Readout Box



Box and components are a collaborative effort between U. Notre Dame, U. Minnesota, U. of Mississippi, Florida State U., U. Illinois at Chicago, U. Iowa, and Fermilab

- Every wedge has a readout box
  - in the barrel and endcap
  - Combines all the optical and electronic components in about 100cm $\times$ 30cm $\times$ 10cm
- each has all of the components to
  - read signals from a single wedge
  - sum energy and convert to tower geometry
  - amplify and condition the signal
  - send the signals to the DAQ
  - necessary services (cooling, N_2, HV, LV)
- Box and components have to survive the radiation environment
- Not susceptible to the local magnetic field
- reliable and serviceable
- "easy" to mass produce
  - over 500 have to be constructed
  - three different configurations corresponding to Barrel, Endcaps, and Tail-Catcher

Conclusions

- The CMS detector will be an excellent, large, general purpose detector
  - design is optimized to discover (and measure) the Higgs boson
  - allows for precision measurement and new phenomena
  - may be able to differentiate between SM Higgs and MSSM Higgs
  - If SUSY is a correct theory, we should see it at CMS
- The Hadron Calorimeter is a critical component of the physics program
  - precision measurement of jet energies and missing transverse energy are critical for many processes
- The electro-optical readout system is designed to
  - provide fast readout of the HCAL into the DAQ
  - low noise system
  - reliable in the radiation environment and the local field
  - fit into a minimum space
  - be accessible in case servicing is required (requires modular design)
  - Converting from layer geometry to tower geometry on the detector reduces the load on the DAQ
- The readout box and associated components are in the final phases of design, and construction will begin soon.
- Construction will be complete in time for CMS surface hall assembly
  - Barrel assembled and burn-in starting summer of 2002